博士論文

Challenges and Improvement for Safety Management Practices at the Organizational and Institutional levels in Japanese High-Speed Railways

(日本の高速鉄道における安全管理の実践上の
組織的及び制度的課題と改善策)

A dissertation presented

by

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to

Department of Civil Engineering

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

THE UNIVERSITY OF TOKYO

March 2020

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Abstract

Safety of Japanese High-Speed Rail (HSR), or *Shinkansen*, is a topic of national and international importance. A series of recent accidents in Japan that could have easily been fatal also warrant attention to the topic of HSR safety in Japan. HSR is a complex socio-technical system comprising of several technical, human, organizational, and institutional system components whose interactions govern the emerging system behavior in the form of Safety. Due to the expected rise in automation, as well as the advancement in technology, the HSR system is expected to become centralized. For such systems, the role of organizational and institutional factors becomes crucial, and hence the current study focuses on studying the organizational and institutional factors for Shinkansen safety management.

Often the concept of Safety Management System (SMS), comprising of safety promotion, safety assurance, safety policy, and Risk Management (RM) strategies are used to manage safety at an organizational level. Using this framework, the study first highlights several relevant academic and practical gaps in the Japanese HSR system. First, the relative importance of the variety of organizational factors has not been examined in the Japanese HSR. Second, at the organizational level, the RM practices of the Japanese HSR operators and at the Institutional level, the risks associated with the current practices of operator-regulator relationships have not been examined. Third, the literature review helps identify a necessity to develop a proactive RM strategy for Japanese HSR operators. Finally, some of the HSR operators in Japan are facing the issues related to the near-miss reporting behavior of their employees; however, only a handful of the studies comprehensively explore the organizational factors affecting the reporting behavior of employees in Japanese HSR TOCs.

The study, thus, aims to answer the following questions: *How do the organizational (Risk-Management, Feedback) and institutional level (Risk-Management) risks that affect Shinkansen Safety? and How can Shinkansen Safety be improved?* The specific objectives for this study are 1. To clarify challenges in the current safety management practices (Risk-management) at Organizational and Institutional levels in Japanese Shinkansen and identify strategies to improve the practices. 2. To Develop methods necessary for implementing pro-active risk-management strategies at the organizational and institutional levels, and 3. To clarify the factors affecting reporting behavior at the organizational level in Japanese Shinkansen.

The focus of the study then shifts towards *Risk Management* at the organizational and institutional levels. Current RM practices of TOC's are not at par with the state-of-the-art safety theory based on System-control principles, and instead utilize event-chain based accident models, which are shown to be limited in explaining the causes of accidents. Furthermore, the applicability of such models for analysis at the organizational and institutional level has already been challenged in the academic literature. An in-depth analysis of the only "Serious Accident" in Japanese HSR is conducted using System-Theoretic Accident Model and Process (STAMP) analysis based on the system-control safety theory. Information on the serious accident obtained through official accident reports and expert interviews is combined, revealing a new accident archetype at the organizational and institutional level. The archetype demonstrates the common failure causes for the operator and the regulator, thereby making their apparent redundancy ineffective. The archetype demonstrates that the accident can happen when both the operator and the regulator base their decision-making on the same set of faulty information based on unsystematic risk-assessment methods. The archetype is helpful in identifying theoretical improvements in current safety practices, such as independent risk-assessments for both the operator and the regulator, as well as developing leading indicators (indicators that indicate the presence of accident causal factors) for non-technical components. The study thus identifies that, despite having achieved remarkable safety performance, the Japanese HSR system relies on excessively often-unsystematic risk-assessment methods, making them vulnerable to the systemic factors that could render multiple defenses ineffective simultaneously, under the ever-growing complexity.

Then, the study develops a leading indicator scheme that could be implemented at the organizational and institutional level by considering several modifications from the existing approaches. The most important among these is the identification of a suitable receiver of the warning signals generated upon monitoring the leading indicator. Two new suitability criteria are proposed in and are validated using real accidents. The criteria are that the warning signal generated upon monitoring the leading indicators should a.) Reach to at-least one controller, who can provide actions to the sub-system concerned b.) reach to at least one controller, who can sense the local adaptation by the components under that controller. The approach thus developed is grounded in safety theory, but when applied to a complex system in Japan, i.e., a decentralized wastewater treatment unit provided mixed results. While the approach was more comprehensive in identifying 15 new leading indicators for the wastewater system, the decision on whether to monitor these indicators is dependent on several trade-offs. These trade-offs include the capacity constraints at the regulator level as well as the necessity to strike a balance between the adequate level of control and autonomy.

Finally, a System Dynamics (SD) model representing the dynamics of people, structure, and the management policy within an organization is developed to identify factors and their impact upon the quality of the *Feedback*. The SD model development involves three main steps – a.) development of the causal structure, b.) validation of the model structure, parameter estimation, and behavior validation, and c.) Simulation and policy analysis. While model development and validation, is suitable in identifying the relevant factors, the simulation and policy analysis are suitable to assess their impact on reporting behavior. Cross-industry literature was first reviewed to develop a dynamic hypothesis explaining employee’s near-miss reporting behavior. The dynamic hypothesis was then validated within the Japanese HSR context through semi-structured interviews involving senior experts from two different HSR operators in Japan using a disconfirmation approach. The key factors affecting the reporting behavior are workload and fatigue level of employees, incentive structure, and management’s commitment to safety in providing feedback to reported incidents. An executable simulation model using the causal factors was then developed and was calibrated using 3 months of daily safety observation data for a construction company. The same causal structure was also validated through the simulation, revealing a level of generalizability for the proposed model. The simulation results developed resembled the trends observed in the data obtained from the construction company on a total of 5 aspects. Simulations were then carried out for testing several policies revealing the path-dependent nature of the results obtained from a policy to reduce the number of working hours, as well as variation in the effect of similar incentives on different types of incident reports, reports in an HSR operator. The numerically executable SD model thus provides an important policy analysis tool to analyze the organizational factors affecting the quality of the near-miss reports in an organization and are shown to be having implications for the Japanese HSR TOCs.

The study has examined organizational and institutional factors affecting HSR safety performance and makes a case for utilizing the system-control-safety theory for pro-active safety management in the Japanese Shinkansen. Through the archetype, the study identifies the necessity of systematic and independent risk assessment by the regulator using a proactive method such as the leading indicators. While the leading indicator implementation study highlights the trade-offs involved in implementing proactive measures. Further, the SD model reveals the dynamic interdependence among a variety of factors. Considering the key messages from all the sections, the study proposes improvements in the current RM practices in Japanese HSR. The proposal identifies the necessity for first carrying out a detailed risk-assessment followed by the due consideration of the trade-off and the dynamics to set up an adequate level and periodicity of monitoring. Such a solution is deemed a win-win approach that can assure safety by adequately considering the system-specific risks while avoiding the burden of extensive indicator monitoring.

Keywords: Shinkansen Safety, Organizational factors, operator-regulator relationship, systems thinking, leading indicators, system dynamics

Acknowledgment

This is the most exciting part of writing the dissertation.

First, I would like to express my sincere gratitude to my supervisor **Dr. Kazumasa OZAWA.** His inspiration and his ability to explain even the most difficult of the concept in the simplest of the words is, which made it possible for me to enjoy my research over here. His positive attitude made it possible for me to learn how to rise again when I was feeling low, how to find opportunities when I thought I had failed and how to move forward when the future is uncertain. I would have been lost without him. No words can describe my gratitude and respect towards him for his tireless and patient teaching.

I would like to extend my sincere thanks to my co-supervisors, **Dr. Yu MAEMURA,** for his valuable support throughout the paper and thesis writing, as well as the presentations. His ability to critically analyze the information was always helpful in streamlining the main points out of the cluttered research findings that I would generate. I can never forget the help provided by other professors of my committee, i.e., Dr. Kazuo FURUTA, Dr. Masahide HORITA, Dr. Hironori KATO, and Dr. Shunsaku KOMASTUZAKI. Without their help, support, and mentorship, it would not have been possible for me to conduct my research.

Without the great support of the several professionals who helped me get access to the valuable information across different stages of my work, this research would not have been possible. I would like to acknowledge the support of Mr. Yoshitaka Ishii, Former Chairman of JR Kyushu, Mr. Masahiro OTANI, Former Senior Railway Official, JR Central and Former Senior Adviser to Taiwan HSR Corporation, Mr. Toru FUKUSHIMA, Senior Engineering Advisor, Japan International Consultants for Transportation, and Former Senior Railway Official, JR Central, Mr. Yoshihiro Kumamoto, Senior Executive Officer High-Speed Rail Project in India and his colleagues including Mr. Tanpei Oda at JR East for their help and support in interviews for gathering information on Japanese HSR. I would also like to acknowledge the contribution from Dr. Shinhi Kumokawa, Director, Center for International Cooperation of Johkasou System, Japan Education Center of Environmental Sanitation for providing me valuable information on the Johkasou system. I would also like to acknowledge the help and support from the JGC corporation to gather information from the construction site. I would like to express my sincere gratitude for Mr. Toru Sugimoto for providing me access to the JGC's professionals, Mr. Marcos Morales, for his support throughout the detailed interviews, information sharing and result verification, and Mr. Mark Germain for his overview of the safety in the construction industry. In addition, I would like to acknowledge the help and support from Mr. Yasushi Ujita, Deputy General Director, International Division, JR Railway Technical Research Institute and his colleagues in the Human Science Division for allowing me an opportunity to discuss my research findings with Human-actor professionals at RTRI.

A great mentor is sometimes all you need to channel your energy, and I was particularly lucky to have them. I feel short on words to say thanks to **Dr. K E Seetharam and Dr. Laxmi Seetharam**. Thank you so much for providing me a home-like environment in Tokyo, for trusting my abilities, for mentoring me, and for showering me with your blessings throughout the past 3 years. Working at the Asian Development Bank Institute (ADBI) was something beyond my imagination before I ventured into my doctoral studies. However, your trust and guidance helped me to bring the best out of me not only to achieve success at ADBI but also in the research.

Love and friendship don't know any boundaries. I was lucky to have people supporting me from all over the globe. A very special thanks to closed ones in Tokyo **Tigmansu, Shreyas, Gunjan, Karthik, Priya, Surjya, Ayushman, Sanjana, Prakhar, Shreya, Sneha, Chaitanya, Yasmin, Danupon, Iman,** and many more. The moments full of fun, understanding, and compassionate conversations over the dinner parties and the long coffee breaks will be hard to replicate ever in life. Thanks to Life-long friends from IIT and school **Ujjwala, Parva, Gargi, Ayushi, Asheesh, Aishwarya, Abhishek, Abhinav, and Avneet (**and the whole F-Bot) for long conversations over the phone, helping me busting my stress. I feel blessed to have the opportunity to take a few breaks in a Ph.D. and celebrate the special moments in the lives of my friends with them.

The life in the lab would not have been fun without the amazing and hard-working lab mates and a special shoutout to my friends **Xu Kai**, Kavalin, Hiraoka, Arashida, Chongsu, Hung, Ilyas other members of the lab. The inspiring work by each of these individuals was the necessary boost that I sometimes needed to push myself. Talking of the work-life, a special mention goes to **Noriko Nogami** and other ADBI colleagues, for providing a jovial workplace, that offered a perfect break when the Ph.D. seemed going tough.

I am sincerely thankful to the secretary of our lab, **Ms. Kubota** for all the help in all situations. I can never forget your kindness and loving support in everyday life at lab. Also, a special thanks to my host family **Ms. Ayuko AKAIKE** for being a family away from home. I was probably not the best of a host-son, but I surely will remember the warmth of the family that I received from her.

I wish to express my greatest gratitude for my parents **JAGMAL SINGH BUGALIA** and **URMILA,** who brought me in life and loved me to the limits. Their strong belief is what kept me going for all this time. The moral support, values, and guidance for working hard will always be there with me. My lovely brother **NITISH KUMAR BUGALIA** for being a life-long mentor and supporting me in all my decisions and the newest member of my family, my sister-in-law, **SWATI** for her care and support for the family.

No acknowledgment would be complete without mentioning "my rock," my fiancé **Vishakha Shankar**. Without her love and support throughout, despite fighting her own battles, I will not have been at a place where I am today. I was expecting life to go like a crazy roller-coaster anticipating life in Ph.D. and staying away from you, but you made it sailing smooth. I have a long list of "to-dos" with you, but the happiest feeling is that soon I will have the life-time full of time to embark on the crazy adventures ahead.

At last, I am grateful for the scholarship granted to be me by the **Ministry of Education, Science, and Culture of the Japanese government**, thereby providing me with the opportunity to study in Japan. A sincere acknowledgment to my Alma-mater, **IIT-Kanpur,** and my mentor **Dr. Sudhir Misra** for the support and guidance throughout.

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Chapter 1. Introduction

1.1.Importance of Japanese HSR Safety

High-Speed Railway (HSR) in Japan, also known as *Shinkansen*, is an ultra-safe complex socio-technical system (Ota, 2008; Kawakami, 2014a; Doi, 2016; Hidema, 2017) and safety is Shinkansen operations is a matter of national and international importance.

Within Japan, Shinkansen is known for its impeccable safety record of zero passenger fatalities in more than 50 years of its operation (Hancock, 2015). Japan is undergoing a demographic change as its population is declining and aging. The changing demographics also have an impact on the geographic distribution of the population. Hence, despite the decline in population, ridership for Shinkansen is expected to show slow but steady growth, as the cities having accessibility from HSR are likely to attract more residents from the nearby regions (MLIT, 2017b). In that, demand for the safety, reliability, and convenience offered by the Japanese Shinkansen is expected to go higher, as the HSR has to adapt to cater to the demands of the aging population.

Also, over the past decade, the world has witnessed a renewed momentum for the development of the High-Speed Railway (HSR) (Leboeuf, 2018). This momentum in HSR growth is expected to continue. An estimate predicts a 50% increase in the HSR network in Asia by 2030. Most of the HSR expansion is expected in South-Asia where the existing experience to operate HSR is rather limited as there are no previous such projects. (Asian Infrastructure Investment Bank, 2018). While the demand for HSR is increasing globally, safety is one of the most favorable arguments favoring the Japanese HSR in the global market (Feigenbaum, 2013). Such an expected growth in HSR demand in both domestic and international markets highlights the importance of studying the safety of Japanese HSR. Table 1-1 also shows the relative strengths of the HSR as travel mode in offering safety, making a strong case for future HSR development.

Table 1-1 Relative strengths of different transport modes (adapted from : (Hidema, 2017))

Transport Mode	Relative strengths of different travel modes				
	Speed	***Accessibility***	***Frequency***	***Capacity***	***Safety***
Flight	✓✓✓	✓	✓	✓	✓✓✓
High-Speed Rail	✓✓✓	✓✓	✓✓✓	✓✓✓	✓✓/✓✓✓
Bus	✓/✓✓	✓✓✓	✓✓	✓	✓
Passenger-Car	✓/✓✓	-	-	*X*	✓
✓✓✓- Strong advantage, ✓✓- Modest advantage, ✓- Intermediate, *X*- Disadvantage					

As already mentioned, the Japanese HSR is an ultra-safe system. Japanese HSR is known for its impeccable safety record of "**Zero** passenger fatalities due to train operation" for more than 50 years of its operation (Hood, 2006; Hancock, 2015). In comparison, the Chinese and Spanish HSRs have suffered fatal accidents in their relatively short history of HSR operations (Kawakami, 2014a; Fan *et al.*, 2015; Doi, 2016).

However, no system is infallible, and in recent years, there have been several accidents in Japanese HSR that warrants attention to the topic of Shinkansen safety (see Figure 1-1)[1]. While none of these accidents resulted in a casualty to HSR passengers through railway operations, up to a certain extent, that can also be considered as a matter of luck. For example, in a recent accident involving a

[1] The figure has been prepared using the data obtained from official accident reports and literature in Japan. These accidents will be discussed in detail later in the thesis (Chapter 4). JR refers to the Japan Railway Companies, which are private HSR operators in Japan. JNR refers to the predecessor organization of JRs, called as Japan National Railway. Detailed information on several JRs is discussed in Chapter 3.

crack in the bogey frame of an HSR train in operation, the crack had reached dangerous levels of depth and could have lead to derailment causing fatalities (Japan Transport Safety Board, 2019). Further, even in several earthquake-related train derailments, the timing of the earthquake was such that no passengers were harmed (Japan Transport Safety Board, 2016b). The accident involving crack in the bogey frame was described as the first “serious accident” in the history of Japanese HSR by the official accident report.

Accidents

Company	*1964-69*	*1969-74*	*1974-79*	*1979-84*	*1984-89*	*1989-94*	*1994-99*	*1999-04*	*2004-09*	*2009-14*	*2014-19*
JNR	1	1 1									
JR Central											1
JR East									1	1	
JR West											1 1
JR Kyushu											1

Figure 1-1 Number of reported accidents in Japanese HSR and their year of occurrence

Source: Author

Such a trend of increasing accidents, with the potential to harm passengers, as well as the growing importance of Shinkansen safety, thus warrants importance for the topic to be studied.

1.2.Characteristics of the HSR System

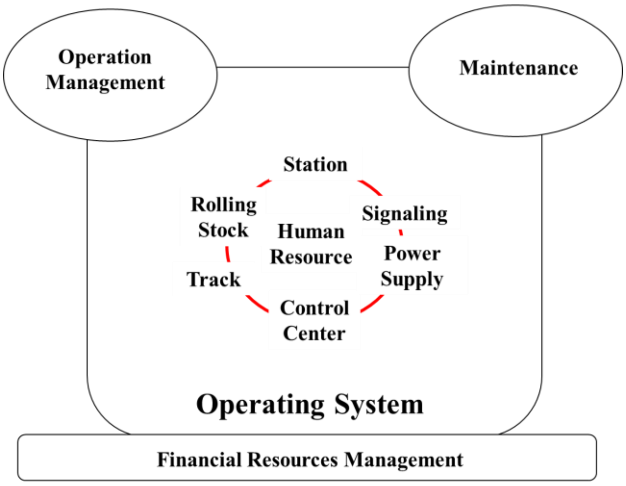


Figure 1-2 Core HSR system

The core system of HSR will be often referenced in this section, and the same is shown in Figure 1-2. HSR has been described as a complex, large-scale, integrated, open socio-technical system (Sussman *et al.*, 2007; Hidema, 2017), consisting of various technical, human, organizational, and institutional sub-systems. Technical sub-systems often refer to physical system components such as the Rolling Stock, Station, Signaling, Power Supply, Control Center, and the Tracks. Humans interact with each of the above-mentioned technical components across the life-stages of the technology, such as its design, development, integration, operation, maintenance, and disposal. Humans and technical sub-systems are both governed by the Organizations that they belong to. The thesis commonly uses the term HSR Train Operating Company (TOC) to refer to the trains responsible for HSR operation. Although depending upon the geographical location, the role of TOC may change. In Japan, in addition to the train-operation, the TOCs are also responsible for managing passenger interface, infrastructure, and control facilities, as shown in Table 1-2. The decision making and resource allocations by the TOCs then govern the operations management, maintenance, and the financial management of the HSR system, and affects the performance of each of the human and technical components. Actions of the Organizations are further governed by the institutional components, such as the regulatory bodies, ministries, etc. Hence, the HSR system can be described through its components (physical and social) as well as the interactions among these components.

Table 1-2 Comparison of functional ownership for different transport modes. Adapted from *(Doi, 2016)*

Transport Mode	***Vehicle***		***Passenger Interface***		***Infrastructure***		***Control facilities***	
	Subsystem	***Owner***	***Subsystem***	***Owner***	***Subsystem***	***Owner***	***Subsystem***	***Owner***
High-Speed Rail	Rolling stock	Train Operating Companies (TOC)	Station	TOC / Infra. manager	Track, Signal, Power Supply	TOC / Infra. manager	Control center	TOC / Infra manager
Air-Transport	Aircraft	Airlines	Airport	Airport authority	--	--	Air traffic control	Industry regulator
Roads	Car/Bus	Owners	Service/Gas station	State/Private	Road signal	Public bodies	Control center	Transport department

On the other hand, HSR is not the only complex socio-technical system. Several other systems have been described as complex socio-technical systems such as aviation, nuclear power plants, construction, etc. A generic representation of safety interactions for a complex system is shown in Figure 1-3 (adapted from (Rasmussen, 1997)). The representation reveals the key stakeholders and their hierarchical relationship. Further, the representation in Figure 1-4 is also useful in identifying several research disciplines at each of the hierarchical levels and their impact on safety. At the top, society exercises control on safety through the legal system. The next level comprises of authorities and industrial associations, workers' unions and other organizations, which provides necessary regulations for system operation. In this thesis, the top-two levels combined are termed as *Institutional level*. Laws and regulations provided by the above-two levels then must be interpreted and implemented for a specific organization (company). Such implementation and interpretation should be context-specific, considering the work processes and equipment of that specific company. In this study, the behavior for the organization as a whole, and the process related to the management are jointly called an *Organizational level*. Details drawn from the local conditions and processes are then added to make the operational rules (Plans) at the Staff level. In this thesis, the term *Human* is used for referring to the Staff level. At the bottom-most level, various engineering disciplines are involved in the design of equipment and in the development of operating procedures. This level is referred to as the *Machine* in this study.

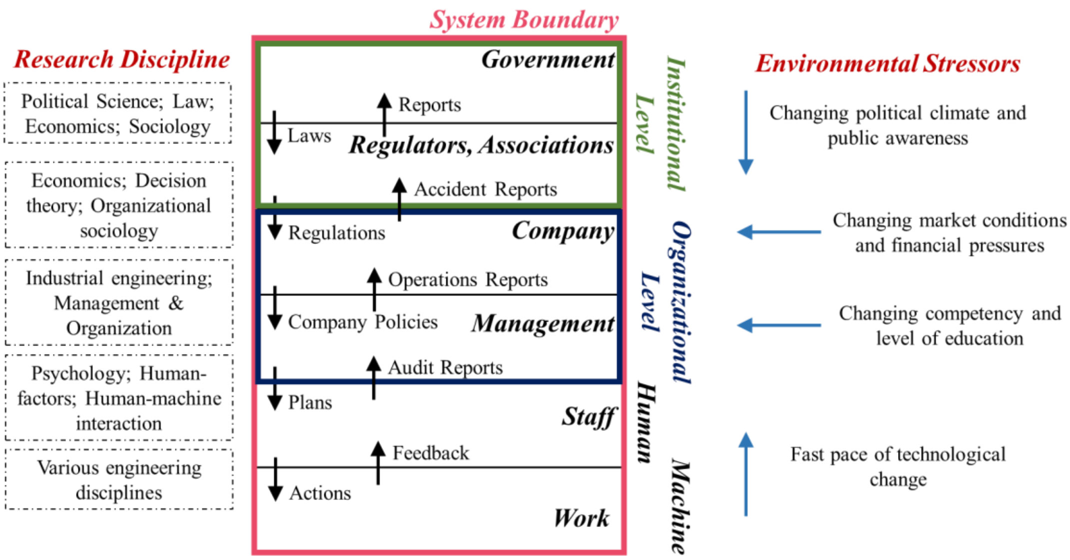


Figure 1-3 A generic representation of interactions affecting safety for complex systems

Adapted from Accimap model (Rasmussen, 1997)

1.3. Concept of Safety

Definitions of the commonly used terms for this thesis are as follows –

An accident is an undesired and unplanned event that results in a loss. Losses can be of the form of loss of human life or human injury, property damage, environmental pollution, mission loss, etc. Consequently, ***Safety*** is a system state free from accidents. ***Hazard*** is a system state that, together with a particular set of environmental conditions, will lead to an accident (Leveson, 2011). ***The causal factor*** is the factor that triggers a hazard. ***Risk*** is a system state that has a *causal factor(s),* which could lead to an accident.

For complex systems such as HSR, safety is described as an emergent property out of dynamic interactions between various components (technical, human, organizational) of the system, and the environment (social, political, economic factors) (Doi 2016; Kawakami 2014; Rajabalinejad and Dongen 2018; Santos-Reyes and Beard 2003; Sussman et al. 2007; Wang et al. 2017).

Thus for complex systems, a concept closely related to safety is risks, which in turn is closely related to uncertainty. In sciences, uncertainty is defined as a state of limited knowledge, where it is impossible to exactly describe a past event, or an existing situation, or a future outcome, or to predict which one of several possible outcomes will occur. Further, the difference between stochastic uncertainty and epistemic is also made for uncertainty with respect to the risk. Stochastic (or random) uncertainty arises from the intrinsic variability of processes, such as the fluctuations in functional performances. Epistemic uncertainty arises from the incomplete/ imprecise nature of available information and/or human knowledge (Pariès *et al.*, 2019).

The key concept of safety is thus linked with how the uncertainty is managed in systems. One approach to manage risks, and thus to improve safety is to reduce the uncertainty as much as possible. In several systems, measures are taken to improve the reliability of the system components, and reducing the fluctuations in their performance, such that the system behavior can be expected and planned for safety. Another direction of reducing uncertainty then refers to reducing the epistemic uncertainty by gaining more and more knowledge about the system behavior and system operation. Both of these responses can be jointly referred to as *Predetermination* of the uncertainty, such that the behavior of the system can be anticipated and accordingly planned for safety. However, in complex systems, often the dynamic interactions between the system components could lead to emerging behavior, that cannot be predicted easily. Hence, there is a growing recognition that a safety approach should also consider to cope with the unexpected by suitability *adapting* to the uncertainty and risks as they emerge. For adequate safety management for a system, a fine balance between predetermination and adaptation is necessary (Pariès *et al.*, 2019).

For a complex socio-technical system perspective, safety is also linked with the nature of the relationship between the components at the various level of hierarchy in systems. Pariès et al. (2019) describe a continuum spectrum of nature of the relationship among system components. On one end of the spectrum is a highly centralized control structure, where the safety behavior is governed largely by the actions of the components at the higher level of hierarchy such as the organization, and regulator in Figure 1-3. At the other end, the behavior of components is individualized, where each player at the lower level of the hierarchy is the manager of their own risks. Such a nature of control is often termed as decentralized management. Each of the centralized and decentralized systems has their own merits and the demerits as described in detail in (Pariès *et al.*, 2019). More so, often, it may be necessary for the organizations to have a mix of both the characteristics to manage their safety (Pariès *et al.*, 2019).

The system-classification scheme, thus proposed by (Pariès *et al.*, 2019), is shown in Figure 1-4. Each of the 4 types of systems has unique characteristics in managing their safety, as summarized in table 1-3. The Railway system is classified as the *Normative Hierarchical system,* whose unique characteristics are discussed in the next section.

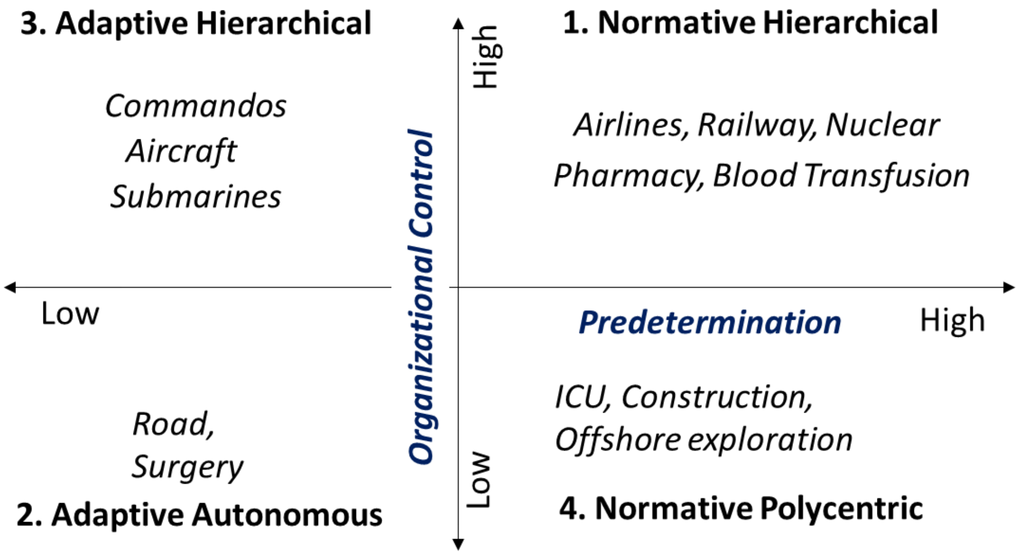


Figure 1-4 Classification of SMS systems

Adapted from (Pariès *et al.*, 2019)

Table 1-3 Characteristics of various systems

Factor	***1 - Normative Hierarchical***	***2 - Adaptive Autonomous***	***3 - Adaptive Hierarchical***	***4 - Normative Polycentric***
Operating Environment	Reduced dimensions of variability	Navigate high level of unpredictability	High level of unpredictability	Variability in operational situations
Expectations of the Front-line Staff	Compliance to norms and hierarchical control	Manage trade-off between risk and performance, Self-regulation among flexible teams	Trained and disciplined front-line staff acting in a tightly coordinated and standardized way	Highly trained, specialized and cooperative teams
Learning	Learning for expanding the repertoire of the unknown	Learning for determining the adaptive response	Learning for determining an adaptive response	Learning for improving coordination among teams
Flow of Information	Bottom-up	Remain at the bottom	Bottom-up	Bottom-Up
Information Processing / Prime responsibility of Safety	Top-Management	Local Agents	Top-Management	Local operative teams
Importance of Standardization	High	Low	High	High

1.4. The uniqueness of Safety Concept for HSR

With reference to the HSR system, a loss event is described as a loss of passenger life and passenger injury and damage to the HSR property (see Figure 1-2). In the scope of the current thesis, the work-place injuries to HSR employees are not considered, although, in many railway organizations in the world, work-place injuries are rampant, including in Japan, up to a certain extent (Hale, 2000).

The definition of the loss, adopted in this thesis is consistent with the Japanese Railway law defining safety (MLIT, 2017a).

As described above, the railway or HSR is considered to be a Normative Hierarchical system. These systems are characterized by a high degree of centralized control, where the response of the front-end staff is determined based upon the pre-agreed standards, procedures, and responses. The objective of the system is to operate in a pre-determined zone of safety. Such organizations engage in learning to improve their responses against the known potential hazard, but not to prepare for any eventuality that may unfold otherwise. Hence, the responsibility of the safety lies at the top management for planning and executing adequate responses against all known eventualities. The role of the front-end staff is largely to execute the procedures.

While the classification presented in Figure 1-4 is for general railway organizations, the management of the HSR system in Japan is also consistent with the classification. An in-depth review of the Safety Management practices for Japanese HSR Operators is provided in Chapter 3; however, at this stage, a few examples are given to support the claim.

Previous academic literature has emphasized on the importance of various technical, human, and organizational factors responsible for Shinkansen safety. The philosophy behind the Shinkansen system development was to remove as many risks as possible. Measures such as the development of an exclusive grade-separated system, minimization of human errors through maximum use of computers, use of tested technology, and implement fail-safe mechanisms in critical parts are some of the technology-related manifestations of this early safety philosophy (Hancock, 2015). These technical factors are known to have the *most significant* impact on the safety performance of HSR (Hancock, 2015). Shinkansen has had zero incidents related to a collision with other trains or to over-speeding, compared to such fatal accidents in Spanish and Chinese HSRs (Kawakami, 2014a). Such is the confidence in the level of technology of the Japanese Shinkansen, that it is often termed as reaching near-perfect (KASAI, 2000). During system operation, focus on human factors such as the enforcement of detailed rules and organizational procedures (Saito, 2002), the use of frequent "On-the-Job" training methods for ensuring sound skills for employees involved in train operation (Hood, 2006), have been considered as essential for safety. Further, the organizational factors, such as the acute focus on preventive maintenance practices following high-quality standards (Hancock, 2015), all have been known to be effective in ensuring safety (Saito, 2002). An important aspect for the safety of Japanese Shinkansen is related to the integration of various technical, human, and organizational factors such as the development of comprehensive traffic control systems that pay sharp attention to issues such as staff management, maintenance management, customer information dissipation management along with train operations. Further, for Japanese HSR operators, there is an acute focus on "Learning from the Past" to continuously improve the system (Hood, 2006; Hancock, 2015). In Japan, HSR operators often develop their own new technology and rigorously test it before putting it into system operation. The feedback received from the testing stage is used to improve the new technology so as to keep on assuring safety as the requirements put on the railway system changes. Such a focus on continuous system improvement based on the "learning from the past" is also visible through the long cycles of product development in Japan, compared to other HSR operators around the world (Yanase, 2010) (see Figure 1-5). Hence, the normative hierarchical style of safety management may even be more prominent to Japanese HSR compared to other HSR systems around the world.

Further, the acute focus on "learning from the past" is also expected to be unique for Japanese HSR when compared to other Normative Hierarchical systems, such as the Nuclear. In that, the cost structure of the HSR technology is of such nature that such prototyping and experimentation may be feasible; however, for Nuclear systems, such prototyping may not always be even possible. Hence, while some lessons from the safety management of other systems could be relevant to the Japanese HSR, the unique nature of the HSR system, makes it important to study the safety issues specific to HSR.

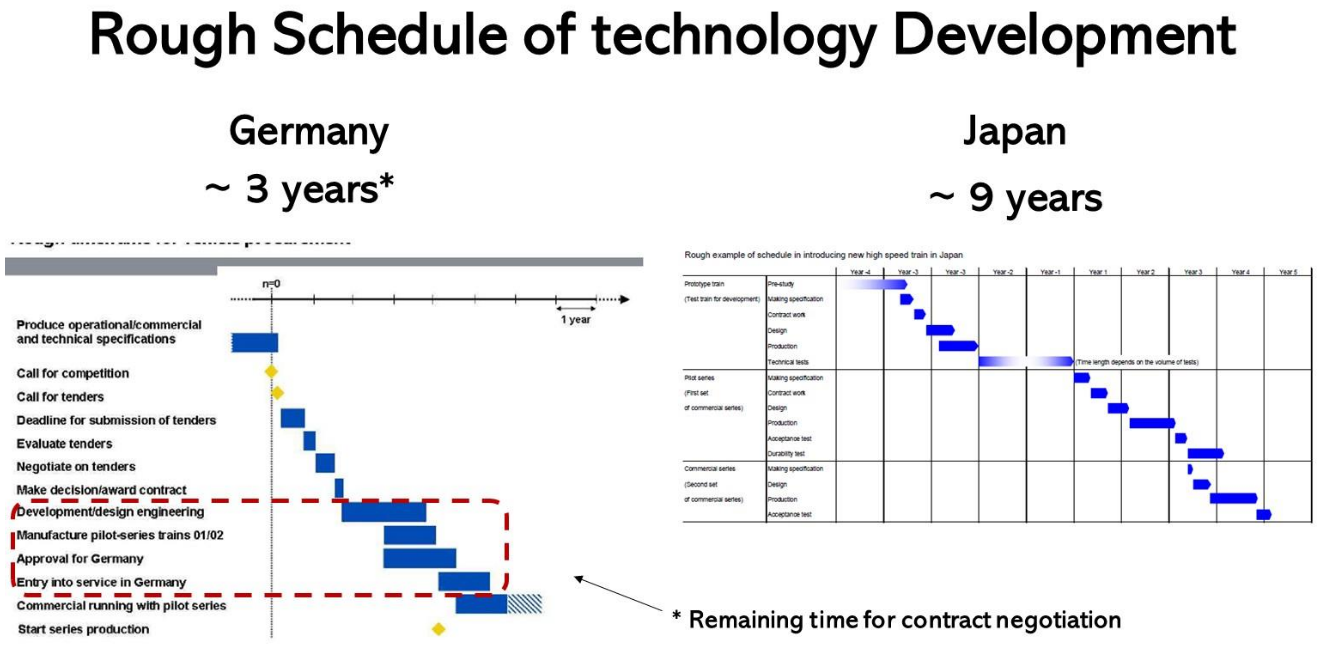


Figure 1-5 Rough schedule of technology development for HSR around the world

Source: adapted from (Yanase, 2010)

1.5. The focus of the thesis

As described above, irrespective of the degree of centralized control in a complex socio-technical system, the safety of it is an emergent property out of the interactions among various technical, human, organizational, and institutional level system components. The previous section has briefly described the importance of technical, human, and organizational factors playing a role in the safety of Japanese HSR. In this section, the focus of the current thesis is specified. In order to understand the necessity of the research described in this thesis, a few contextual factors and their related impacts on the system needs to be understood. Accordingly, the focus of the study is chosen such that it caters to the present as well as the future needs of safety improvement in the Japanese HSR. Table 1-4 summarizes a few contextual factors in Japanese HSR and their potential impacts on the system of Japanese HSR. Table 1-4 provides a general overview and is not considered exhaustive in nature.

Table 1-4 Contextual factors in Japanese HSR and their impacts

Context	The expected effect on Japanese HSR Business	Expected change in System Characteristics
Aging and declining population	1. The expected increase in ridership 2. Increasing safety demands from aging passengers 3. Difficulty in generating revenues through railway and non-railway businesses 4. An expected decline in the number of employees	1. Rise in automation to improve efficiency, and to cope with lack of human resources
Internet of Things	1. Efficiency gains and optimizations using the information obtained	1. System components are expected to be much more integrated and inter-connected.

Aging and declining population is a context that affects a variety of aspects in Japan, and the HSR business is also expected to be affected. As described above, the ridership of the HSR in Japan is still expected to increase, even when the population declines. Further, a strong demographic shift for the passengers is also expected to occur, which will not only affect passenger's travel behavior but will also put an additional burden of managing safety for the aged passengers (JR East Group, 2018). Such changes are also expected to change the revenue structure of the HSR TOCs in Japan. Further, all HSR TOCs in Japan face challenges in hiring new recruits and, in some cases retaining the existing ones. Currently, Humans are still an integral part of the overall railway systems in Japan, and the HSR TOCs will have to navigate challenging environments for managing their work as well as skilling their employees (MLIT, 2018).

On the other hand, the railways in Japan have always relied on the use of technology as much as possible. With the advent of newer technologies such as the Internet of Things (IoT), and Artificial Intelligence (AI), the Japanese HSRs are expected to rely even more on such technologies to improve their businesses (JR East Group, 2018).

These effects in the business environment are also expected to impact the characteristics of the Japanese HSR system. Firstly, a reduction in the role of the Haman operators in the Japanese HSR system is expected. The Japanese HSR has always been designed to keep the role of human involvement to the minimum level. Unlike the regular trains, the Shinkansen system in Japan does not rely on track-side signals. All related speed-limits are directly shown to the driver inside the cabin. Japan uses the Automatic Train Control (ATC) system for signaling and automatic braking actions. An overview of the ATC system is shown in Figure 1-6. For this system, the trackside ATC circuits, detect the accurate positions of the two trains. The onboard ATC system at the preceding train then calculates the *Braking Curve* for that specific train. The driver is accordingly shown speed limits inside the cab, and if the driver fails to apply brakes, the onboard ATC system automatically applies brakes. The ATC system is designed to apply automatic brakes in normal, and many of the emergency situations, thus assuring the safety of the operations. In fact, the Japanese system is designed as a fail-safe system, such as using system-redundancy, so that safety will not be compromised even when the human-errors occur (Hancock, 2015).

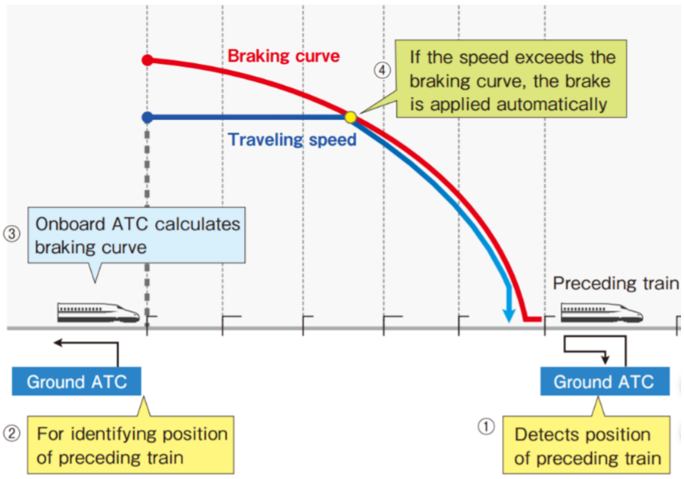


Figure 1-6 Overview of the ATC system in Japanese Shinkansen

Figure taken from a public source- https://www.ihra-hsr.org/_pdf/factbook_2016_E_for_web_all.pdf

With the upcoming, maglev technology in Japan, the human dependency for safe railway operations is going to be further minimized. In a maglev system, the onboard driver, if any, will have virtually no role to play in the train operation. The train control center on the ground will prepare the train-speed curves in advance. These train-speed curves are then fed to the power generation system, which automatically adjusts the power supply in the superconducting magnets to control the speed of a given train. The concept of system redundancy is also used here, where an onboard system, independent

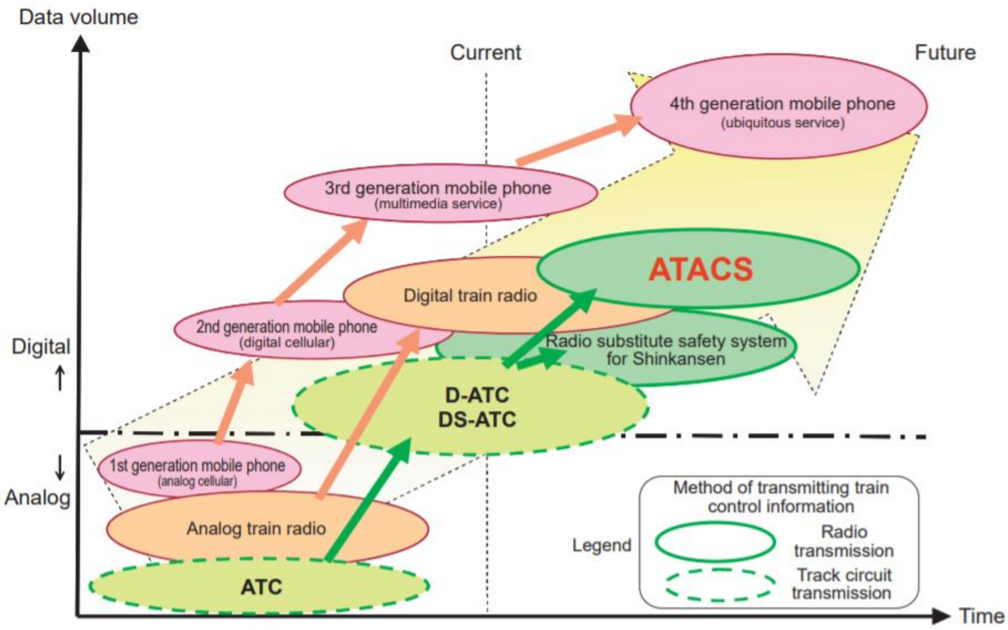


Figure 1-7 Trend in the necessity of processing data volume with the advent of technology

Source : (Kato, 2015)

of the control center, will be able to apply brakes to stop the train to a safe state [2]. Regardless of the financial viability of the maglev systems, sooner or later, such advanced systems of signaling will become available to be used in the HSR technology.

Further, with the advent of technology, machines will be required to communicate with each other and rely on each other for ensuring their functions, as illustrated through the trends in the necessity of data volume in Japanese HSRs as the technology evolves (Kato, 2015). Hence the HSR system is expected to grow in complexity, and the parts are expected to be tightly coupled with each other, such that disturbances in one part of the system could quickly result in system-wide implications.

With both the trends discussed so far, the HSR system is thus expected to grow even more centralized, and the discussions on safety-related challenges of such centralized railway systems have been gaining momentum recently (Hollnagel, 2016; Crawford and Kift, 2018). High-level of automation can create *opacity* in the system; the human controller often doesn't know the true system state and hence find it difficult to ensure safety when the abnormal situation arises. The centralized system also increases the distance between the key system controller and the real operational environment, as often, many works can be done remotely. Under such a situation, the loss of situational awareness can occur, leading to negative effects on safety. Further, under such expected trends, the conventional role of train operation by the human is going to move further up the hierarchy in the SCS, thus further emphasizing the importance of the centralized control for railway systems. In the advanced technological systems, the rules of the operation, the envelope of safe operations, etc. all will be defined by the system components at a higher level in safety control structure, and the adequateness of these rules will then determine the safety performance of the system. Thus, the responsibility of safety is expected to be more and more concentrated at the higher levels of system hierarchy, such as at the organizational or the regulatory levels. While the importance of the technical and human factors affecting safety cannot be undermined, the academic literature has also brought notice to the importance of organizational and institutional factors affecting safety for ultra-safe complex socio-technical systems such as HSR (Rasmussen, 1997; Leveson, 2004, 2011). For adequately supporting safety, the organizations and the institutions are also expected to make necessary adaptations in order to keep up with the pace of changing technology. In the absence of necessary improvement at the organizational

[2] https://scmaglev.jr-central-global.com/about/system/

and institutional level for complex systems such as HSR, the overall system is still expected to become vulnerable. Such vulnerability for Japanese HSR, at an organizational and institutional level, is now becoming more evident, as demonstrated by the first "serious accident" in the history of Shinkansen, which occurred in December 2017 (Japan Transport Safety Board, 2019).

Considering the importance of the organizational and institutional factors affecting the safety of Shinkansen, the current study thus focuses on the analysis of organizational and institutional factors affecting the safety of Japanese HSR. As a general implication, the findings from the current study will not only offer valuable lessons of the HSR system in Japan but will also offer meaningful lessons for countries that are adopting the Japanese HSR system such as India.

1.6. Concepts of the organizational and institutional factors in Safety

In this section, the focus is on describing the relevant disciplines and the associated safety-related concepts at the *Institutional* and *Organizational* levels.

1.6.1 Organizational factors and Safety

The system components at the organizational level (refer to Figure 1-3) can then be studied from multiple perspectives. Stroeve et al. (2011) have elaborated on aggregation levels that are used to study organizations. Three levels, namely micro, meso, and macro levels, are described. At the micro-level, the behavior of individuals and groups in an organization is studied. Issues such as the perception of individuals within the organization, their motivation and work satisfaction, work-related behavior of individuals, group formation, leadership, power of influences and groups, and conflict in an organization are all topics of interest of the micro-level. The structures and dynamics at the level of the whole organization are topics of interest for the meso level. In this regard, topics such as authority and power structures within the organization, reward systems within the organization and theory of organizational change, etc. are considered relevant. At the macro level, interactions between the organization and its environment, including interactions with other organizations, governments, politics, society, and markets, etc. are considered. A detailed review of subtopics in each of these levels is discussed in (Eurocontrol III, 2007; Stroeve, Sharpanskykh, and Kirwan, 2011).

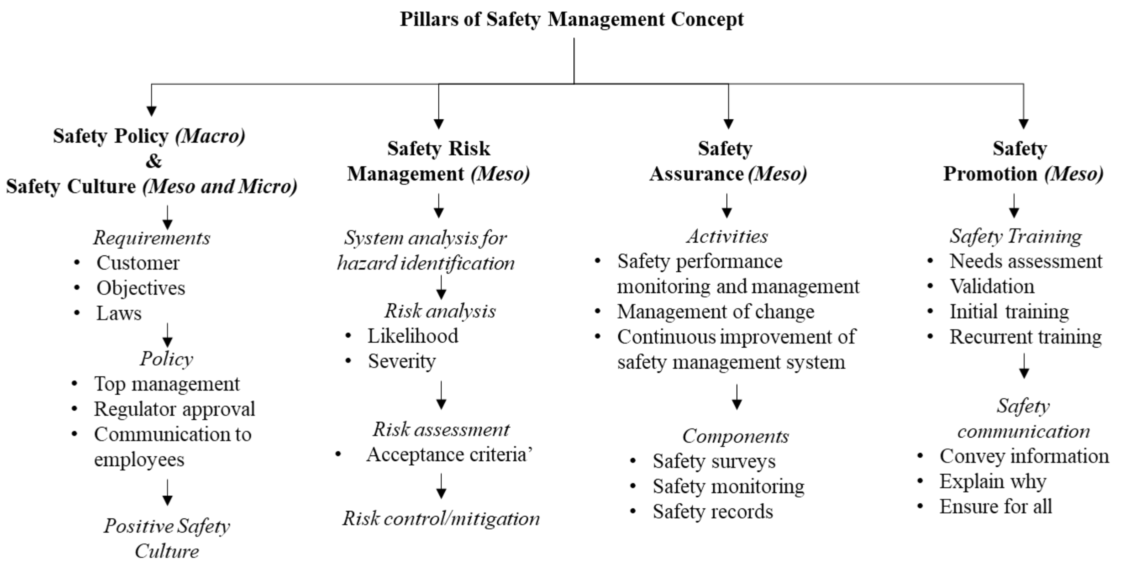


Figure 1-8 Concept of Safety Management System and its mapping with a framework of organizational study

Source – Prepared by author by adapting from Schubert et al. (2010)

Further, the safety-related topics at an organizational level are commonly discussed under the framework of a Safety Management System (SMS) (Stringfellow, 2010; Pariès *et al.*, 2019). SMS refers to an approach that is designed to manage safety elements in an organization. Figure 1-8 describes the key components of SMS and their mapping with the organizational studies (e.g., Macro, Meso, and Micro perspective). Figure 1-8 has been adapted from Schubert et al. (2010).

The key pillars of the SMS are briefly discussed here. *Risk-Management* (RM) refers to the process of identifying, assessing, and mitigating various risks affecting the organizational functions. The RM process helps identify the organizational priorities to manage the safety of their operations. *Safety Promotion* activities refer to the process of modifying the organizational process, structure, etc. in order to achieve the desired level of safety. Key activities include revision of the rules, procedures, training processes, and communicating safety-related information to all employees and departments in the organization. The effectiveness of the safety promotion activities is then measured using the *Safety Assurance* activities within the organization. Safety Assurance refers to the monitoring and management of the existing safety-related practices, issues, and the SMS itself. Safety surveys, monitoring, assessing the records, etc. are all part of the safety assurance activities. Further, numerous decisions have to be taken in implementing each of the steps described above, such as the RM, Safety Assurance, and Safety Promotion. Very often, the decision-making involves assigning priority to resource allocation, etc. under the resource constraint environment. This is where the role of the *safety policy* of the organization and the *safety culture* within the organization becomes important. Further, in simplest terms, the safety culture refers to the "the way things are done around here," thus referring to the prevalent decision-making practices, priorities to several goals in an organization (Antonsen, 2017). Clarke (1998) describes the key elements of a safety culture, as comprising beliefs and attitudes that are shared among employees and are expressed in the day-to-day behavior of the staff. In this regard, the safety culture is a topic relevant to the *Micro* perspective of the organization. However, more recent of the theories have identified the influence of organizational structures on safety culture (Hopkins, 2019), thus hinting that safety culture is a topic of *Meso* perspective on the organization as well. Activities related to risk management in an organization are related to organizational decision-making and thus should be studied from the *Meso*,perspective. Further, the issue of Safety Assurance and Safety promotion are a subset of organizational change and hence, must be studied at the *Meso* level.

Safety Policy refers to the explicitly stated goals of the organization and the relative priority between the various goals. Specifically, the safety policy of an organization is influenced by the institutional factors such as the corresponding legal requirements, the goals of the organization, and influence from other stakeholders and hence should be studied from a *Macro* perspective of organizational studies. The next section briefly discusses safety-specific institutional factors.

1.6.2 Institutional factors and Safety

Beginning at the top-most level, i.e., for Government, the primary objective is to set the law governing the whole socio-technical system. The law sets the broader objectives of the entire socio-technical system and defines responsibilities and authority (to exercise responsibilities and to gather resources necessary for exercising responsibility, etc.) for each of the stakeholders. Further, laws define various processes necessary for engaging the qualified stakeholders and often set the necessary penal provisions for cases where the responsibilities defined in the law are not appropriately executed by the involved stakeholders (reference Railway business Act of Japan[3]). A number of research disciplines such as political science, economics, sociology then become relevant and serve as tools to the understanding of the law formation. In this regard, the issues related to loopholes in the law, e.g., gaps and overlaps in the division of responsibility, the imbalance between the responsibility and the authority, and sub-standard qualifications, etc. all become topics relevant to safety.

The main responsibility of the regulator is to monitor the performance of the system with respect to its goals and objectives as set by the law and provide regulations necessary to bring the system performance close to its goals. A number of related study areas can then be classified into two broad categories. The first set of studies focuses on the relationship between the government and the regulator, while the second set of studies focuses on the relationship between the regulator and the organization it is set to regulate. Often, there are also interactions among the two sets of studies. For example, generic

[3] http://www.mlit.go.jp/english/2006/h_railway_bureau/Laws_concerning/01.pdf

principles of sound regulation emphasize the independence of the regulator, defining the clear legal authority of the regulators, ensuring transparency, openness, and accountability of the regulator (The World Bank, 2017). The topics described above have important safety implications and can be categorized as type 1 of studies. Examples for the second type of studies include topics such as the balance of economic, safety, environmental and technical regulations, or the type of regulator instruments such as licensing and concession, and ensuring predictability in the regulator behavior for ensuring the effective functioning of the regulators (The World Bank, 2017).

The discussion on the safety specific research-discipline provided in this section can then be combined with the generic representation of the complex system to reveal a safety specific representation of the complex system (Figure 1-9). The safety specific representation is more elaborate and clear in indicating the research disciplines at the interface between various hierarchical levels. These research disciplines at the interface signify that for analysis of a complex system, it is never fully possible without giving consideration to effects from other sub-parts of the environment, and hence, any attempt at scoping of the research should duly consider these topics at the interface. While the pillars and topics of the SMS system at the organizational and institutional level have been discussed for a generalized complex system in the current section, academicians have argued that the function and implementation of the SMS could be different for different kinds of a complex system (Pariès *et al.*, 2019). Hence, it is necessary to examine the functionality of each of the above-mentioned pillars in the context of HSR and whether the SMS approach is in synergy with the system-theory framework described in Figure 1-9. The next section examines the suitability of an integrated framework combining the concepts in system safety, organizational and institutional factors for its applicability to HSR management.

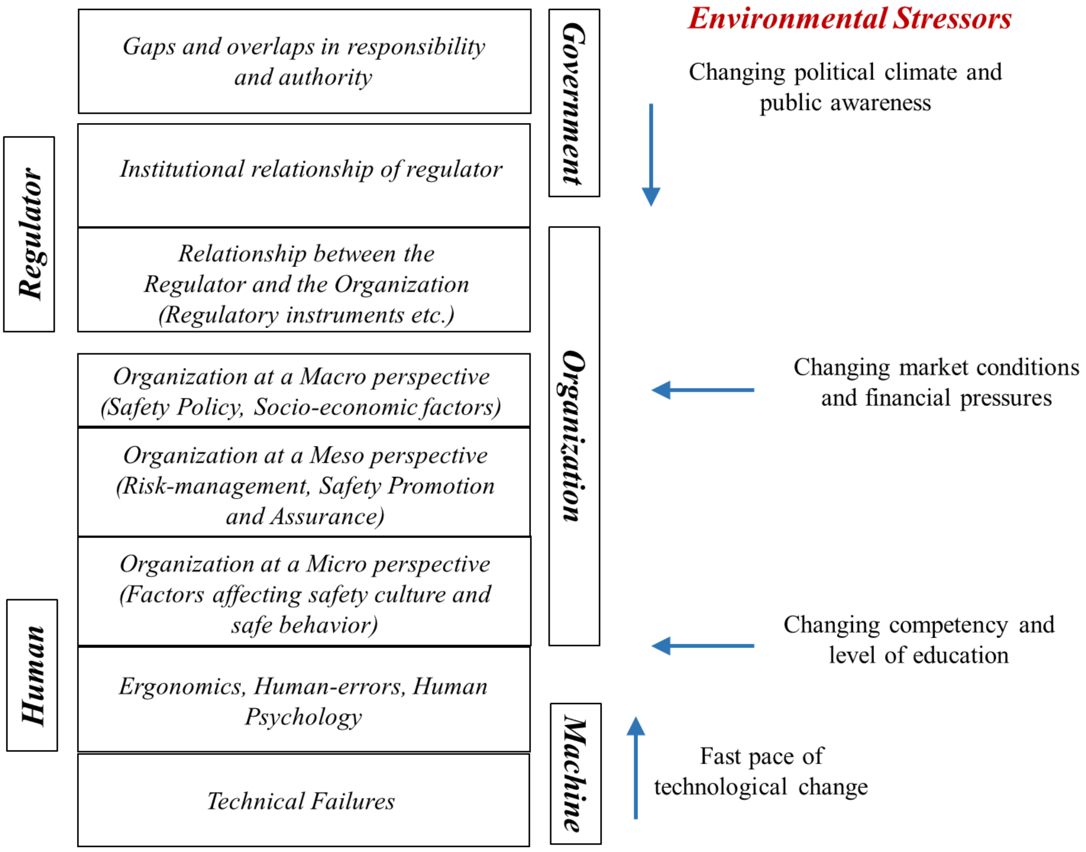


Figure 1-9 Safety specific generic representation of a complex socio-technical system

Source - Author

1.7.Framework for studying HSR safety at Organizational and Institutional level

In previous sections, the thesis has established the synergy between the HSR system in Japan and the normative hierarchical systems described in (Pariès *et al.*, 2019). The concept is revisited here to identify synergy between the SMS and the structure provided by (Pariès *et al.*, 2019). The classification thus proposed is shown in Figure 1-10.

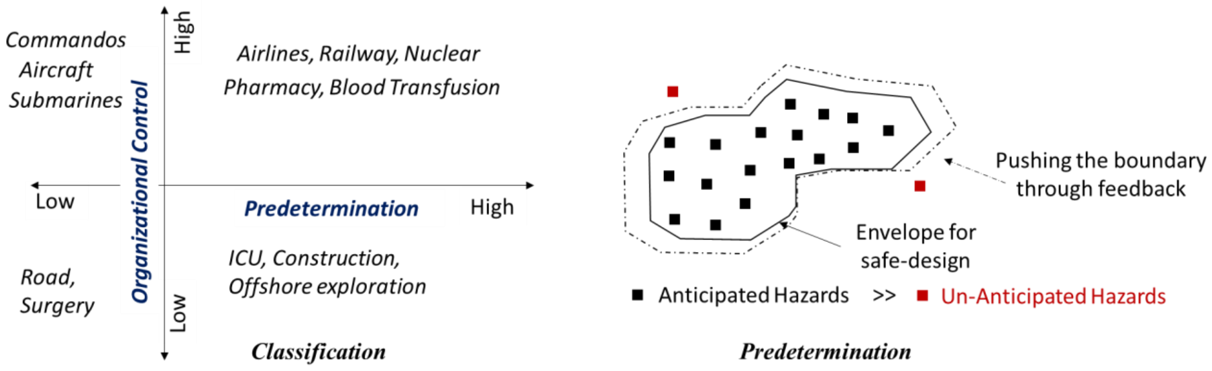


Figure 1-10 Concept and classification system for SMS for complex systems

Source : Author, based on Pariès et al.(2019)

Normative hierarchical organizations tend to continuously expand their boundaries of the anticipated hazards (shown as the *Envelope for Safe-Design in Figure 1-10)* through various activities at the meso level in an organization such as risk management and safety assurance, etc. The main objective of the safety assurance is to prepare a response to the newly discovered un-anticipated hazard instead of modifying their systems to adapt to the unknown. Once the hazard is known, these organizations are known to demonstrate a high degree of centralized control in implementing system changes (*i.e., RM)*. In that, detailed rules, procedures are created (*Safety Promotion)* for the front-line staff to follow. Front-line staff is given adequate training (*Safety Promotion)* to fulfill their responsibilities while their actions are governed by pre-agreed upon operating procedures. Thus, the process of centralized control described by Pariès *et al.*(2019) can then be expressed in terms of the pillars of the SMS. As described above, the RM process helps identify the organizational priorities to manage the safety of their operations. The results from the RM then are reflected in the Safety Promotion activities of an organization. The effectiveness of the Safety Promotion activities is then measured using the Safety Assurance activities. The results from the Safety Assurance activities then feedback to the RM and help to identify pressing safety issues in the organization. Hence, the safety of the system at an organizational level is ensured by continuously implementing the cycles of RM, Safety Promotion, and Safety Assurance.

From the organizational perspective, the HSR TOCs implement several Safety Promotion activities to keep the system within the envelope of safe design (control). The promotion activities are, in turn, determined by the RM process. The RM process is, in turn, affected by the results obtained from the Safety Assurance activities (Feedback). Within the organizational context, RM is also affected by the safety policy of the organization, and the effectiveness of the whole cycle is dependent on the safety culture of the organization. While the *Risk-management* , *Safety Promotion, and Safety Assurance* can largely be regarded as the matter internal to the organization, in a regulated system, Risk-Management is also affected by Institutional factors such as the operator-regulator relationship. The Regulator influences the Risk-Management practices of the organizations often through standards development, approval processes, and sharing knowledge based on industry-wide risk-analysis. Thus, an integrated framework of analyzing organizational and institutional factors can be developed, as shown in Figure 1-11. relationships influencing the safety performance of an HSR system at organizational and institutional levels are then graphically represented in Figure 1-8.

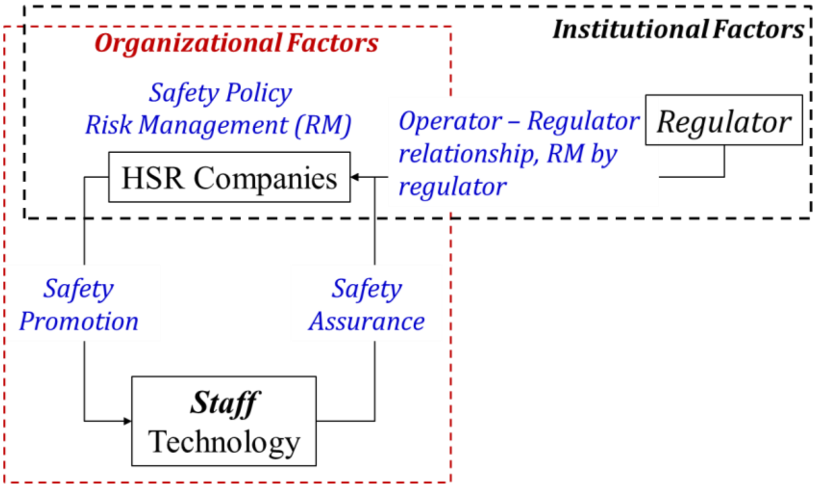


Figure 1-11 System-thinking based integration of organizational and institutional factors affecting safety

The integrated framework for Figure 1-8, is then useful in determining the potential causes of why safety is not achieved in a given system. While accidents can surely occur when the provided Safety Promotion activities are not implemented adequately, they can also occur when the *Safety Promotion* provided is inadequate (Leveson, 2004; Pariès *et al.*, 2019). Potential reasons, the safety promotion provided could be wrong are discussed in detail by (Leveson, 2004; Pariès *et al.*, 2019), but the most common among them being the improper Risk-management including deficiencies in Risk analysis & Risk assessment (Improper predetermination) and Risk Mitigation (Incorrect estimation of the required control). Risk-management is also dependent on the quality of Safety Assurance activities, which tells about the current state of the system (such as the gaps between the expected system defenses and the reality of them) and the quality of the Safety Assurance can then also have implications for the system-safety. The integrated framework is also useful in demonstrating that Safety is an dynamic emergent property, emerging through the structured interactions described through the integrated framework shown in Figure 1-11. The integrated framework, as shown in Figure 1-11, is then useful in guiding the further analyses in the study, including in conducting a literature review of the studies discussing organizational and institutional factors in the context of Japanese HSR.

1.8.Literature Review: Organizational and Institutional factors in Japanese HSR

This section provides an overview of the research on organizational and institutional factors affecting the safety of Japanese HSR. Although the conventional lines are significantly different in terms of the core railway technology, studies focusing on the conventional lines also have been discussed here, as, in Japan, all HSR TOCs also have operations for conventional railway lines, and their organizational practices are similar. The objective of this section is to provide an overview of the key challenges of safety management practices in Japanese HSR that are yet to be addressed. The review will further help identify the specific objectives of the current study. A brief review of issues for relevant issues in other general systems is also provided, in order to identify studies that are relevant to the HSR and will also contribute to the academic discussions for the general complex systems. The literature is structured on the basis of the framework of the thesis, as shown in Figure 1-11. The relevant literature is classified for each of the components of the framework, i.e., Safety Promotion, Safety Assurance, Safety policy, and Risk-Management at the organizational and institutional level.

1.8.1 Safety promotion activities and their impact on safety

A detailed discussion of various safety promotion-related practices and their supposed effects on improving the safety of Shinkansen will be presented later in Chapter 3 of the thesis. Here a summary of the review is presented. The three key safety promotion activities that a railway organization must undertake are related to the introduction of new technology, promote safety training among their employees, and emphasize on asset maintenance.

While the general consensus among academicians and practitioners alike is that Safety Promotion causes improvement in the Safety performance of the railway system, the empirical evidence remains inconclusive at best (Hood, 2006; Evans, 2011; Kyriakidis, Hirsch and Majumdar, 2012; Hancock, 2015; Kyriakidis, Pak and Majumdar, 2015). There are several possible reasons behind such inconclusiveness of the literature.

The first reason is related to the definition of safety performance. A popular notation of measuring safety performance in the industry as well as academia alike was originally proposed by Heinrich (1941). As per Heinrich's pyramid, incidents/accidents in a system could be categorized based on their level of severity, for example, a death, an injury, an incident, a near-miss, etc. Further, Heinrich had proposed an approximate proportion that for every 1 death, there are about 29 injuries and 300 incidents that usually precede the main-event or the death. What Heinrich proposed as a rule of thumb, and the message was that in order to prevent a big accident, organizations should also focus on preventing injuries or near misses. However, often the rule of thumb has been confused with a causal relationship, thereby assuming that for every 29 injuries, 1 big accident is about to happen. However, such causal relationships are rarely true in complex systems. Hopkins (2019) has provided a great review of organizations that are successful in preventing injuries, but not in big accidents such as the case of British Petroleum involved in several of the biggest accidents having huge environmental, ecological, and financial losses. For the railway sector, the relationship between near-misses and injuries are also at best weak-correlation (Kyriakidis, Hirsch and Majumdar, 2012).

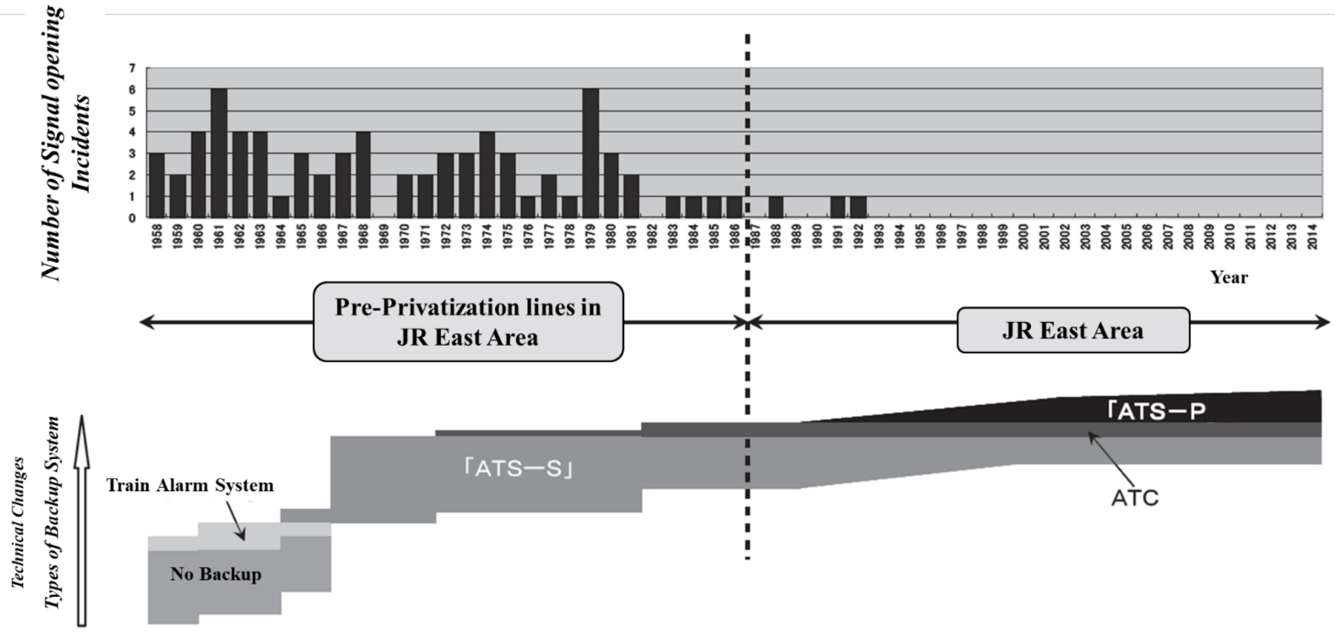


Figure 1-12 Impact of technological changes on Safety performance in JR East

Adapted from 片方喜信 et al. (2015)

The second difficulty in ascertaining the impacts of safety improvements on safety performance is related to the fact that often changes in one part of the system, will improve the performance on the certain dimension, but may cause issues that are new or previously unknown, or starts affecting other parts of the system. For example, 片方喜信 et al. (2015) have discussed the impact of technological changes on one of the aspects of safety performance. As shown in Figure 1-12, the number of Signal crossing incidents reduced drastically at JR East once advanced technical systems providing braking assistance to the human operators were introduced on the network. While the long-term trends clearly show that the number of signal crossing incidents dropped significantly after the introduction of new and new technology, the study also points out that the nature of operation errors changed, and new issues started emerging at a higher level in the system hierarchy. Similar observations have also been made for other Safety Improvement related interventions such as the effect of improving Human-

Training and improving maintenance. (Marais, Saleh, and Leveson, 2006; Kontogiannis, 2012) have recorded numerous “side-effects” or “unintended consequences” of certain efforts to improve safety, for example, while in-general safety-training is positively associated with the skill level improvement of their employees, but excessive focus on training may also have a negative effect on employee’s trust about whether or not employer trusts their skills and judgment. Such mistrust then is also linked with poor safety performance. In certain cases, even improving safety may not have any effect on safety performance. Often organizations end up using training as a tool to police their employees, but fail to address the underlying systemic issues such as the lack of system maintenance, etc., hence, even improving the safety training is likely have a limited effect where employees can execute only a limited control to ensure safety (Stringfellow, 2010). Similar issues have also been recorded for maintenance-related aspects of railway systems. A study on Swedish railway has concluded the while lack of maintenance is also one of the major contributing factors for accidents in Swedish Railway (6% of the total accidents), the maintenance activities itself contributes to large proportion of accidents (24% of the total accidents), where the trackside workers involved in maintenance are vulnerable to accidents and deaths (Holmgren, 2005).

The third reason relates to the nature of safety improvement interventions in the railway systems. Among practitioners, a systems-perspective of the railway system has existed for long. Hence, the interventions often tackle the multiple aspects of the railway system simultaneously, making it difficult to capture the effect of one dimension alone. In a long-term analysis of the UK’s railway industry, Kyriakidis et al. (2015) concluded that while the number of incidents has decreased significantly, however, the number of accident causes and their relative prominence have remained same. The analysis from Kyriakidis et al. (2015) provides the support that railway safety improves simultaneously across multiple dimensions. In a comparative study of UK and the other European-Union member countries, Evans (2011) also concludes that railway safety has uniformly improved across multiple aspects, thereby making it difficult to provide empirical evidence to support that a specific intervention of either of the technology, training, and maintenance has improved safety performance.

To address the numerous methodological issues highlighted above, the new safety theories have proposed several approaches. A detailed review of some of the theories will be provided in Chapter 2. Firstly, the safety theory for complex systems has argued to differentiate between workplace safety and process safety (Leveson, 2015; Hollnagel, 2016). Numerous examples exist for systems that are safe but hazardous to its workers, and vice versa and the factors related to two could be independent of each other. Second, the safety theories have emphasized on considering a systems-perspective to manage their process safety, in which interactions among various system components are duly considered to improve the systems. Third, these theories have warranted considering system-specific risks and not the generalized risks that are shared across the industry. Each system varies in characteristics of its components and their interactions, and hence, their emergent risks will also be different (Leveson, 2011). In that analysis of accidents specific to the system in question are deemed necessary to understand the trends in underlying accident mechanisms and adequately improve the system (Underwood and Waterson, 2014).

As will be summarized in Chapter 3, within Japan, the HSR TOCs all understand the systems-perspective to the Shinkansen Safety, up to a certain extent, and uniformity in their practices of various safety promotion activities can be observed. All HSR TOCs continue to focus on the introduction of improved technology, improving the training of their human resources as well as optimizing their system maintenance efforts and see it as an important effort to ensure safety. On the contrary, JR Hokkaido, another child-company of JNR, but cash strapped since the privatization, was recently marred with a series of fatal and serious accidents, and the underlying causes included lack of system maintenance and degraded human resource development activities (The Japan Times, 2013), thereby providing support to the argument that the emphasis on Safety Promotion leads to the improvement in Safety Performance of the Railways in Japan.

Practitioners also argue that the safety of the *Shinkansen* is largely attributed to its robust technology (Kasai, 2000) and human behavior management through strict enforcement of elaborate operational rules and procedures (Saito, 2002; Hancock, 2015). However, as seen from the previous examples within Japanese Railway, as well as for other complex systems, with an improvement in robust technology and front-line staff, the roles of the mid-and top- managers within the organization ted to become safety-critical (Rasmussen, 1997; Leveson, 2004; Hollnagel, 2016; Crawford and Kift, 2018). However, whether such a shift-up in prominent factors contributing to safety has occurred in Japanese HSR is yet to be clarified, and one possible way to clarify is to conduct an analysis of the accidents in Japanese HSR and reveal the prominent issues affecting the safety of Japanese HSR.

1.8.2 Safety assurance in Japanese HSR

At an organizational level, safety assurance can refer to the two types of assessment activities, i.e., assessment at the level of physical systems and assessment at the level of the human subsystem. In Japanese HSR, the importance of the assessment at the physical subsystem level has been very well documented (Hancock, 2015). Japanese HSR operators rely extensively on collecting real-time information through an array of sensors distributed through-out their assets to monitor the conditions of their assets and make necessary decisions (Hancock, 2015).

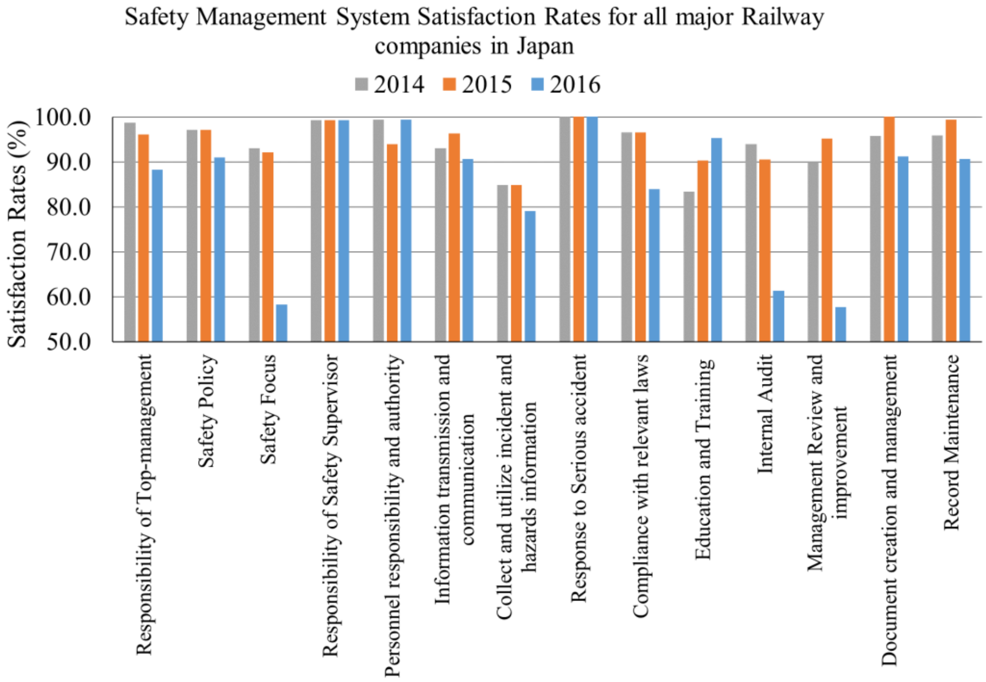


Figure 1-13 Safety Management System Satisfaction Rates for all major railway companies in Japan

Crated by author using data from (MLIT, 2017b)

On the other hand, the issue of safety assurance for the human subsystem has received increased attention in the recent few years. The feedback received from employees about various safety-related observations, hazards, near-miss reporting, etc., are included among the 14 dimensions considered important by the 2006 reform by MLIT (Figure 1-13). However, the data presented in Figure 1-13, also demonstrates the least satisfactory performance on the associated dimensions such as hazard collection and analysis and internal audit. The importance of the feedback from employees about potential hazards, or the near misses, etc. have been emphasized by the railway operators themselves. Several Japanese HSR operators conduct group-discussion sessions, where employees would share their safety-related concerns (Miyaji, 2017). In that, a few projects from Railway Technical Research Institute (RTRI), Japan, have examined the issues in detail, where the focus has been on improving the number and the quality of the safety-related observations from the employees, during the group discussion sessions. Other academic studies have examined the organizational factors affecting the quality of employees' inputs in these discussion sessions (Miyaji, 2017). However, the topics such as the overall reporting behavior of the employees, such as reporting through voluntary reporting channels, and how the reporting behavior is affected by the various other organizational factors have not been examined so far. The issue of receiving safety-related feedback from the employees is an important aspect of Organizational culture. Such reporting behavior is often classified as a sub-dimension of the organizational culture, namely *Reporting Culture* (Reason, 1997). The issues related to reporting culture and the organizational culture in Japanese railway companies have been examined extensively in the aftermath of the Amagasaki railway accident in 2004 (Chikudate, 2009; Atsuji, 2016). In the Amagasaki accident, the prevalence of strong punitive measures had resulted in employees seeking to avoid reporting safety-related concerns (Ota, 2008). Even after the implementation of the regulation in 2006, many of the existing railway and HSR TOCs face difficulties in improving the organizational culture and reporting culture. For example, JR Hokkaido, one of the major TOCs in the northern region of Japan, was found to be involved in a series of scandals which involved falsification and underreporting of maintenance related data and was involved in a few serious accidents (The Japan Times, 2013; Nikkei, 2016). Further, in a recent incident in Japan, the driver of a High-Speed Rail failed to report an abnormal noise or bump, which came from the front of a train operating at high speeds. The driver thought that an animal must have hit and did not consider it worthy of reporting. HSR tracks in Japan are grade-separated, and such obstructions on the track are instead a rare event. Nevertheless, the driver failed to communicate despite the recent addition of a rule mandating the reporting of abnormal situations. When the train arrived at the next station, the station staff noticed that the nose of the train was heavily damaged, even then, the station staff reported this incident to control center only after the train left that station (The Asahi Shimbun, 2018). The event demonstrates that even in ultra-safe organizations with adequate means of reporting available, the reporting practices could still be ineffective, and hence, should be considered in detail in future studies.

Chapter 6 of the study also provides a detailed review of the literature focusing specifically on the Reporting Behavior of the employees. In the past, the discussions on the reporting behavior of the employees had examined the effects of a few aspects and their impact on reporting performance of the employees. Despite the long-standing notion that reporting culture is developed through interactions with people, structure, and control systems within an organization (Uttal, 1983) and is thus dynamic, it is only recently the discussions have been targeted at the underlying dynamics of these interactions (Leveson, 2011; Hopkins, 2019). Also, it is also only recently, that culture is analyzed through its relationship with existing organizational structure and controls. However, even now, the interactions among the people, structure, and control systems and their impact on the reporting behavior of employees are not fully understood. The limitations suggest that consideration of interplay among various causal factors may be necessary to explain the reporting culture of an organization fully and such a study could also be helpful in seeking the solution for the case of Japanese HSR TOCs.

1.8.3 Safety policies in Japanese HSR

The safety policy of an organization serves a crucial role in ensuring the effectiveness of the Safety Management within the organization. Any systems are utilized to serve multiple functions, and the demands put by several of these functions may sometime create a detrimental effect on safety (Schubert, Hüttig, and Oliver Lehmann, 2010). In this regard, the safety policy serves as the general guiding principle of all decision making within the organization. An organization, with a weak safety policy with only implicit mention of safety, may systematically assign lesser priority to safety in daily decision making (Pariès *et al.*, 2019). Hence, an explicit safety policy clearly assigning the highest priority to the safety of operations is deemed necessary in safety prone organizations. As will be seen in Chapter 3, all HSR TOCs in Japan, have an explicit safety policy for their respective organizations that puts a strong emphasis on "Safety First" principles.

However, even after a strong safety policy, the realities of the day-to-day decision making in an organization may still prioritize other functional requirements compared to safety. Such could be a priority assigned to the other functional requirements, that safe behavior may even get punished and thus gradually becomes neglected in the organization. Even in Japan, despite having an explicit high-priority assigned to safety in HSR TOCs, several of the organizations perform poorly on improving employees' perceptions about safety (Figure 1-13). Often employees see that the management ends up becoming hostile to employees even when employees have supposedly taken safe actions, as reported through the official statements of workers union in Japanese Railway (JAPAN RAILWAY TRADE UNIONS CONFEDERATION, 2016).

While the adequate implementation of the Safety Policy is a challenge that many Japanese HSR TOCs face, rarely academic studies have attempted to address these challenges. One obvious limitation is of accessing reliable information from the employees within the private HSR TOCs in Japan, which often consider safety as a sensitive issue, and thus warrant extreme caution for the information that can be shared publicly.

1.8.4 Risk-Management and Shinkansen Safety

The literature on RM practices of the Japanese HSR TOCs is rarely available (Ota, 2008). While the concept of risks to the safety of HSR operations, is very well focused within the Japanese HSR TOCs, the process of managing the risks is based on experiential learning rather than a formal adoption of the RM strategy (Ota, 2008). Business writings and RM related information in Japanese HSR TOCs are considered to be vague and informal, and rarely the RM practices in Japanese HSR TOCs have been critically evaluated (Ota, 2008).

The observations summarized in (Ota 2008) can able be verified from the results for a number of academic studies of these research disciplines in the context of Shinkansen, as shown in Figure 1-16. The academic discussions in the context of Shinkansen safety have focused mainly on technical and human-related aspects. Risk is commonly mentioned in these articles; however, the articles on details of the risk assessment, risk analysis, and overall safety management are rare. A common notion of risk in the context of Shinkansen is related to its vulnerability to external shocks such as the natural disasters and the protection measures thus adopted, but rarely the risk-management practices of the Japanese HSR operators are critically evaluated.

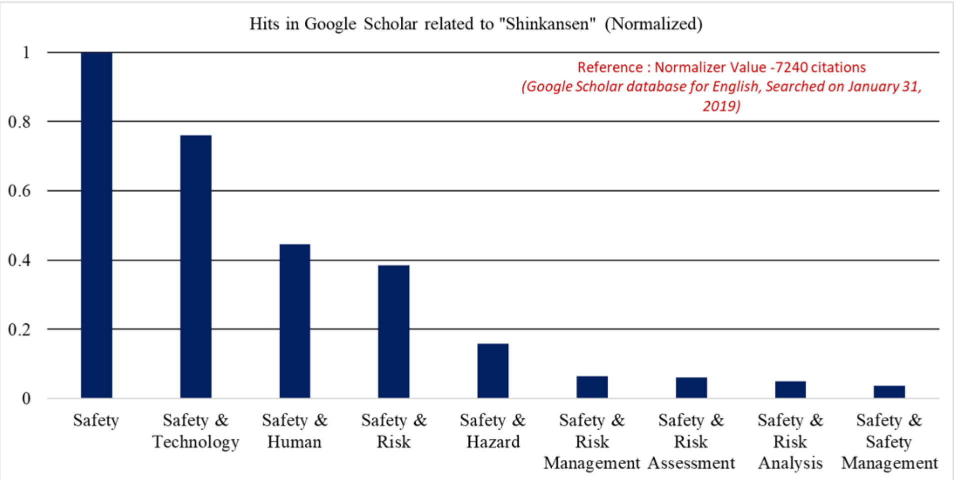


Figure 1-14 Number of studies on organizational factors for HSR Safety in Japan

Source: Author

On the other hand, there is a growing concern about "organizational accidents" in Japanese HSR TOCs. There is an increasing understanding that the human-errors are caused by the latent organizational factors, and hence to clarify the roles of the organization, a few new RM methods have been developed (MIYACHI, 2008). The key idea of several of these RM practices adopted in Japanese HSR TOCs is to define a "Desirable Action" that would ensure the safety of the operation. "Deviation" from the desirable can than being measured by identifying the actual actions. Background factors for each of these deviations are then traced to the organization related factors (such as the rules and procedures), and recommendations are generated for improving safety practices (MIYACHI, 2008). However, one of the fallacies of the arguments above that is commonly missed in the Japanese HSR TCOs is that accidents can also occur when the "Desirable Action" itself is inadequate in preventing accidents from happening (Pariès *et al.*, 2019). As will be discussed in later sections, in the accidents involving a derailment of the Kyushu Shinkansen, the response of the commonly adopted and world renown, earthquake emergency braking system in Japanese HSR, was such that even when the system functioned as designed, it was not effective in stopping the train in a timely manner. In the strict sense, such performance of the system was not a deviation from the desirable action, but the desired action from the system itself was not appropriate, which is an issue related to the RM adopted in an organization. The accident in Kyushu Shinkansen could have been easily turned fatal, and it was a matter of chance that the train which derailed was only approaching the station but did not have onboard passengers in it (Japan Transport Safety Board, 2017). Thus, there exist challenges in RM practices of the Japanese HSR TOCs that still need to be addressed in order to improve its safety performance.

Further, while learning from the accidents is surely one way to improve safety; however, learning from experiences is a “reactive method,” no matter how carefully conducted. Given the changing context in the Japanese HSR, and its potential impacts on the Shinkansen System, a RM strategy must also be pro-active, where the hazard-analysis, etc. can be conducted in a systematic manner, to anticipate risks and accordingly planned for Further, an experiential strategy is surely useful for technical systems, where several running tests can be conducted to assure the safety of the system, however, for organizational and institutional level components, such a strategy is not meaningful. As will be discussed in Chapter 5, currently, several methods of pro-active safety management have been proposed, but rarely these methods have been applied and developed for non-technical systems (Leveson, 2015). Hence, if possible, an attempt should also be made to develop methods that are generally applicable for complex systems and can be used for pro-active RM for non-physical components.

Further challenges in the RM practices of the Japanese HSR TOCs can also be obtained through a review of the related literature published by the principal railway safety research institute in Japan, i.e., RTRI. The RTRI website publishes the detail of various research projects and their conclusions on a yearly basis. Detailed information is available for years 2004-2017 at https://www.rtri.or.jp/eng/rd/seika/. Since RTRI conducts joint research for many TOCs in Japan and is an official agency providing supports for the development of Railway standards and policies etc. Hence, an important assumption can be made that the research projects concluded at the RTRI represents the topical interests of the Japanese railway industry.

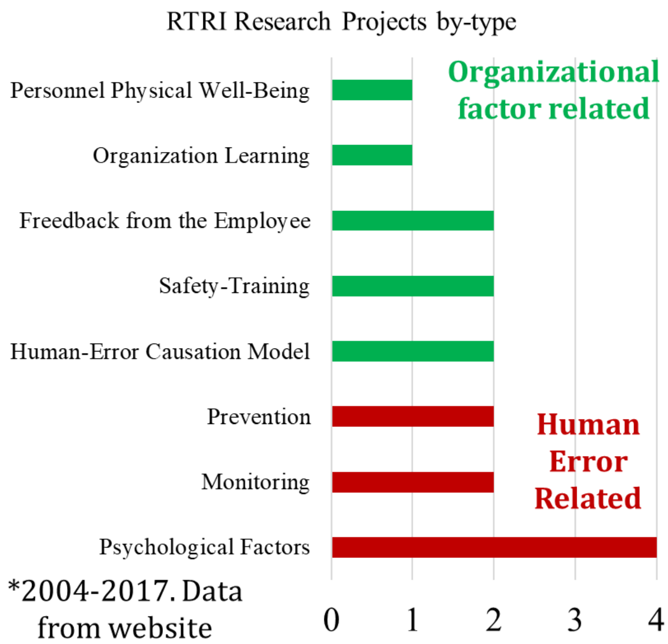


Figure 1-15 Human and Organizational research projects at RTRI

Source: Author

About 90% of the research-related activities under the theme “Improvement of Safety” is aimed at improving the technology. The remaining 10% of the research focusses on “soft”-issues such as Human-factors and the organizational factors, a trend very consistent with available literature in the English language, as shown in Figure 1-16. Figure 1-17 shows an overview of the RTRI research projects focusing on human and organizational factors. A majority of the human-error related projects had focused on analyzing psychological factors, error monitoring, etc. Even the research related to organizational factors is focused almost extensively on the human-errors, and not on organizational factors affecting human behavior. For example, the accident causation models related to projects useful for risk analysis at the organizational level focus on human-errors. These projects take a quantitative approach to human-error and its management, where the focus is on measuring the deviance from the acceptable factors but hardly on identifying underlying contextual factors under which Human-error is made. Similarly, research focusing on safety training, also focuses on treating the symptoms rather than offering systemic solutions, for example, one of the research projects had focused on identifying factors to improve the inter-personal communication within railway organizations without providing any regard to understand the context under which such communication errors are made. A similar observation can be made for a project focusing on feedback from the employee, where the employee’s perception about the safety meetings is analyzed rather than the low-participation rate in these safety meetings.

However, the issues of lack of information on the RM practices is not only specific to HSR but is also applicable to other systems. Over the past few years, the academic discussions focusing on RM for the complex systems have been increasing steadily, and only now, a plateau in the trend has been reached (Figure 1-16). A detailed review of the safety theory for complex systems and the associated risk-management practices are reviewed in Chapter 2, and some of those theories can be applied to the Japanese HSR system directly.

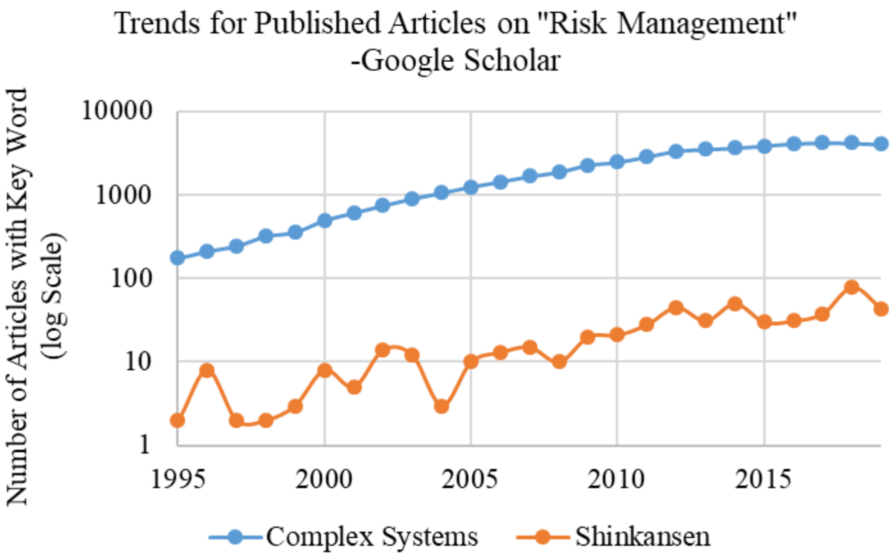


Figure 1-16 Trends in RM related published articles in Google Scholar

1.8.5 Operator-Regulator Relationship in Japan and its impact on Safety

The safety-related implications of the regulator-operator relationships are also not fully understood for the *Shinkansen* system. The literature reviewed in this section was mostly written from the perspective of analyzing trends across countries and across the transport sectors. Studies specifically focusing on railway/HSR in Japan are few.

While the impact of RM practices on an organization’s safety performance has been conceptualized effectively by SMS research, the HSR industry is further complexified with inter-organizational dimensions. We must also consider the influence of prevalent laws and regulations, as well as the relationship between HSR operators and regulators (Rasmussen, 1997; Leveson, 2004).

Existing economic and safety standards and their enforcement by the regulator will impact the risk priorities, risk analysis methods, and in turn, the RM processes of the operator. On the other hand, industry-wide trends and performance patterns produced by the RM processes then form the basis of refined regulations and the operator-regulator relationship itself. Although the operator-regulator relationship and organizational factors have been identified as crucial causal factors for many HSR systems around the world (Dong, 2012; Kawakami, 2014b; Fan *et al.*, 2015), rarely have such factors been discussed in the context of the Japanese HSR system. Very few studies have focused on identifying specific safety risks and implications for the operator-regulator relationship for HSR. Safety implications have been discussed for cases where the HSR operator is a public entity, and the regulator has a relative stronghold over setting up technical standards, such as the Chinese HSR (Fan et al., 2015). Fan and colleagues have argued that a leading causal factor of the Chinese HSR accident of 2011 was the inspectorate style of regulation that placed high demands on the system, without due consideration for the operator's capability to fulfill the demands. The proposed reform suggested a model somewhat similar to the Japanese system before it was privatized, where the public operator adopts a self-regulation model (Fan et al., 2015). In a self-regulation model, the operator largely governs their own standards, and the regulator facilitates a bottom-up approach for enforcement. This was how the formerly public Japan National Railway (JNR) company was structured. Before being privatized, Japanese railway companies maintained stellar safety records while managing to lead the development of new technologies and set self-imposed standards (Rao and Tsai, 2007). For privatized transportation services, Estache (2001) describes a shift in the operator-regulator relationship from a self-regulated to a co-regulated arrangement, with the presence of an independent and competent regulatory body. However, in several countries, including Japan, the issue of establishing and managing standards largely remained with the operators even after privatization, and the role of the regulatory body was to oversee the public-sector obligation (Rao and Tsai, 2007). An overview of the Japanese railway technical standards is shown in Figure 1-17. Figure 1-17 was adapted from a public presentation by Mr. Naoto Yanase, given at the UIC [4]. For Japan, railway safety performance has improved over time, although statistical evidence of the impact of privatization on safety performance remains inconclusive (Evans, 2010, 2013).

In Japan, HSR operations are privatized, since 1987, and operators are responsible for not only asset operation but also asset maintenance. Thus, each Japanese HSR operator has largely developed its own safety standards supported by extensive research and development (Rao and Tsai, 2007). Continuous improvement to safety is also part of the HSR operators' strategy to maintain a competitive advantage over other travel modes (Sone, 2001; Mizutani and Nakamura, 2004; JR East, 2017). These efforts to continuously improve safety then become part of a virtuous cycle of operator's management as Japanese passengers are willing to pay for such a level of safety (Sone, 2001).

However, some recent events in Japan cast some doubts on the sustainability of industry-driven safety practices and call for a proactive regulation from MLIT. In Japan, there is a risk that railway operators may succumb to pressure from an increasingly challenging business environment due to aging and declining population and increasing competition from low-cost airlines. The risk has already manifested in some cases where scandals (serious accidents and falsification of data) associated with a cash-strapped railway operator fueled the debate of more proactive safety regulation and enforcement (The Japan Times, 2013). In other companies, the aging and declining population are affecting revenues for operators, generating new safety demands on existing assets while affecting operator's ability to maintain the level of safety through labor shortage (Sakakibara, 2012). In extreme conditions, similar incidents could also occur to HSR. A recent accident involving the discovery of a cracked bogey frame on an operating *Shinkansen* was designated as the first "serious accident" in the history of the *Shinkansen*. The accident report suggested the presence of organizational and institutional causal factors (Japan Transport Safety Board, 2019), thus further demonstrating the necessity of studying the Shinkansen specific risks for the operator and regulator relationship.

Further, the intra-organizational complexity and its impact on safety for complex socio-technical systems is a topic of interest to safety academicians (Milch and Laumann, 2016, 2018, 2019;

[4] https://www.scribd.com/document/285978672/Japanese-Technical-Standards-pdf

Le Coze, 2017). Currently, research on intra-organizational complexity on safety has been conducted in silos, allowing lesser and lesser knowledge to be transferred across systems (Quinlan, Hampson, and Gregson, 2013), and there is a necessity to identify generalizable accident mechanisms that can help improve safety across systems.

1.8.5.1 Summary

Table 1-5, summarizes the important gaps identified in the literature review. Several observations can be made on the basis of the review of the literature about Organizational and Institutional factors affecting the Safety of Japanese HSR. There is a paucity of literature critically examining the safety-related practices at the organizational and institutional levels. In that, a few specific issues are summarized as follows.

Table 1-5 Summary of the literature review on safety practices in Japanese HSR

Topic	***Literature Gap in Shinkansen***	***Literature Gap in general systems***
Safety Promotion	Safety Promotion activities (such as technical and training improvement, and maintenance) are well emphasized in Japanese HSR. However, with the advent of technology, the role of organizational-level factors in safety is expected to grow. Such relative prominence of the organizational and institutional factors contributing to safety in Shinkansen has not been studied**.**	
Safety Assurance	Near-miss reporting is an issue for Japanese HSR TOCs	The interplay among various causal factors may be necessary to explain the reporting culture of an organization fully, and such a methodology needs to be developed
Safety Policy	The difference between the stated safety policy in HSR TOCs and the realities are different. However, data accessibility issues limit the study of such factors	
Risk-Management	Current RM practices face a challenge in their ability to consider important potential accident causal factors. The current RM practices in Japan are rather reactive.	The pro-active RM methodologies applicable for non-physical system-components (organizational and institutional) needs to be developed
Operator-Regulator Relationship	The current nature of the relationship between the operator and the regulator is not shown to be effective in some cases; however, relationship-specific risks need to be understood in detail.	Generalizable lessons for inter-organizational complexity are thought necessary to advance discussions.

R1. Due to changes in the system characteristics of the Japanese HSR (see section 1.5), the role of organizational-level factors is expected to change; however, such relative importance of the variety of organizational factors has not been examined in the Japanese HSR.

R2. At the organizational level, the RM practices of the Japanese HSR operators have not been critically examined and face challenges in considering important potential accident causal factors. Further, At the Institutional level, the risks associated with the current practices of operator-regulator relationship, and its impact on RM of the operator, and the overall safety-related implications have not been examined.

R3. There is a necessity to develop a pro-active RM strategy for Japanese HSR operators and the general complex systems.

R4. At the organizational level, some of the HSR operators in Japan are facing the issues related to the near miss reporting behavior of their employees; however, only a handful of the studies comprehensively explore the organizational factors affecting the reporting behavior of employees in Japanese HSR TOCs or otherwise in general systems

The specific issues thus identified, serves an important basis for setting the objectives of the study that are described in the subsequent sections. The scope of the thesis is visually described in Figure 1- 18 (blue colored letters in the bold font). The thesis broadly focuses on topics of RM, Near-miss reporting at the organizational level, and the topic of RM at the institutional level, i.e., on the operator-regulator relationship.

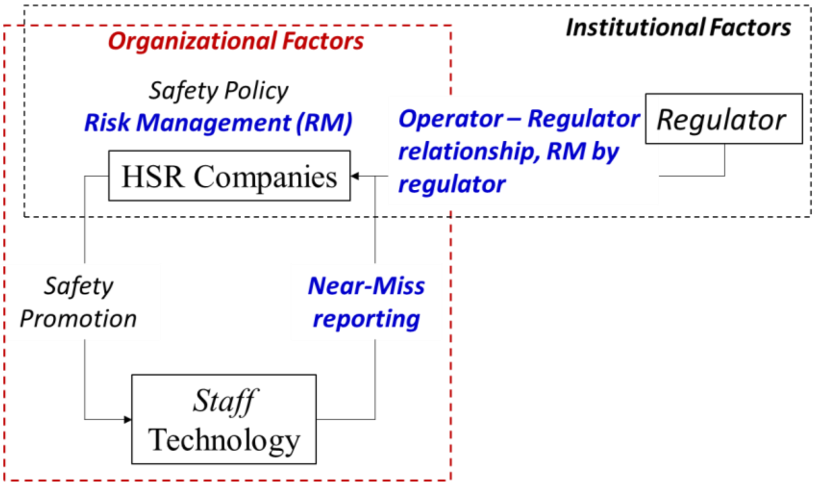


Figure 1-17 Scope of the thesis

1.9.Research Question and Objectives

The research question for this study is –

Q1. How do the organizational (Risk-Management, Reporting Behavior) and institutional level (Risk-Management) risks affect Shinkansen Safety? And Q2. How can Shinkansen Safety be improved?

The specific research objectives to answer these questions are –

O1. Clarify challenges in the current safety management practices (Risk-management) at Organizational and Institutional levels in Japanese Shinkansen and identify strategies to improve the practices.

O2. Develop methods necessary for implementing pro-active risk-management strategies at the organizational and institutional levels.

O3. Clarify the factors affecting reporting behavior at the organizational level in Japanese Shinkansen.

1.10. Chapter Structure

The chapter structure of the thesis is shown in Figure 1-19. A brief description of the contents of the chapters is described below

Chapter 2 – presents a review of state-of-the-art safety theory and methodology. Incoherence with the safety theory for the complex systems at the organizational and institutional level, only qualitative approaches are discussed, and the probabilistic approaches on safety are not considered. Key ideas discussed in the chapter include a description of accident models such as STAMP and SHOW. Approaches for reading indicator development have also been reviewed. The chapter ends with a review of System Dynamics (SD) and the use of Archetypes in understanding deriving safety-related lessons.

Chapter 3 – Review of the prevalent practice of safety management in the Japanese context. Existing literature and the publicly available information from the 4 of the 5 HSR operating companies in Japan are used to identify their practices. The chapter identifies the pro-active practices of safety management, such as top management's commitment to HSR safety. However, the chapter concludes by highlighting gaps and limitations of the current safety management practices in Japanese HSR companies when compared to the state-of-the-art safety theory.

Chapter 4 – To identify specific safety-related issues at the organizational and institutional level in Japanese HSR, reported accidents in Japanese HSR are reviewed. An attempt has been made to identify lessons from multiple accidents at the organizational and the institutional level by adopting a suitable accident taxonomy. Further, the relative merits and demerits of the RM practices in Japanese HSR are discussed. Detailed accident analysis has also been conducted for one recent major accident in Japanese HSR. The accident reveals a safety archetype generalizable in the Japanese context. Further, lessons and potential improvements can be identified by applying existing archetypes to the Japanese context. A large time-lag between the Risk of the accident and the realization of the accident suggest that the leading indicators should be developed for the organizational components to help make the Japanese system more pro-active.

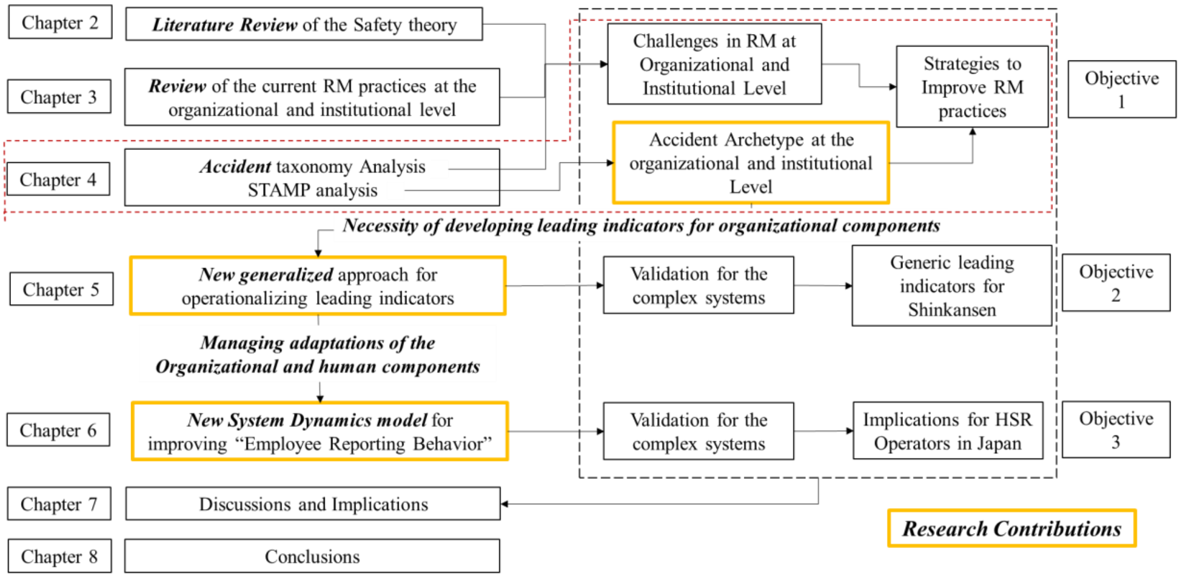


Figure 1-18 Chapter Structure of the thesis

Chapter 5 – Following the issue of implementing a leading indicator program for the organizational or human component, a new generalized leading indicator approach called GEWaSAP is developed. The GEWaSAP approach is an improvement from its predecessor's STAMP and EWaSAP in that it is generalizable for all types of components in the system and not limited only to physical subsystems such as EWaSAP. The approach develops novel criteria to identify suitable controllers who should receive the warning signals originating from the monitoring of the leading indicators. Accidents are known to occur when the warning signs are not delivered to appropriate controllers in time. The proposed method is then validated for the context of the Johkasou system in Japan, a system of decentralized wastewater treatment prevalent in Japan. General implications are also identified for the HSR. In the future, the approach can be applied for the case of Shinkansen with the support of the appropriate stakeholders. However, leading indicators at the organizational level may include subjectivity as the risk level cannot be ascertained as it can be done for the physical subsystems. Owing to this limitation, there is a possibility that the human and the organizational controller may locally adapt, and hence, studies must also focus on identifying approaches that can promote the reporting of such leading indicators.

Chapter 6 – To address the limitations identified in Chapter 5, a System Dynamics (SD) model is developed for identifying key factors and potential organizational policies that can affect the reporting behavior for the identified leading indicators. "Near-miss reporting" prevalent in many organizations is thought of as a proxy of the leading indicator reporting. Although slightly different, both share common characteristics. Both of these are usually not associated with immediately visible consequences. The Dynamic hypothesis is supported by a robust literature review and is qualitatively validated for the context of the construction industry and the Japanese HSR. Data from the construction industry was also obtained, and quantitative validation of the model was also conducted. The model thus developed is useful in identifying important organizational policy lessons for HSR organizations.

Chapter 7 – Related discussions and implications are summarized in Chapter 7

Chapter 8 – Key conclusions, academic contributions, future work, etc. have been summarized in Chapter 8.

1.11. Note on Case-Selection

In this thesis, a general limitation was to access HSR specific information due to langue barriers as well as the in-general lack of public information on the HSR safety to be utilized for academic purposes. While efforts have been made to conduct the studies for HSR systems as much as possible, it was not possible for different studies, and hence case-study is conducted in a variety of different systems. In particular, a case study has been conducted for a system on a decentralized wastewater management system in Japan, which is contrary to its name, is a Normative Hierarchical system as per the classification proposed by (Pariès *et al.*, 2019). The HSR system is also a normative hierarchical system, and hence, generalized lessons can be deemed transferrable from the wastewater system to the HSR system. Further, a case from the construction industry is utilized during the study on near-miss reporting behavior. As per the classification in (Pariès *et al.*, 2019), the construction industry is a normative poly-centric system. This system also relies extensively on a high degree of pre-determination to similar to the HSR system. Hence, the lessons about reporting behavior are deemed transferable. Nevertheless, discussions are made on how information from such diverse systems will be useful for HSR.

Chapter 2. Safety theory

This chapter serves the two-fold objectives. First, a review of the organizational safety theories is presented. Such a review is helpful in establishing the robustness of the integrated framework of analysis adopted in this study (Figure 1-8). Once such robustness has been established, the chapter provides a review of the state-of-the-art safety theory for complex systems, including an overview of various accident models, methods of hazard analysis, etc. The chapter will also provide an overview of other concepts related to organizational and institutional factors such as safety communication and safety culture. The review will help clarify the suitability of the existing methods for achieving the objectives of this study as well as identify areas that will need further improvements.

2.1. Overview of Approaches to Organizational Safety

Two popular theories of accidents and the role of organizations in safety: Normal Accident Theory (NAT) and High-Reliability Organizations (HRO) are discussed here in detail.

2.1.1 NAT

Charles Perrow's NAT (Perrow, 2011) is considered among the pioneer theories of organizational safety. Perrow classifies complex systems on the basis of the degree of tight coupling and the interactive complexity among system components. Perrow takes a pessimistic viewpoint on the accidents, that occurrence of the accidents in tightly coupled and highly non-linear systems is expected and unavoidable. Perrow considers unanticipated component failures to be the cause of system accidents. However, he further notes that accidents can also occur from unintended interactions between subsystems and components even when, all components and subsystem work as intended. Perrow also notes the unintended consequences of the redundancy, as the addition of redundancy to tightly coupled and interactively complex systems could increase the risk of the accidents.

Perrow’s contribution to identifying complexity and coupling as the defining characteristics of high-risk design is considered substantial, and the work has been the basis of many future kinds of research, including the HRO (Leveson *et al.*, 2009). However, academic studies have also critically examined Perrow's theory. The most significant revelations among these are that the high-risk systems noted by Perrow are also among the systems with the safest historical records. Perrow’s theory could not provide an adequate explanation for the same (Leveson *et al.*, 2009). In fact, the optimistic reconsideration of the Perrow’s pessimistic theory on “Normal Accident” served the basis of further theories on Organizational Safety, such as the HRO.

2.1.2 HRO

Taking an optimistic view on Perrow’s NAT, the HRO framework characterizes some organizations, which could be classified as high-risk (as per NAT) but demonstrate consistent safety record for a long period of time (Roberts, 1990; LaPorte and Consolini, 1991). The theory was further refined by (Weick, Sutcliffe, and Obstfeld, 2008) as they proposed five characteristics of the HROs, namely, preoccupation with failure, reluctance to simplify interpretations, sensitivity to operations, commitment to resilience and a learning orientation. Collectively these characteristics are responsible for “mindfulness” of the organization that keeps them working well when facing unexpected. A brief explanation for each of the characteristics is as follows.

Preoccupation with failure refers to HROs treatment to “abnormal” as symptoms of a problem with the system. In that, it is expected that the latent organizational weaknesses can contribute to small errors, which can then contribute to large problems. As a solution, errors should be reported promptly, and problems must be addressed.

Reluctance to simplify interpretations refers to the practice by HROs to take careful steps to meticulously understand the work environment as well as a specific situation. HROs regards the operating environment as very complex, and hence they look across system boundaries to determine the path of problems.

Sensitivity to operations refers to HROs sensitivity towards the unexpected change in operating conditions. HROs monitor the systems' safety controls to ensure they remain in place and operate as intended. Such situational awareness is extremely important to HROs for the adequate management of the unexpected.

Commitment to resilience refers to HRO's capability to detect, contain, and recover from errors.

Deference to expertise refers to the HRO's communication hierarchy during routine and emergency operations. During routine operations, the HROs follow regular communication hierarchy, but during the emergency conditions, decisions are made at the front line, with people who can solve the problems having the most authority regardless of their hierarchical ranks.

In short, the HRO theorists stress the importance of the behavior and attitudes (or organizational culture) as an important tool for organizations to become highly reliable and avoid system accidents (Weick and Roberts, 1993).

At this stage, it is difficult to ascertain whether the Japanese HSR operators demonstrate the features of an HRO. The specific safety-related organizational practices are yet to be reviewed in this study (Chapter 3). However, a few parallels can already be drawn between the integrated framework adopted in this study (Figure 1-8) as well as the HRO theory. The equivalent to the *sensitivity to operations* from the HRO theory is the safety promotion activities in the integrated framework. As stated before, the main objective of the safety assurance in railway systems is to prepare a response to the newly discovered un-anticipated hazard instead of modifying their systems to adapt to the unknown. Hence, the railway organizations can be thought of as being sensitive to their operations as they are constantly attempting to ensure control over their operations, keeping them under the safety-envelope. Further, parallels can also be drawn for Safety Assurance related activities and *Preoccupation with failure.* The purpose of implementing safety assurance activities is to identify the accident symptoms and assess whether safety promotion activities have been effectively implemented. However, for a comparison of the remaining aspects, the existing practices of the Japanese HSR operators will be reviewed later in the thesis.

While HRO's offer a promising theory, and it is often hard to argue that the features promoted by HRO are not essential for safety, the theory itself has been criticized since then (Leveson *et al.*, 2009; Stringfellow, 2010). One of the fundamental disagreements against the HRO theory is in HRO's oversimplification of the culture without paying due attention to the underlying structure of organizational processes, stakeholders, etc. HRO sees organizational culture in isolation of the underlying structure and thus often presents an overoptimistic view that by improving the culture alone, safety for the complex systems could be achieved. Numerous studies have challenged the excessive emphasis on the organizational culture as a *panacea* for system safety in several complex systems such as aviation, and medical (Stringfellow, 2010), NASA's space exploration programs (Dulac, 2007) and for Oil exploration sector (Hopkins, 2019). The strongest argument is that the safety should be designed in the system by putting appropriate controls, and without having the necessary structure supporting the safety, there is only a little that could be achieved through a change in culture (Stringfellow, 2010; Hopkins, 2019). For example, a particular nuclear power plant discussed in (Stringfellow 2010) spent as high as 25% of their work time on safety preparation. Stringfellow (2010) argues that while training is an essential component for the overall safety, training alone for a poorly designed system, is not sufficient for ensuring safety and that more training does not correlate with higher safety.

Another important limitation of the HRO is discussed in (Leveson *et al.,* 2009). This limitation lies in the underlying model of how an accident happens. Both NAT and HRO view accidents as caused by some component failure (technical or human). This is an important distinction between the system-theory perspective, where accidents are seen to be caused by the dysfunctional interactions between the system components (Rasmussen and Suedung, 2000; Woods, 2000; Leveson, 2004). Component failure may lead to dysfunctional interactions, but component failure is not the only reason for the dysfunctional interactions. As already demonstrated in Chapter 1, over the years, the safety paradigm for railway has also shifted to now adopting a systems perspective on safety. Hence, the integrated framework utilized in this study to understand the organizational and institutional factors (Figure 1-8), stands firm on the system-safety approach. Even if all the elements of the integrated framework, do not correspond to each of the characteristics required by HRO, the framework is useful in analyzing the safety-related issues at the organizational and institutional levels in Japanese HSR.

The focus of the discussions now shifts towards one of the fundamental building blocks in the whole safety theory, i.e., the Accident model, which essentially governs what safety-related aspects will be addressed.

2.2. Accident Models and Risk Analysis

Accidents, near-misses, injuries all offer valuable learning opportunities to prevent accidents from happening again. In this regard, accident-model explains how accidents occur. By analyzing how the accidents occur, factors contributing to accidents can be identified as a measure for addressing them can be taken. The same accident models, then serve important tools for hazard identification, which can help analyze the systems in advance and identify potential failure causes.

2.2.1 Event-chain models

Traditional “chain of events” accident models assume that an accident and its causal events occur in a specific sequential order. As per these models, if the event-chain can be broken, the accident can be prevented from happening. This implies that the accident can be prevented by breaking the chain connecting the events in any way. One of the earliest and famous event-chain accident models was proposed by (Heinrich 1941) called the Domino Accident Model. This model specifies five stages when an accident occurs. By removing the middle domino can cut off the event chain leading to an accident or injury (Figure 2-1).

The second popular event-chain accident model is James Reason’s “Swiss Cheese Model,” a model widely applied to various industries. As per this model, an accident is caused as a result of failures in four layers, namely- organizational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts. These layers have gaps or holes in them, which can be described as lacunae in the safety defense. Then, an accident happens when the holes in many layers, line up to permit a trajectory of the

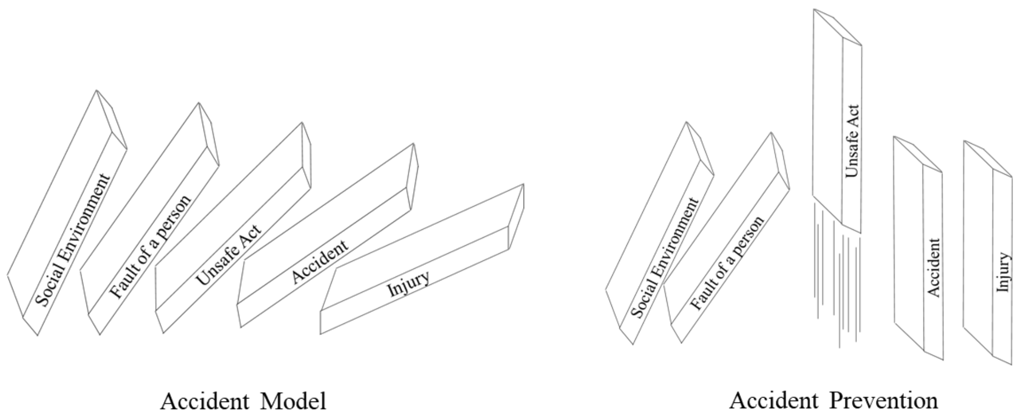


Figure 2-1 Domino Accident Model

Adapted from (Heinrich, 1941)

accident to permeate (Reason, 1990). The schematic of the "Swiss Cheese Model" is shown in Figure 2-2.

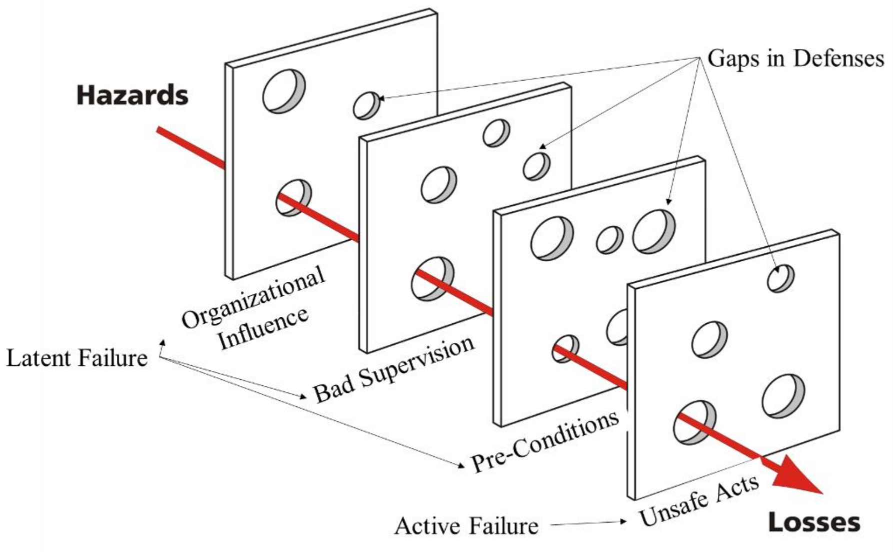


Figure 2-2 Schematic of the Swiss Cheese Model (Reason, 1990)

The idea of event-chains has been then widely adopted in many of the quantitative and qualitative hazard analysis techniques. By estimating the failure probabilities for each of the events, combined in the sequence derived from the event-chain can then be used to calculate critical safety paths (Kawakami, 2014a). One of the most commonly adopted methods of calculation of failure probabilities is failure occurrence frequency, which can be obtained from various tests conducted during manufacturing or during system operation.

Event-chain models are also widely popular in analyzing organizational factors contributing to accidents. In event-chain models, the emphasis is provided on analyzing multiple scenarios of risk origin in a system. Complex systems are often interconnected, and hence, the responsibility of the analyst is to identify as many as possible scenarios and take the appropriate risk-mitigation strategies. Utilizing the idea of event-chain models, many further accident models have been proposed, such as 3M or 5M models, which analyze the accidents from multiple angles to identify comprehensive mitigation strategies.(Li, Zhang and Liang, 2017).

However, the applicability of such event-chain models for the complex socio-technical systems has been widely challenged as per the recent system-control based safety theory (Rasmussen, 1997; Leveson, 2004), and instead use of system-theory based accident models is suggested (Rasmussen, 1997; Leveson, 2004; Hollnagel, 2016). A discussion on the relative merits and demerits of the two types of accident models is discussed later in the thesis (Chapter 3), in the specific context of the railway.

The next section presents an overview of the comprehensive accident models based on system safety theory. While many of the systemic accident models have similar theoretical foundations, each of them differs in methodology, consequently in obtained conclusions. With a review of 449 non-duplicated articles, Underwood and Waterson identified a total of 13 systemic models. These models are Rassmussen's AcciMap model (Rasmussen, 1997), Leveson's System-Theoretic Accident Model and Processes (STAMP)(Leveson, 2004) and Hollangel's Functional Resonance Accident Model (FRAM) (Hollnagel, 2016). A citation search for these techniques showed that the three most cited models were STAMP, FRAM, and AcciMap, with them being referenced in 52.0%, 19.9%, and 17.9% of the identified references, respectively (Underwood and Waterson, 2014). Consequently, our study presents an overview of the STAMP, FRAM, and AcciMap, a discussion on comparative advantages of various models, as well as details of the STAMP and its subsequent modifications.

2.2.2 FRAM

FRAM is a method to analyze the process of work activities. FRAM can be used for accident analysis or for hazard analysis. FRAM analyzes work activities to produce a representation of the work process. The selected event or performance is described in terms of the essential functions necessary to carry out the activity, the potential couplings between the functions, and the typical variability of the functions (Hollnagel, 2016). FRAM makes four key assumptions on the processes. These are –

- The principle of equivalence of successes and failures explains that actions that can describe the system can also describe the accidents in the system.
- The principle of approximate adjustments assumes that people continuously adjust their actions to match the conditions.
- The principle of emergence is the acknowledgment that not all results can be explained as having a specific, identifiable cause.
- The principle of resonance describes that functional resonance can be used to describe and explain non-linear interactions and outcomes.

A function in the FRAM represents the acts needed to produce a certain result. Functions are described by means of six aspects. These aspects are Inputs, Outputs, Resource, Controls, Precondition, and Time. Inputs are needed to perform the function. Inputs constitute the links to previous functions and can be either transformed or used by the function to produce the outputs. Outputs are produced by the function. Outputs constitute the links to subsequent functions. Resources represent the requirements of the function to process the input (such as hardware, procedures, manpower, financial, etc.). Controls serve to regulate the function by monitoring and adjusting the functions when it goes off-target. Preconditions are system conditions that must be fulfilled before a function can be carried out. Time is regarded as a special kind of resource in that all processes take place in time and are governed by time.

Coupling between functions is created when the same values are assigned to aspects of different functions. For example, the output of Function 1 when is the same as Control of Function 2, creates a potential coupling between these functions.

As a summary, the FRAM application consists of the following steps:

1. Identify and characterize essential system functions, using aspects such as Input, Output, etc.
2. Variability in each function is characterized. In FRAM, every function of the system has an inherent variability. Such variability could arise from humans, technology, latent conditions, and barriers.
3. Define functional resonance based on identified coupling among functions. When the variability of the different functions within the system becomes greater than a threshold variability (system's capacity to absorb variability), undetectable, and unwanted outcomes, such as accidents are generated. Such a situation is termed as a "functional resonance," which makes the system is unable to cope with its normal functions.
4. Identify barriers for variability (damping factors) and specify required performance monitoring.

2.2.3 System-Control based accident models

A complex system is often characterized by the non-linear behavior generated through the interactions among systemic components, and hence, dysfunctional interactions among the system components can be thought of as a general way to describe accidents.

For complex socio-technical systems, safety is seen as a control problem (Rasmussen and Suedung, 2000; Leveson, 2004, 2011), according to which, the adequate hierarchy of feedback-control structures are necessary to maintain the safety within acceptable levels. A sample control-feedback loop is shown in Figure 2-3. At each hierarchical level, the *controller* provides information, commands, or *Control Actions* to component below or *controlled process*. In turn, the controlled process gives *feedback* to the controller about the effectiveness of constraint enforcement. This feedback is crucial for updating the mental model or *process model* (current state of the process being controlled) of the controller. The controller uses the current information in the mental model to issue further commands (control-actions) based on a *control-algorithm* (rules, process, etc.)(Leveson, 2004).

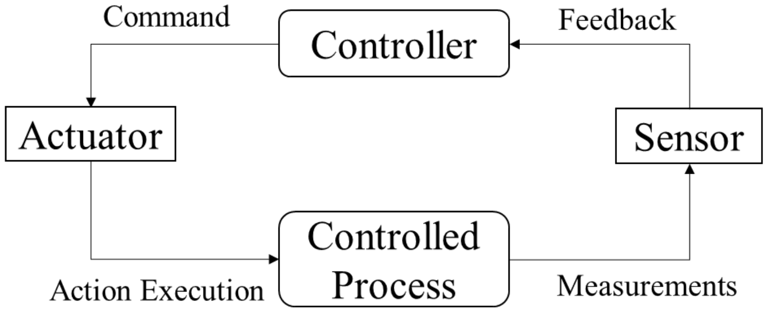


Figure 2-3 A generic feedback-control structure

2.2.3.1 Accimap

Rasmussen highlights some of the macro-world trends and their potential impacts on the risk-management for systems. Rapidly changing technology, increasing the scale of industries, rapid growth in ICT technology, etc. have potential effects on the safety of the systems. Consequently, Rasmussen stresses that a top-down system-oriented approach utilizing control-theoretic concepts is required for safety modeling.

Rasmussen sees accidents as a control problem. Rasmussen also summarized a hierarchical safety control structure comprising of multiple components arranged in a hierarchical fashion. The interactions between these system components arising out of their vertical alignment affect safety. As per Rasmussen, the decisions made at upper levels should transmit down the hierarchy, whereas information about processes at lower levels should move up through the level. Such a vertical flow of decision and information creates a complete feedback (control-feedback) system, which is essential for the safety of an overall complex socio-technical system.

Further, Rasmussen describes the possibility of the system's gradual movement toward unsafety. When the various system components optimize to achieve goals other than safety, corresponding system defenses are degenerate systematically through time. Rasmussen's approach thus requires identification of the boundaries of safe operation and the underlying dynamic factors that may cause the socio-technical system to migrate towards boundaries of safe operation. Rasmussen then emphasizes the importance of making these boundaries visible to system components so that adequate control can be executed. Based on the Rasmussen's risk management framework, the AcciMap accident analysis technique developed (Rasmussen, 1997; Rasmussen and Suedung, 2000). An AcciMap arranges various accident causal factors in an accident mapped divided according to various levels of a complex socio-technical system. AcciMap then links the causal links both horizontally (within each level) and vertically (between levels).

2.2.3.2 STAMP

Leveson (2004) had proposed Systems-Theoretic Accident Model and Processes (STAMP), an accident model for complex socio-technical systems. Three essential elements of STAMP are Safety

Constraints, Hierarchical Control Structures, and Process models, and control loops. In STAMP, accidents are considered to be the result of the interaction among components that lead to the violation of safety constraints. Safety constraints are the relationships among system components that are important to achieve non-hazardous system states. The interaction among components is described through a control-feedback loop at each hierarchical level.

In STAMP, an accident occurs because of unsafe control actions or the failure of the controlled process. An unsafe control action can be when – a control action required for safety is not given, an unsafe control action is given, a safe control action is given too late, too early, or out of sequence, or when a safe control action is stopped too soon or applied too long. Further, accidents can also happen when the appropriate control action is provided, but the controlled process does not follow these actions. Consequently, Leveson (2004) has proposed guidewords, that are useful in identifying causal factors behind unsafe control actions. A generic set of guidewords for STAMP is shown in Figure 2-4.

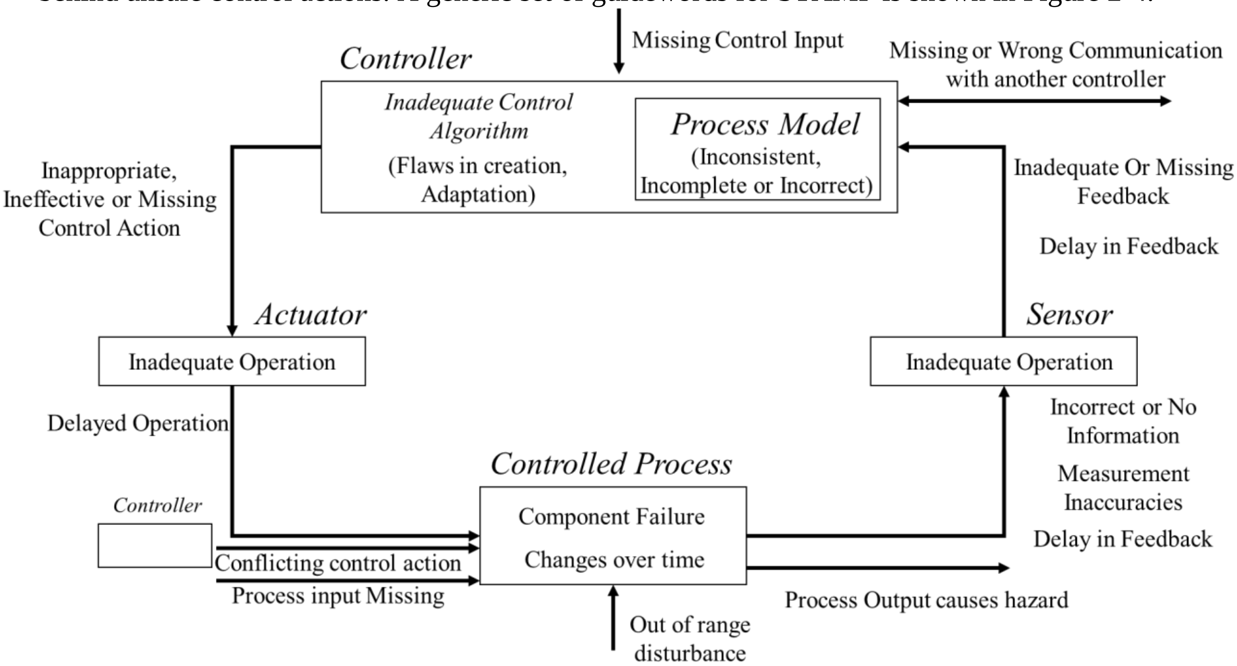


Figure 2-4 Guidewords for causal factors in STAMP (Leveson, 2004)

One crucial improvement in STAMP over its predecessor hierarchical accident model is related to its due consideration to various life stages of the system, across various hierarchical levels of the system. In STAMP, overall safety is achieved through socio-technical controllers arranged in a hierarchy named Safety Control Structure (SCS). Every level of the hierarchy can impose its own safety constraints on lower levels, which, in turn, contributes towards the safety of the whole system. Hence, by use of the STAMP approach, both “top-down” and “bottom-up” interactions within a complex socio-technical system can be systematically analyzed to reveal the dysfunctional interactions affecting safety. Leveson (2004) stresses the need for “building safety into the system” and thus proposes the dual-hierarchical structure, one each for System Development and System Operation (Figure 2-5). This is because, for many systems, safety must be built during the development stage based on the assumptions about system operation conditions. The SCS must also enforce constraints during the System Operation stage. The proposed SCS then assumes a state of dynamic equilibrium between development and operation stages through System Evolution, where the system is revised based on the feedback received during the design operations stage (Figure 2 -5).

Ideally, a system would be safe if its control-structure can be built to enforce all possible expected safety constraints during system operation. However, the importance of adaptation in accidents have also been stressed, where a system drift towards failure as its safety defense erodes because of local production pressures and changes (Woods, 2000) or systematic migration of organizational behavior toward safety boundary under pressure and competition leads to accidents (Rasmussen, 1997). Hence, the control-feedback structure built in an organization can gradually deteriorate over time naturally, or through organizational changes as organizations adapt to the environment fulfilling their diverse goals (Leveson, 2004). Further, in the domain of complex socio-technical systems, changes in one part of the system may affect the other part’s ability to achieve safety known as asynchronous evolution (Leveson, 2004). In recent times, such asynchronous development is increasingly seen among the more prominent cause of safety failures (Leveson, 2004).

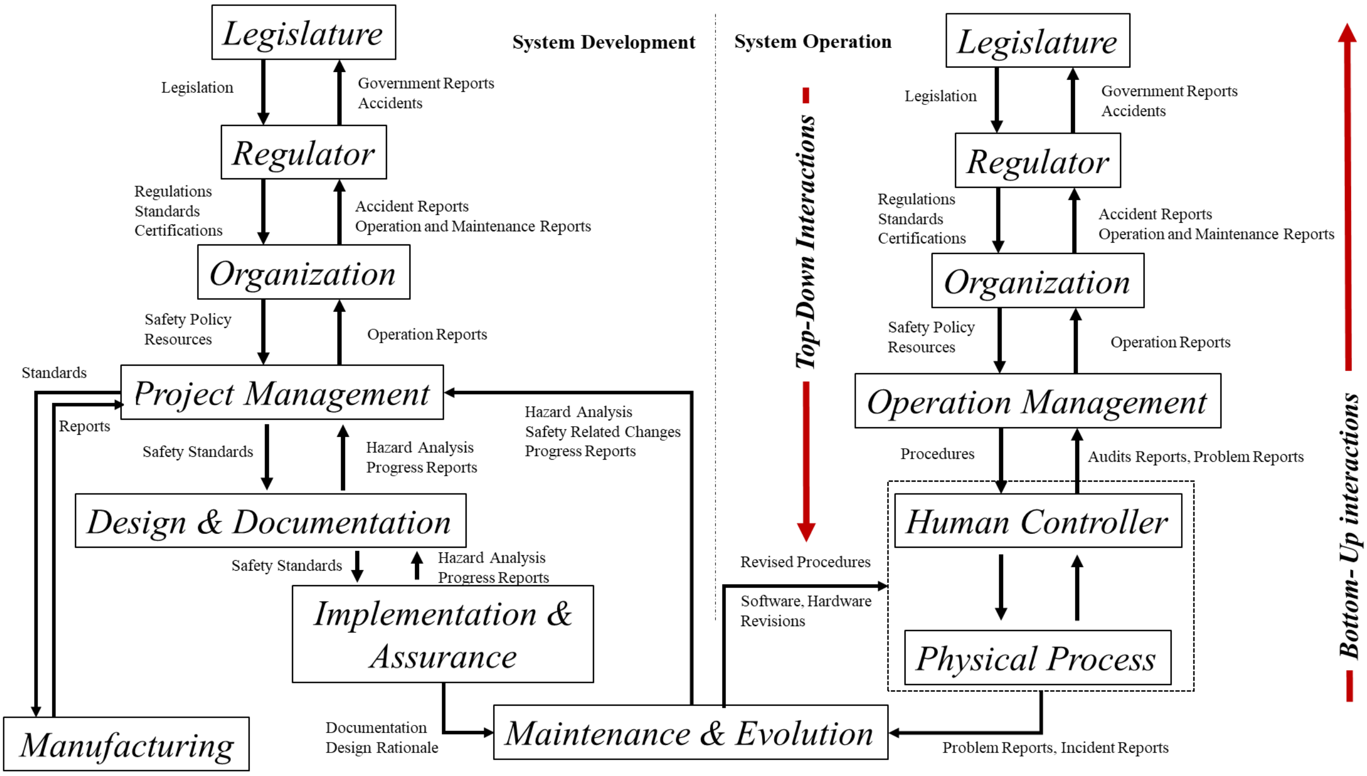


Figure-2-5 Generalized Safety Control Structure (SCS) (Leveson, 2004)

Since its introduction, STAMP has been used extensively for analysis of a large number of socio-technical complex systems, and have been shown to provide a systematic approach for accident analysis, hazard identification in an easy to understand and communicable manner (Underwood and Waterson, 2014). STAMP accident model can then be used for Hazard analysis and accident analysis. STAMP based hazard analysis is known as System-Theoretic Process Analysis (STPA), whereas the corresponding accident analysis is known as Causal Analysis based on STAMP (CAST). Table 2-1 lists the steps involved in STPA and CAST.

Table 2-1 Steps involved in STPA and CAST

STPA	CAST
1. Define Accidents 2. Define system boundary 3. Define high-level system hazards using 1 and 2 4. Define system requirements and safety constraints 5. Construct a hierarchical safety control structure based on 4 6. Allocate responsibilities, define control actions, feedback, a process model for each of the components 7. Identify unsafe control actions 8. Identify causal factors for unsafe control actions	1. Identify high-level hazards involved in the accident 2. Identify system requirements and safety constraints involved in hazards 3. Develop the existing safety control structure and enforce the safety constraints 4. Determine the proximate events that led to accidents 5. Analyze the accident in the physical system. Analyze why the physical controls in place were not adequate in preventing the hazard. Identify the contribution of the physical and operational controls, physical failures, dysfunctional interactions, communication and coordination flaws, and unhandled disturbances to the events. 6. Move up the hierarchical safety control structure and analyze the contribution of the higher levels in providing inadequate control at the lower level

	7. Analyze overall gaps and overlaps in the coordination 8. Determine the weakening of the safety control structure over time by identifying changes in the safety control structure relating to the loss 9. Generate recommendations

STAMP model has also been often criticized for its acute focus on the Physical subsystem and not on other subsystems (Kazaras, Kontogiannis and Kirytopoulos, 2014). For example, in the generalized SCS, the system evolution is stressed only for the operating process, largely consisting of technical components. Although, STAMP introduces an important concept to analyze accidents for components involving Humans, i.e., the context behind the actions or decisions taken by humans. The context shapes the behavior, and that influences the way safety constraints are enforced in a safety-critical system at the human, organizational, and institutional levels (Leveson, 2004). Nevertheless, a few studies have further improved the STAMP model for human and organizational components. These studies are reviewed in the subsequent sections.

2.2.4 STAMP or FRAM or AcciMAP?

An overview of the comparisons between the three models is discussed here. Detailed comparison of STAMP and FRAM has been presented in several studies (Underwood and Waterson, 2014; Li, Zhang, and Liang, 2017), while a few others have compared all three models (Yousefi, Hernandez and Peña, 2019). STAMP is rated higher in the generality of its application, communicability to different stakeholders, consistency in analysis, and completeness in identifying recommendations at several levels in the system hierarchy when compared to AcciMap (Li, Zhang, and Liang, 2017). On the other hand, AcciMap was rated higher on its simplicity, detailed failure taxonomy, and integration capabilities with the existing models, when compared to the STAMP (Li, Zhang, and Liang, 2017). The basis for such simplicity for the AcciMap compared to the STAMP, could also be related to the fact that AcciMap utilizes the event-chain models for analysis at the physical and human level subsystems, making the models compared to the other event-chain accident models that are most commonly used in industries.

While there are many similarities between AcciMap and STAMP, STAMP has been shown to be more comprehensive compared to AcciMap (Leveson, 2004). The SCS in STAMP focuses on both System Development and system operation, while AcciMap only focuses on System operation. In this regard, AcciMap does not consider the effects arising from bad system development and system design, errors during which often are often more prominent in affecting safety (Leveson, 2004). Further, AcciMap still relies on analyzing accidents using event-chain models at the physical and human subsystem level, essentially, losing the purpose of utilizing a systems theory perspective beyond the component failures (Leveson, 2004).

Yousefi, Hernandez, and Peña (2019) took a case-study based approach to provide a relative comparison of the various accident models. They analyzed a case of Richmond refinery accident and concluded that the STAMP was most comprehensive in identifying causal factors at all levels of the hierarchical systems, while FRAM had shown only a limited potential to identify causal factors at the organizational and institutional level, given the limited information that was available to be included in analysis. Further, Stringfellow (2010) reported that FRAM does not provide any guidance for how to discover resonance modes within the system or address system, making it difficult to apply for the organizational and institutional factors. Based on the relative merits of the STAMP for its usage for the organizational and institutional factors, the current study has selected STAMP and the related methods as its principal methodology for the various accident and hazard analysis. Application of STAMP for various analysis at the organizational and institutional levels are widely shown in the literature (N. G. Leveson *et al.*, 2003; Dulac, 2007) and even for Railway (Ota, 2008; Kawakami, 2014b).

2.2.5 Combination of event-chain models with the control theory

Event-chain accident models are still in predominant use in the industry, and many formats of such models have evolved over the years. Many of these models also assimilate a number of concepts borrowed from the system-theory. For example, a number of these models, such as 3M, 5M models give an acute focus on organizational and institutional factors while conducting the accident analysis (Li, Zhang, and Liang, 2017).

However, often, these accident models involve subjectivity, as the interactions between the system components are not systematic. To reduce the subjectivity of analysis, Li, Zhang, and Liang (2017)proposed Accident Causation Analysis and Taxonomy (ACAT) . ACAT method uses a combination of subjects and their functional characteristics to classify accident causes. In ACAT analysis, there are a total of 6 subjects, i.e., Man, Machine, Management, Information, Resources, and Environment.

Man usually refers to frontline staff such as train operators, maintenance workers, or field supervisors; Machine is related to technical components such as fixed assets including tracks, or the moving assets such as rolling stock for HSR; Management refers to decisions made by managers, companies, or the government; Information relates to existing rules, procedures, work-standards, or job-description within for example the TOC; Resource refers to both Human and Financial resources. Finally, Environment refers to the safety culture within the company of the related stakeholders.

In the ACAT method, there are 4 functional characteristics of each subject, namely Actuator, Sensor, Controller, and Communication (the same as the elements of a control-feedback loop). An Actuator executes commands; a Sensor monitors the output; a Controller compares output performance with references and gives commands, and Communication connects elements and conveys information. Each combination of a subject and function refers to one-element in the accident taxonomy (or classification). A detailed taxonomy is not included in this study and is shown in (Table 2 (Li, Zhang, and Liang, 2017)).

For socio-technical systems for which accidents are rather infrequent, accident taxonomies can help to gain valuable information through the development of common failure patterns across multiple accidents. However, analyses based on theories of system-control, described in the sections above, are often complex, limiting their practical applications .When patterns from numerous accidents have to be analyzed, it becomes necessary to adopt a method which can provide a consistent and detailed accident factor classification scheme with the ability to consider a sufficient number of contributing factors in a simplified and communicable manner. Based on a comparison of 7 accident analysis methods based on system-control engineering, and a consideration of the criterion described above, the ACAT method is considered suitable for the same (Li, Zhang, and Liang, 2017).

2.2.6 Further Development of STAMP

2.2.6.1 SHOW

Stringfellow (2010) extended the idea of STAMP from man-machine feedback-control structure developed for physical subsystems in STAMP to man-man feedback-control structure for human and organizational subsystems. Stringfellow (2010) showed that for control loops comprising of humans, a feedback loop between each control element and the controller would be useful to allow the controller to have more immediate feedback regarding the state actuators and sensors themselves are in. For example, for a human actuator, a feedback channel to the controller from the actuator would allow the actuator to let the controller know about the requirements of additional resources to actuate the commands. The generic feedback-control loop consisting of humans is shown in Figure 2-6.

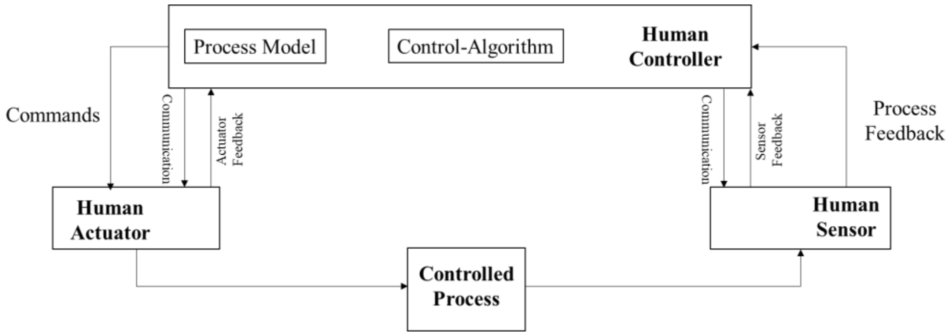


Figure 2-6 Feedback-Control loop comprising of Humans

Adapted from Stringfellow (2010)

Stringfellow (2010) developed a complete set of controller-level requirements for both Human and Organization controllers. These controller-requirements were then used to create error taxonomies having additional error types than the original STAMP. Further, these accident taxonomies were operationalized for Human and Organizational controllers, using the guidewords for identifying the context in which the errors were made. A combination for each item in error taxonomy and guideword would then result in a comprehensive Hazard analysis matrix.

Table 2-2 Accident taxonomies for SHOW, summarized from Stringfellow (2010)

Individual error taxonomy	Organizational error taxonomy
1. Inadequate Control Goal 1.1 Goals are unknown 1.2 Achievement of Goal violates safety 1.3 Goal Priority is wrong *2. Control Algorithm design does not enforce safety constraints* 2.1 Control algorithm different from the scope of the process model 2.2 Incompatibility of control algorithm with control levers 2.3 Controller's inadequate understanding of the control authority 2.4 Controller is unable to execute the control algorithm *3. Model of the controlled process is inconsistent, incomplete, or incorrect* 3.1. Inadequate understanding of the boundaries of the process 3.2. Inadequate understanding of factors influencing one's controlled process 3.3. Method for updating feedback is inadequate *4. Model of the organization structure is inconsistent, incomplete or incorrect* *5. Inadequate coordination between decision-makers* *6. Inadequate execution of control-loops*	*1. Inadequate assignment of Goals, control authority and responsibility to controllers* 1.1 Inadequate coordination among controllers and decision-makers 1.2 Unsuitable role for human control 1.3 Inadequate reassignment of roles and goals during an organizational change process *2. Inadequate allocation of resources throughout the organization* *3. Inadequate assignment to control hierarchy* 3.1. Hierarchy surrounding the organizational process does not support safe control *4. Inadequate communication channel provided for in the organization* 4.1 Communication channel does not exist 4.2 Communication channel do not have sufficient bandwidth 4.3 Communication channel are not created or eliminated in response to changing circumstances *5. Inadequate communication of safety-goals and constraints* *6. Inadequate safety management and the learning process* *7. Inadequate interactions with external bodies*

Following the concept introduced for STAMP, SHOW also relies on a context-based analysis of organizational and human errors. Stringfellow (2010) analyzed many accidents and identified contextual factors affecting safety using a grounded theory approach. She then compiled a comprehensive list of guidewords that represent many contexts for human and organizational decision making. These guidewords then are shown to be important in conducting both the accident analysis and hazard analysis. A full list of contextual guidewords is shown in Table 2-3.

Table 2-3 Contextual guidewords developed in SHOW (Stringfellow, 2010)

History – Experiences, Education, Cultural norms, Behavior Patterns
Resources – Staff, Finances, Time
Tools and Interface – Risk Assessments, Checklists, Human-machine interfaces, etc.
Training
Human Cognition Characteristics – Person task compatibility, Risk tolerance, Control-role
Pressures – Time, Schedule, Resource, Production, Incentives, Compensation, Political
Safety Culture – Values, Expectations, Incident Reporting, Workarounds, Safety Management
Communication – Language, Procedures, Data
Human Physiology – Intoxication, Sleep deprivation

Stringfellow (2010) has then proposed steps for accident analysis and hazard analysis. Since the process is based on the STAMP model, the steps are almost as close to that shown in Table 2-1. When performing hazard analysis, SHOW recommends modification after step 7 of the STPA. At this stage, the SHOW recommends identifying the accident causal factors by adopting multiple perspectives. In the first perspective, all the controllers are analyzed from Individual error taxonomies and the guidewords, as shown in Table 2-3. In the next perspective, the controllers are analyzed from an Organizational perspective, thus adopting the organizational error taxonomy along with the Guidewords. These two perspectives must be repeated until new causal factors are not being discovered.

Further modifications to STAMP have also been presented for Human controllers. Thornberry (2014) had enabled an additional element in the feedback process of Human-controller, i.e., “detection and interpretation,” to specify that human operators’ inability to perceive the feedback correctly could then result in the wrong update of mental models thus leading to accidents. In addition, an active component is also included in human controllers’ control-feedback process through which the human controller can “afford” the actions whether they are suitable for manipulating controls of the user interface.

2.2.6.2 STAMP-VSM

On the other hand, a few other researchers have focused on finding synergy between known organizational models and the safety control requirement concept from STAMP to propose frameworks more suitable for application at the organization level. A joint STAMP-VSM framework for safety assessment proposed by Kazaras et al. (2014), also provides potential accident taxonomy for the organizational control-flows. A quick comparison of the proposed taxonomies of SHOW and STAMP-VSM shows a great similarity between the two (Table 2-4), validating the consistency of the two frameworks for their application for the organization.

Table 2-4 Comparison of Accident taxonomies for SHOW and STAMP-VSM

Items for Taxonomy	**STAMP-VSM**	**SHOW**
Inadequate formation of Safety policy and goals	1. Ambiguous safety policy or lack of safety policy 2. The imbalance between exploration and exploitation 3. Goals change to achieve what's being monitored 4. Goals Degradation	1. Presence of policy and its effective communication 2. Context-specific conflict arising in multiple goals

Inadequate adaptation to change	1. Open-loop - Lack of mechanisms to allow adaptation based on feedback 2. Close loop - Mechanisms to get feedback on existing feedback channels	1. Adequate Dynamic Safety Management: Having a continual process of assessment
Inadequate Assignment of Control Authority and Responsibility	1. The imbalance between autonomy vs. control 2. Gaps and Overlaps of responsibilities 3. Responsibility not assigned to a suitable person	1. Proper assignment of roles and responsibilities to enforce system-level safety constraints 2. Gaps and Overlaps in responsibility 3. The role is not suitable for Human Control 4. Inadequate organizational change for reassignment of roles and goals
Inadequate Design and Ineffective implementation of Safety Plans	1. A mismatch between safety plans and the strategy to manage uncertainty 2. Lack of coordination 3. Inconsistency between plans and routines in practice 4. Plans not following changes in the system 5. Lack of resources 6. Ineffective Training Procedure	1. Inadequate allocation of resources 2. Communication channels do not exist 3. Communication channels do not have sufficient circumstances 4. Communication channels are not modified in response to changing the environment 5. Inadequate communication of safety goals, requirements, throughout the system 6. Organization level decisions must match the stated priorities
Inadequate Feedback Control	1. Inadequate Safety Audits 2. Inadequate Learning from past Events 3. Improperly designed reporting schemes	1. Inadequate Learning Process 2. Inadequate channels to communicate information in response to, or in anticipation of, disturbances impacting safety constraints
Inadequate Feed-Forward Control	1. Inadequate Risk Analysis 2. Lack of Leading indicators	1. Lack of Leading indicators
Inadequate Management of organizational, functional Interaction		1. Organizational controllers must not undermine the Safety Control Authority
Inadequate Interaction with external bodies and stakeholders		1. Such communication should be effective

2.3. Risk Management

While system identification and hazard or risk analysis is the first step for the Risk Management (RM) activities of a safety management system, the next steps involve steps to assess the risk, i.e., develop a priority scheme for all the identified risks. Once the priorities have been assigned, the limited resources are awarded for treating the prioritized risks (Figure 2-7).

In principle, many approaches to risk assessment can exist; however, one of the most commonly adopted schemes involves the development of a risk assessment matrix. In this approach, risks are categorized on two dimensions, i.e., likelihood of the risks and the severity of the risk as well as the frequency of occurrence of the risks (Stringfellow, 2010). Likelihood refers to an estimate of how likely is that a specific risk will materialize. Commonly adopted method for likelihood estimation is to utilize the historical trends in failures, such a failure frequency, during system testing, and system operation stages. Further, the severity is an estimate of the impact of the risks on the values that are important for the system, e.g., the impact of risk materialization on the loss of life, loss of production, loss of reputation, etc. Hence, for an adequate RM, identification of risks alone is not sufficient, but also an estimation of risk likelihood and risk severity is necessary.

The choice of the accident model also affects how the estimates of the likelihood and severity are made, as the accident model itself defines what is considered to be a failure. Hence, a choice between system-thinking based accident analysis or the event-chain accident analysis method will determine the

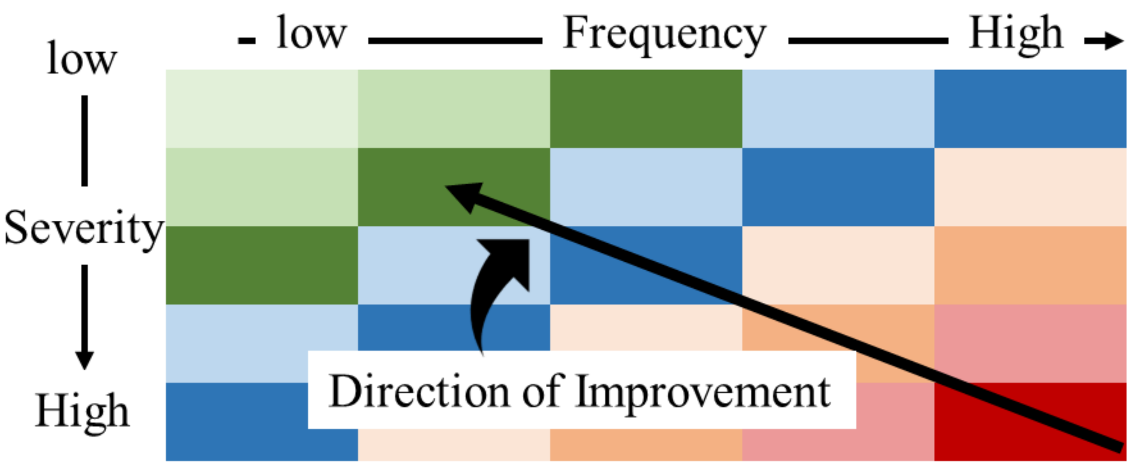


Figure 2-7 Commonly adopted Risk Assessment Matrix

effectiveness of the RM strategy as well. The relative merits and demerits of the two types of models will be discussed later in the thesis, with appropriate reference to the existing practices RM practices prevalent in Japan.

2.3.1 Risk-Management at the regulatory level

While the concept of RM within the organizational context is shown in Figure 2-7, the same should also be explored at the Regulatory (or the institutional) level. Multiple approaches have been adopted by regulators in different sectors such as defense, aeronautics, railway, etc. However, they share commonalities between them due to their common origin from defense systems and gradual adaptation in other systems such as the railway. In this study, an overview of the common approaches prevalent in the railway sector is presented.

IEC 62278, or EN 50126, is the top-level document in European railway standards, that covers the overall process for the total railway systems. IEC 62278 relies on the idea of RAMS (Reliability, Availability, Maintainability, and Safety) methods. The purpose of IEC 62278, as defined in its introduction, is as follows.

"This International Standard provides Railway Authorities and railway support industry with a process that will enable the implementation of a consistent approach to the management of reliability, availability, maintainability, and safety, denoted by the acronym RAMS. Processes for the specification and demonstration of RAMS requirements are the cornerstones of this standard. This standard aims to promote a common understanding and approach to the management of RAMS."

IEC 62278 is a performance-based standard and does not define numerical targets, requirements, or specific railway solutions. It only specifies RAMS requirements as a way to demonstrate the RAMS process. The definitions of RAMS elements in the standard are:

- **Reliability**: the probability that an item can perform a required function under given conditions for a given time interval (t1, t2) ;

- Availability: availability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided;

- Maintainability: the probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources;

- Safety: freedom from unacceptable risk of harm.

IEC 62278 adopts a risk concept that is the combination of two elements, i.e., probability of the occurrence and the consequence of the hazard. Further, IEC 62278 does not assign numerical values to both the elements and take a qualitative approach to their definition. Frequency of occurrence is categorized into 6 categories, namely *Frequent, Probable, Occasional, Remote, Improbable,* and *Incredible.* A detailed definition of various categorizations can be found in (Ota, 2008; Doi, 2016).

Further, the hazard severity is categorized into 4 categories namely *Catastrophic* in which, Fatalities and/or multiple severe injuries and/or major damage to the environment can be expected; *Critical* in which Single fatality and/or severe injury and/or loss of a major system significant damage to the environment can be expected while the service is likely to witness a Loss of major system; *Marginal* in which, Minor injury and/or significant threat to the environment is expected, and a sever system damage to services is expected; and *Insignificant* in which minor injuries are possible while the services sustain minor system damages.

A combination of frequency and hazard severity is then assigned 1 of the 4 risk categories, namely *Intolerable, Undesirable, Tolerable, and Negligible.* Intolerable risks should be eliminated, and the Undesirable risk is accepted only with agreement with the regulatory authority.

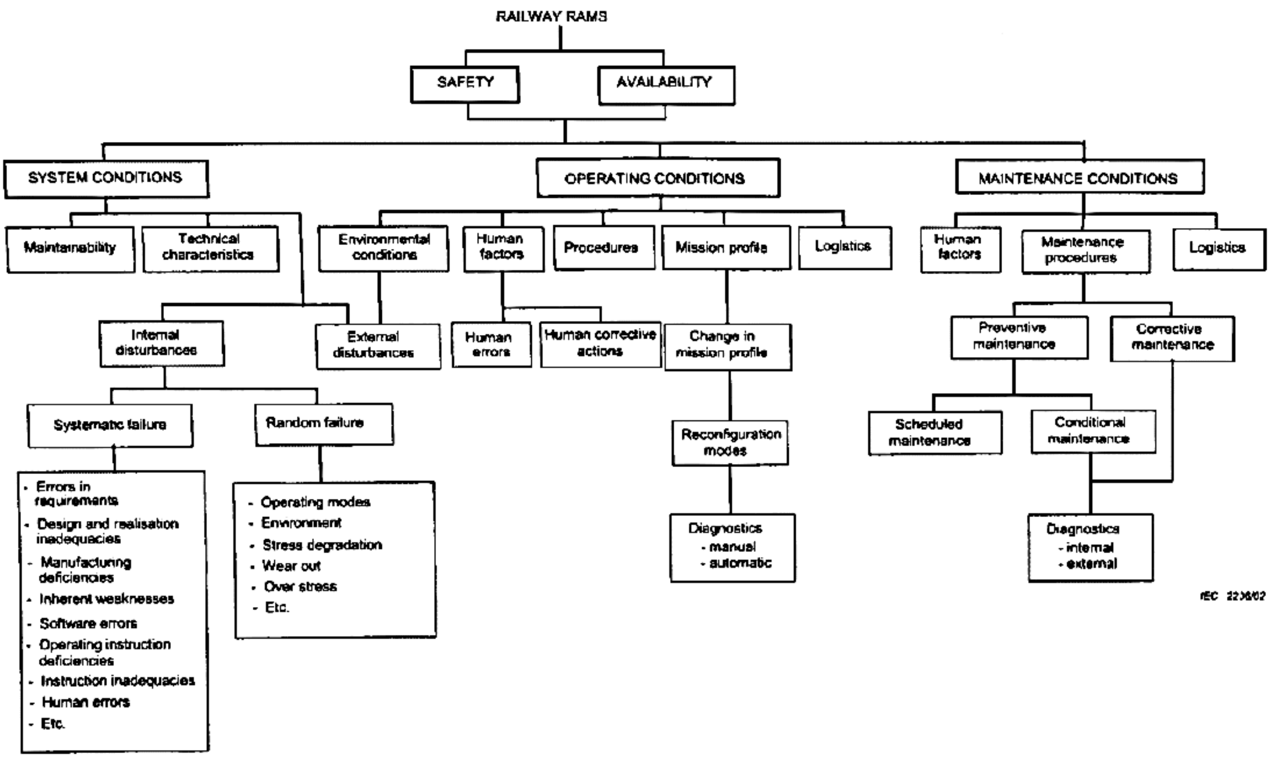


Figure 2-8 Factors affecting Railway RAMS

Source: Doi, (2016)

Also, RAMS defines factors affecting RAMS. Factors are categorized for each of the system stages, such as system condition, operation, and maintenance conditions. Under each category, there are multiple contributing factors, as shown in Figure 2-8. Several factors, such as systemic failures or human factors, are sometimes difficult to apply in a purely reliability-based approach, and so a system-based approach is required to understand the interactions among several factors (Doi, 2016). RAMS then defines several stages of the whole lifecycle of the system and provides the requirement for risk analysis and system improvement, as shown in Figure 2-9.

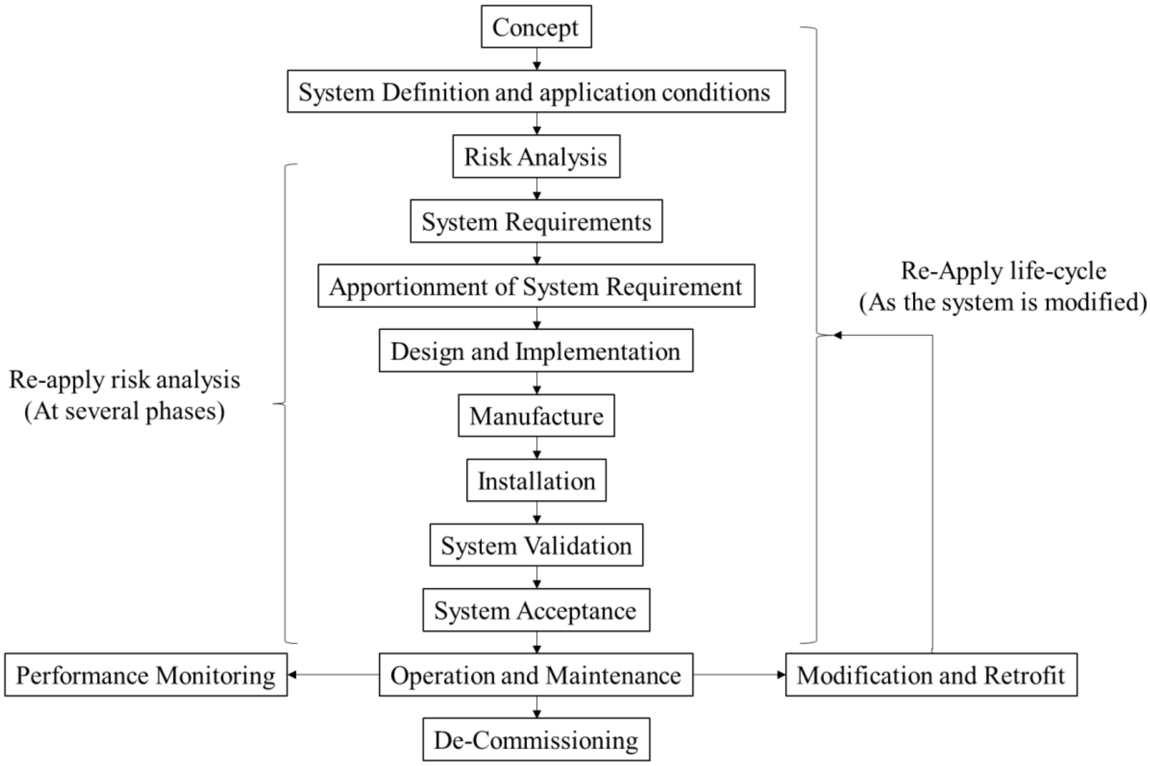


Figure 2-9 Lifecycle Safety Management

Adapted from IEC 62278

It is important to note that the IEC 62278 does not specify any method or tool in particular for hazard and risk analysis. Although, it provides some "informative" methods and tools for which compliance does not have to be assured. Details of several of these informative are discussed in (Ota 2008).

While the approach specified above is taken from European standards, they are often considered industry gold-standards. Many HSR operating companies have adopted European standards, such as Korea, Taiwan, and up to a certain extent China (Rao and Tsai, 2007). While few exceptions also exist, such as Japan, where such formal processes are not adopted (Ota, 2008). Similar approaches also exist for other transport modes, e.g., the process adopted for aircraft certification in the USA is also very similar (Stringfellow, 2010; Federal Aviation Administration, 2017).

However, Ota (2008), in his analysis for the RM requirements for the maglev system, identified 5 requirements of the hazard analysis and discussed the limitations of the current RM standards in fulfilling those requirements. Table 2-5 summarizes the findings from (Ota 2008). Although the requirements have been derived for maglev systems, they are assumed to be applicable also for a similarly complex Shinkansen system.

For complex systems such as HSR, reliability, and safety should not be confused with (Ota, 2008; Leveson *et al.*, 2009). While for some complex systems, reliability may mean improved safety, but there exist complex systems that are reliable but not safe and vice versa. For complex systems, accidents happen due to dysfunctional interactions and human factors, and assigning a failure probability to these interactions is deemed an impossible task(Ota, 2008). Hence, the emphasis is given on qualitative hazard analysis. While Table 2-5 highlights that many of the prevalent hazard analysis approaches are quantitative in nature.

Table 2-5 Features of various Hazard Analysis Approaches (Developed by the author based on (Ota, 2008))

Risk assessment requirements for Maglev Systems	*International Standard*	*Hazard Analysis Approach*		
	IEC 62278	*FTA*	*FMEA*	*STAMP*
1. Hazard analysis must emphasize Qualitative analyses over Quantitative (Ericson, 2015)	✓	×	×	✓
2. Deductive analysis (*How can*) over Inductive analysis (*what if*)	-	✓	×	✓
3. Ability to identify future hazards resulting from asynchronous evolution	✓*	×	×	✓
4. Ability to consider human errors	✓*	✓	×	✓
5. Focus on the severity of accidents, rather than probability	×	×	×	✓

✓- Strictly true, × - Strictly not-true, ✓* - Partially true, - - NA

Ota (2008) then provides a distinction in inductive and deductive analysis approaches. In the inductive analysis, an analyst first supposes failure in a sub-element and then determines its effect, However, in deductive analysis, an undesirable event is identified first, and then a range of potential events leading to the loss events are identified. Deductive approaches, although they are cumbersome and time-consuming, but are deemed necessary for the analysis of complex systems.

For complex systems, many accidents are expected to happen due to asynchronous evolution, where one part of the system changes without due consideration to the other parts of the system. While, IEC 62278 emphasize on re-applying the hazard analysis method when the system changes (Figure 2-9), it does not specify any method that can inherently manage the asynchronous evolution. Ota (2008) then demonstrated that none of the current hazard analysis approaches have the ability to consider asynchronous evolution.

Further, human factors are deeply involved in accidents for complex systems such as HSR, and they should be adequately considered in the analysis. Finally, Ota (2008) highlights the importance of low probable but highly severe accidents in complex systems. Often, analysts confuse the low probability with low severity events, because of the inherent difficulties in estimating the probability and the severity of the events for complex systems.

The review of the RM practices at the regulatory level presented here highlights the difficulties of RM at the regulatory level. While the current RM approaches are very well established and are very comprehensive in nature, generally speaking, they are still not suitable for their usage in complex systems.

2.4. Leading Indicators for proactive safety management

"Learning from the past" is an important strategy for organizations managing safety for man-made complex socio-technical systems. In this regard, the conventional approach of closely monitoring "near misses," an event which must be followed by some other failure to result in major failure, offers valuable learning opportunities and paves the path for future development (Leveson, 2011). However, as much as it may be justified as being a "proactive" safety management approach, in reality, it will always be a "reactive" approach (Dokas, Feehan and Imran, 2013). Thus, the need of the hour is to introduce approaches that will support proactive risk management strategies in organizations.

In this context, it is generally argued that early detection of potential failure causes of a system is an essential task in a proactive risk management strategy (Dokas, Feehan and Imran, 2013). Early Warning Signs (EWS), indicating the presence of accident causal factors, do exist and precede accidents(Leveson, 2011), and hence, systematic collection of these warning signs is essential for proactive risk management (Dokas, Feehan and Imran, 2013; Leveson, 2015). In this section, various leading indicator approaches suitable for complex systems are discussed.

2.4.1 Assumption Based Leading Indicator (ABLI) Identification (Leveson, 2015)

Dokas et al. (2013) define the term EWS for a feedback-control process as- "The value of an observation made by the sensor, which according to the process models and accident scenarios possessed by the controller indicates the presence of causal factors to a potential loss or the violation of safety-related designing assumptions." This idea of the EWS system for a complex system is also equivalent to the concept of Assumption-Based Leading Indicators (ABLI) proposed by Leveson(2015), who states that useful leading indicators (or EWS) can be identified using the assumptions underlying safety engineering practices. In this study, the term EWS or ABLI is used interchangeably.

Leveson(2015) has then described several assumptions that may arise in a system. A generic overview of the type of assumption, their details are shown in Table 2-6. Leveson (2015) describes how the STAMP can be used to perform a systemic hazard analysis to generate a comprehensive set of assumptions.

Table 2-6 Overview of assumptions in a system based on (Leveson, 2015)

Type of assumptions	**The general classification of assumptions**	**Examples and Comments**
Technical	Overall System Goals	Traffic alert and Collision Avoidance System (TCAS) can provide protection for any two aircraft closing horizontally at a rate up to 1200 knot
	The environment in which the system will operate	All aircraft will have a legal identification number
	Environmental requirements and constraints put on the system	The TCAS advisories must be independent of master caution and warning system
	Hazard Analysis	Check for the occurrence of hazards
	The assumption about the operation of control structures	If the control structure is not being operated as designed, it could serve as a leading indicator
	Limitations in the design of safety-related controls	1.Limitations related to functional requirements of the system 2.Limitations about the environmental assumption
Organizational and Managerial	Expected control responsibility of the controllers	If some or more control responsibilities are not being fulfilled, these can serve as leading indicators of the presence of financial or political pressures
	The assumption about safety culture	The assumption about safety culture weakening is a leading indicator
	Assumptions underlying coordination risk	When similar responsibilities related to the same component are assigned to multiple controllers, assumptions about how action must be taken should be clearly documented and could serve as leading indicators

The key idea behind the ABLI by Leveson (2015) is the development of system-specific leading indicators for ensuring the safety of the process. In her review, she found that many of the systems adopt an industry-wide generic set of indicators; however, more often, such indicators do not represent the true hazards for the system specific to the study. This leads to a situation where management is overwhelmed by the continuous monitoring of a large set of generic indicators that are not contributing to the safety of the system at all. Further, most industries tend to confuse the process of safety with that of workplace safety. Leveson's (2015) idea is developed, keeping the process safety in mind, whereas workplace safety can be considered as a subset of the process safety.

However, identification of EWS alone is not sufficient, and efforts must be made to integrate these warning signs in the safety management practice of the organization as much as possible. Thus the second set of studies has focused on the operationalization of EWS in an organization. Operationalization refers to defining potential reactions of various components in a system, once the possible warning signs are detected. Accidents can still occur when the organization-wide responses to these warning signs are not adequate (Leveson, 2015).

2.4.2 EWaSAP

Dokas et al.(2013) have created EWaSAP, a process to design leading indicator programs. The important steps in EWaSAP correspond to (i) defining the data indicating the violation of safety constraints and design assumptions and (ii) specifying the characteristic of the sensors in order to perceive these data. For identifying the data corresponding to step (i), EWaSAP relies on STAMP based systemic hazard analysis process. In addition to the conventional generalized feedback-control structure, the study defines an additional type of control action, known as awareness action. An awareness action allows the controller to provide a signal to other controllers, within or outside the system boundary, when the data indicating the violation of safety constraints are perceived by the controller. EWaSAP had conceptualized a total of 4 types of signals. “All Clear” signal states the presence of the system being in a safe state. “Warning” refers to a signal that makes other controllers aware of the perception of flaws in the process that a controller control. “Alerts” represent a state that a hazard has occurred. Finally, “Algedonic Signals” refer to special warning or alerts about a perceived serious condition directly to the controllers at the highest level of the control structure. The generic control structure is shown in Figure 2-10. Additionally, guide words for accident taxonomy are then proposed, such as accidents can happen when warning signals are not transmitted, are wrong, or are not perceived.

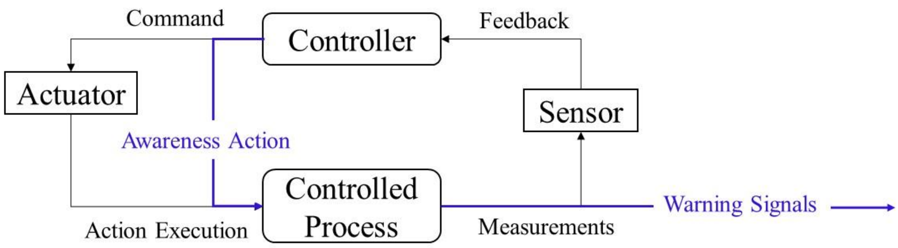


Figure 2-10 Generalized feedback-control structure for EWaSAP

Adapted from Dokas et al.(2013)

2.5. Reporting Culture

Reporting culture is described as an organizational trait where workers will be willing to report near misses and accidents openly and honestly (Reason, 1997). Naturally, a good reporting culture is essential for the effective functioning of leading indicator programs in an organization. Reporting culture is considered an integral part of organizational safety culture (Reason, 1997). Hence, it also shares certain characteristics of safety culture. There is no universally agreed-upon definition of safety culture. However, key characteristics of the safety culture are that it is a system of shared values and beliefs within an organization (Antonsen, 2017). Naturally, reporting culture, like safety culture, also interacts with an organization’s people, structure, and control systems to produce behavioral norms (Uttal, 1983).

One example of interactions between reporting behavior and organization’s people, system, etc. leading to a fatal accident in the Railway sector is from Japan. In 2005, in the Amagasaki railway accident, the train derailed because of over-speeding on a curve. It is well established that the driver of the train was distracted from performing his duties. The reason for such distraction was that the driver was contemplating his response to an anomalous report of a delay by the conductor of the train. Such an anomalous report was deliberately made by the conductor upon the request from the driver. Academic studies highlight that the conductor had changed his reporting behavior because he had shared an understanding of the consequence of a punishment culture that prevails in the railway operator (Chikudate, 2009).

Reporting culture has also been linked with reporting of both major as well as minor accidents. In many cases, major accidents are reported well, but the same is not the case with minor accidents, near misses or incidents (Clarke, 1998). However, focus on such minor accidents, near misses, etc. becomes of particular importance for organizations where accidents are generally rare, such as the HSR system in Japan, where no fatal accident has occurred in more than 50 years of its operation (Hancock, 2015).

Hopkins (2019) suggests the idea of *centralized control* for managing catastrophic accidents. Centralized control refers to a situation where important decisions regarding the management of the catastrophic hazards are made as close to the top of management as possible, and these decisions are kept free from the influence of other competing demands of business such as profitability. The idea of centralized control affecting culture is also evident from a recent reorganization of railway operators in Japan (MLIT 2007). To improve the safety culture of railway operators in Japan, the railway regulator of Japan mandated a change in the organizational structure of the operator. The regulator mandated the appointment of a Chief Safety Officer who is responsible for implementing safety management systems in their respective organizations and is involved in all critical business decisions. This appointment was deemed meaningful even in the Japanese railway, where the conventional practice of safety management could also be argued to be highly centralized (Saito, 2002).

However, reporting culture can still be a problem even in organizations exercising a high degree of centralized control. In a recent incident in Japan, the driver of a High-Speed Rail failed to report an abnormal noise or bump, which came from the front of a train operating at high speeds. The driver thought that an animal must have hit and did not consider it worthy of reporting. HSR tracks in Japan are grade-separated, and such obstructions on the track are instead a rare event. Nevertheless, the driver failed to communicate despite the recent addition of a rule mandating the reporting of abnormal situations. When the train arrived at the next station, the station staff noticed that the nose of the train was heavily damaged, even then, the station staff reported this incident to control center only after the train left that station (The Asahi Shimbun, 2018). The event demonstrates that even in centrally controlled organizations, with adequate means of reporting available, the reporting practices could still be ineffective. The event also suggests that a consideration of interplay among various causal factors may be necessary to explain the reporting culture of an organization fully. Thus, the development of a generalized theoretical model that can qualitatively explain the reporting culture of an organization and help identify the focus areas of improvements becomes essential, and an attempt will be made in this study for the same.

2.6. Dynamics of safety

One of the common themes of discussion for System-Control based accident models is their perception of safety as a dynamic property arising out of systemic interactions among components. In particular, the dynamic behavior is known to arise from two mechanisms. First, among these mechanisms, is the change in safety arising due to change in the safety control structure (the *structural dynamics*). The second mechanism is related to context-based adaptations of individual controllers in the safety control structure, especially the human and the organizational components (the *behavioral dynamics)* (Leveson, 2004). These mechanisms and corresponding approaches to study the mechanism are explained using examples in the subsequent subsections.

2.6.1.1 Structural Dynamics

Through an analysis of the E.Coli outbreak in for a small town named Walkerton in Canada, Leveson *et al.*(2003) have demonstrated the effects of structural dynamics leading to a system reaching an unsafe state. At a time near to the accident, the water supply in the town was established with the help of three wells, namely Well 5, 6, and 7. The actual E.Coli outbreak had happened because of the water supply from Well 5, which was contaminated by the bacteria being produced by manure at the farm nearby. At the initial investigation, a serious lapse by the operator of the wells in ensuring chlorine treatment of the water was found to be the accident cause. However, a detailed and systematic accident analysis using STAMP revealed the underlying structural causes of the accidents.

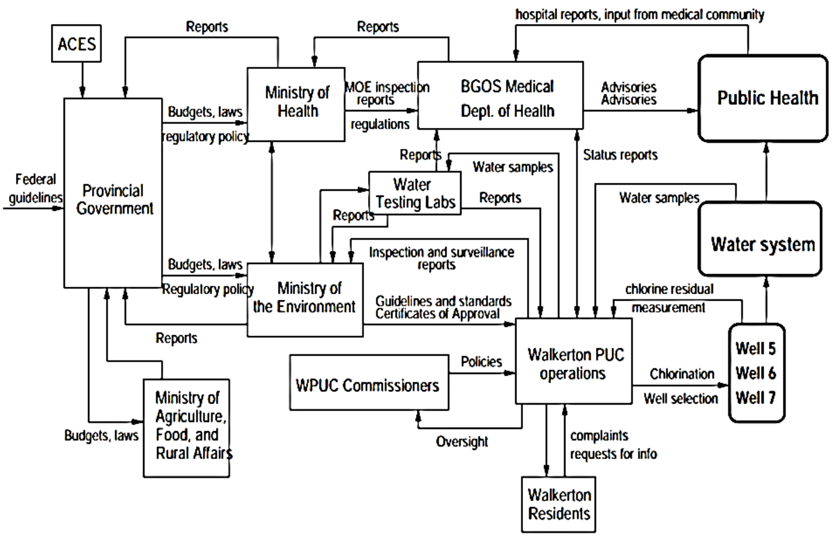


Figure 2-11 Theoretical Safety Control Structure for ensuring water quality in Walkerton

Source: Leveson et al.(2003)

Figure 2-11 shows the theoretical safety control structure for ensuring water quality in Walkerton town. The utility (PUC) was responsible for ensuring the chlorination of the water before releasing it to supply pumps. The PUC, in-turn, had to submit inspection reports to the Ministry of Environment (MOE). Based on the report, MOE would exercise approvals and issue guidelines to the PUC. Theoretically, MOE also receives reports of water quality from independent Water Testing labs.

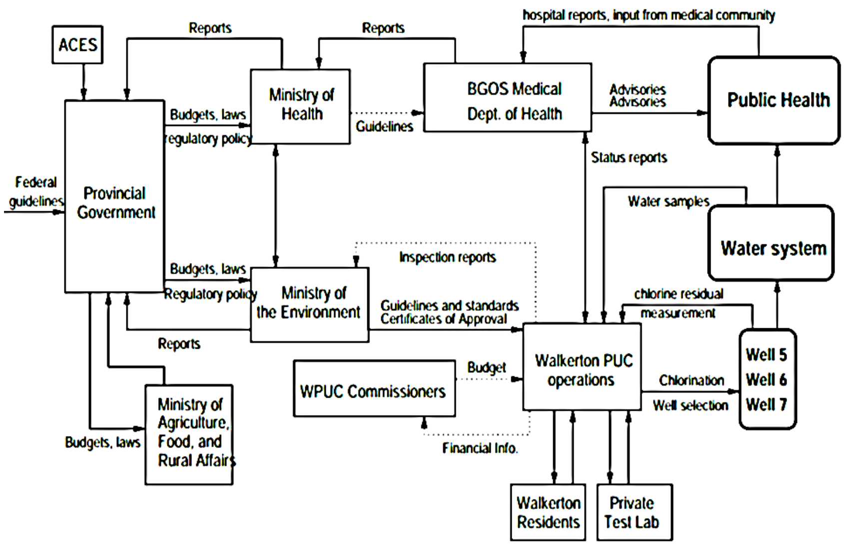


Figure 2-12 Real safety control structure in Walkerton

Source: Leveson et al.(2003)

The Water Testing Lab was also required to share the test results with local public health officials, who, in turn, would issue advisories for water use, such as boiling before drinking, etc.

In contrast, Figure 2-12 shows the real safety control structure at the time of the E.Coli outbreak. A detailed description of the event leading to the structure at the time of the outbreak is presented in (N. Leveson *et al.*, 2003). However, the key difference from the theoretical structure is the virtual elimination of the Water Testing labs. Over the years, the Labs were privatized and were deployed by the PUC. However, the test results were accessible only to the PUC, and these test results were tampered with before being shared with the MOE or the public health officials. It was almost impossible for the MOE to execute its licensing requirements fairly, and continued permits nurtured a sense in PUCs that the lapses in ensuring the proper chlorination were to an extent acceptable. In this way, the static structural diagram of STAMP, when plotted over time, can reveal the new gaps in safety enforcement and prove to be useful in safety management.

2.6.1.2 Behavioral Dynamics

Systems and Organizations continuously adapt in response to pressures and short-term performance goals. Also, people adapt to their environment, and several decision-makers in different parts of the organization make their local optimized efforts but compromising safety for the systems. In that, system dynamics (SD) is an approach that identifies, explains, and eliminates the problems problematic behaviors in socio-economic systems. As per SD, the behavior of the system arises from its structure described through causal feedback loops, levels (stocks), rates (flows), and delays. All dynamic behavior can be generated through a combination of the two types of loops, i.e., *reinforcing loops* and *balancing loops*. In reinforcing loops, change in one variable of the system ultimately causes more change in the variable in the same direction, while balancing loops counteract changes, thus can be used to stabilize the system. In system dynamics, research, many patterns of behavior are generated by a small set of simplified "generic" structures, known as archetypes. The study of these archetypes has been proven to be useful for analysts to recognize the commonly occurring organizational and human safety behaviors and thus guides them for providing solutions (Marais, Saleh, and Leveson, 2006; Kontogiannis, 2012). A few commonly reported Archetypes are shown in Table 2-5.

Table 2-7 Organizational Safety Archetypes based on (Marais, Saleh, and Leveson, 2006; Stringfellow, 2010; Kontogiannis, 2012)

Name	***Behavior***
Stagnant safety practice in the face of technological advancements	One action in one part of the organization, intended to achieve safety is successful initially (e.g., technology advance). However, soon, a constraint on system performance is reached, thus limiting the outcome. E.g., as the technology change accelerates, understanding of its safety implications lags. The problem can be solved by investing more in improving understanding of the complex systems.
Decreasing Safety Consciousness	A safety promoting strategy or policy that initially promotes safety may eventually lead to a decline in safety. For example, in ultra-high safe systems, over-optimization of safety measures may numb the adaptive capabilities of the humans, thus leading to a different type of accident. Thus, a minimum number of incidents may be necessary. Redundancy is often useful in increasing reliability, and possibly safety. In practice, redundancy may 'cover-up,' or mute, design errors, and prevent them from becoming visible until something catastrophic occurs. Second, increasing redundancy increases system complexity. More complex systems are difficult for testing and maintenance, and their properties and behavior are difficult to predict accurately.
Unintended side-effects of safety fixes	The unintended consequences of a response to safety problems (both systemic and symptomatic responses) can worsen the problem. Consider a plant facing increasing equipment breakdowns attributed to poor maintenance. A typical 'fix' such problems are to write detailed maintenance procedures and to closely monitor compliance with these procedures. The detailed procedure could be helpful in reducing errors for a specific task. Excessive restrictions on behavior discourage problem-solving and encourage blind adherence to procedures, even when compliance may not be optimal for safety. Blaming or disciplining individual workers encourages all workers to hide problems.

Shifting the burden- "fixing symptoms and not root-cause."	Symptomatic solutions decrease the possibility of recurrence of the same accident, but in that root-causes of the accidents are not treated. Symptomatic solutions show visible positive results immediately. A side effect of this approach is that the pressure to find root-cause solutions is decreased. Organizations should instead perform root cause analysis and address the underlying systemic causal factors.
Eroding Safety - Complacency	Regulated organizations managing complex systems can often become complacent when they achieve low accident rates. Low accident rates also put pressure against the regulation sentiment. Such sentiment combined with budget pressures leads to a decrease in system oversight. However, decreasing oversight leads to decreased commitment to safety and thus leads to a reduction in training, certification, inspection, and monitoring, which in turn increases the risk of accidents and hence, the accident rate. Complacency trap can be avoided by continuously monitoring risk and set the level of oversight accordingly. Complacency arises because the accident rates usually do not immediately increase following a decrease in oversight, thus leading to a false perception that the oversight is adequate. Further, when accidents start occurring, the link to decreased oversight is not immediately obvious, as it can be hidden under the latent factors. Hence, for setting up an adequate level of oversight corresponding to a level of risk, the long-term trend in the risk level must be considered rather than short-term fluctuations.
Eroding Safety Disappointing Safety Programs	Safety improvement programs can be expensive, and they often do not show immediate results. Despite the high benefits in the long-term, the immediate cost of a safety program is subject to various performance and financial pressures. The pressure combined with seeming ineffectiveness of the solutions, thus, makes it tempting to adjust the goals of the safety program. In this regard, safety goals could be anchored either to external enforceable standards or to industry-wide benchmarking, etc., so that goals do not erode as swiftly.
Eroding Safety Incentives	In implementing safety programs, incentives, or rewards used to ensure compliance should be carefully examined. If symptomatic behavior is rewarded (e.g., fewest reported incidents), it is likely that workers will find other ways to generate the same symptoms (e.g., underreporting incidents). If incentives are inappropriately formulated, compliance with the intent of the program may be lower than if no incentives were offered. If the purported rewards are often not visible and employees view the requirements as impeding their normal working processes. The intent of safety programs must be communicated at all levels of the organization.
Getting away with risky decisions seems safe	The risky decisions made individually have a small probability of causing a disaster. Further, the lack of immediate negative consequences does not provide the decision-maker with accurate feedback about the severity of risks caused by their actions. Also, by behaving in a risky fashion, the number of immediately obvious successful outcomes can be increased, which is also rewarded by the management. The rewards, coupled with the lack of negative consequences, ensures that the decision-maker will likely continue to make risky decisions. Such a system is characterized by 1) long delays before negative consequences reach decision-makers combined with immediate rewards for risky decisions; 2) numerous decision-makers, and 3) an asymmetric distribution of benefits and negative consequences among related stakeholders in a system. Often, the benefits of risk-taking are experienced by a decision-maker in the short term, while the consequences to other stakeholders are experienced for years. When decision-makers receive needed feedback about the effect on the rate of adverse events by their risky decisions to increase production, they are less inclined to overlook unacceptable rates of adverse events. Hence, such feedback will prove useful to improve safety.

The archetypes described above can prove meaningful in finding hidden causative and contributing factors at the organizational level, even when the information is readily available for technical failure and human errors etc. Fan *et al.*(2015) have utilized the archetype "shifting the burden" (Figure 2-13 and Table 2-5), to analyze the Yong-Tai-Wen HSR accident in China. On July 23rd, 2011, a high-speed train from Beijing to Fuzhou rear-collided with Yong-Tai-Wen High-Speed train. The trigger of the accidents was problems in the signaling control system that arose because of the lightning strike and damaging of the instruments. The official accident report has focused on a number of technical failures and human-errors contributing to the accident; however, Fan *et al.(*2015) were able to uncover a number of systemic factors by accounting for the context in which HSR were developed in China. His analysis had focused on three questions, i.e., problems in the defective design of equipment in the control system, Approval of defective equipment for use, and faulty response to signal failure.

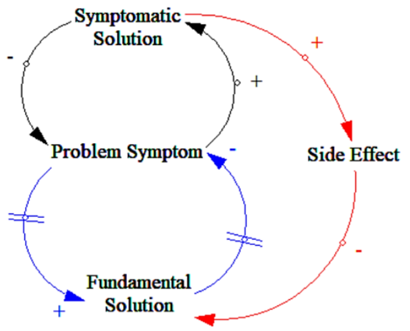


Figure 2-13 Shift the burden archetype as discussed in Fan et al., *(2015)*

Fan *et al.(*2015) describe that from a period of 1997 to 2007, China had witnessed a great improvement in its train speeds. In this background, the technology developer for the signaling system was eager to earn more opportunities, and hence completing a design in record time may have been the most important performance indicator. Such pressure led to a reactive approach by the system developers, and they adopted a fly-fix-fly approach that focused on the symptomatic fixes. Such symptomatic fixes brought relief to the pressure for applying the system safety concept. Further, the

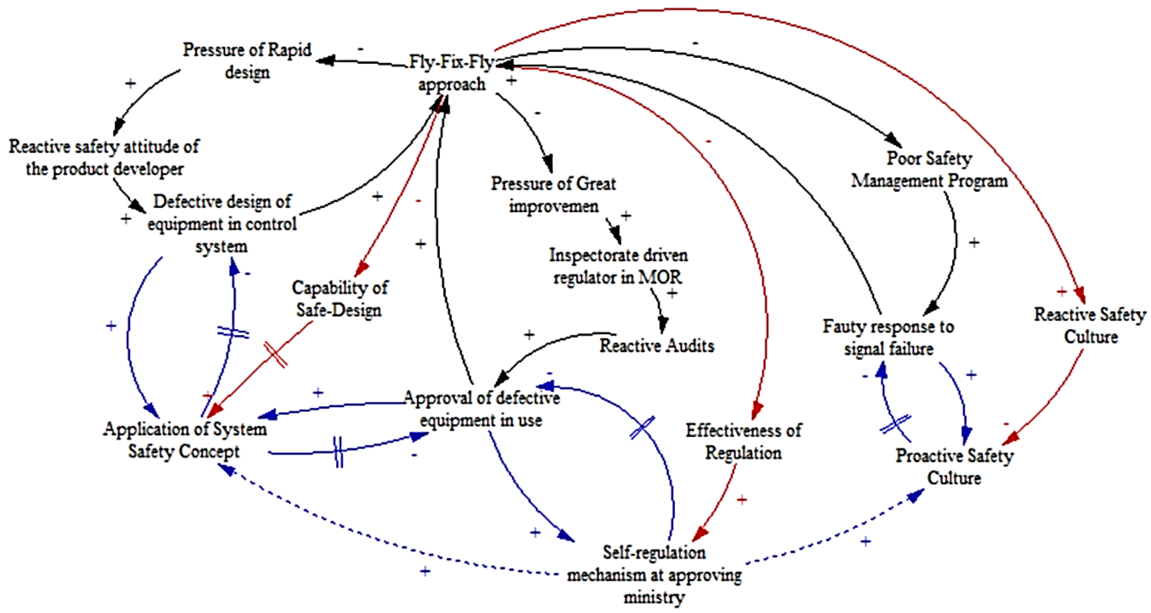


Figure 2-14 Overview of the causal factors for Chinese HSR accidents

Created by author using information from Fan et al., (2015) fly-fi-fly approach adopted reduced the capability of the engineers to undertake systemic actions. For the analysis related to approval of the defective equipment for use, Fan *et al.* (2015) once again attributed the effect to adoption of a fly-fix-fly approach and an inspectorate driven regulation in the ministry responsible for approval. The inspectorate driven regulation lead to the adoption of a reactive auditing system, which led to the approval of faulty systems that could address the symptomatic pressures. Fan *et al.* (2015) have then supported the idea of "self-regulation mechanism," under which the product development companies will accept primary responsibilities reducing accidents, and the regulatory agencies will provide continuous supervision and rigorous enforcement. However, under the increased use of the fly-fix-fly approach, the effectiveness of regulation (a side-effect) will decrease. Similarly, the use of the fly-fix-fly approach led to the adoption of poor safety management programs in the TOC and had promoted a reactive safety culture, which further reduced their ability to take system-principles based safety management activities for Chinese HSR. In this-research, the fly-fix-fly approach adopted by many stakeholders in the Chinese HSR development stage, has been identified as the root-causes of a number of accidents causing factor. In particular, the "self-regulation mechanism" has been considered as an important solution as its introduction is not only expected to reduce the approvals of the defective equipment but also is expected to reduce defective designs and faulty responses when the equipment fails (Figure 2-14).

2.7. Suitability of current safety theory for the scope of this thesis

Based on the review of safety theory presented in this chapter so far, this section focuses on analyzing the suitability of the current theory in achieving the objectives of this study within the scope of this research. Such analysis will elucidate the gaps between the current safety theory and the desired studies for this thesis. Efforts made in this study will then directly contribute to the academic gaps highlighted in this study.

2.7.1 Gaps in accident models

The system-control based accident models discussed in section 2.2.2 (such as STAMP, SHOW, STAMP-VSM, ACAT) are generally applicable for HSR, which is also a complex system.

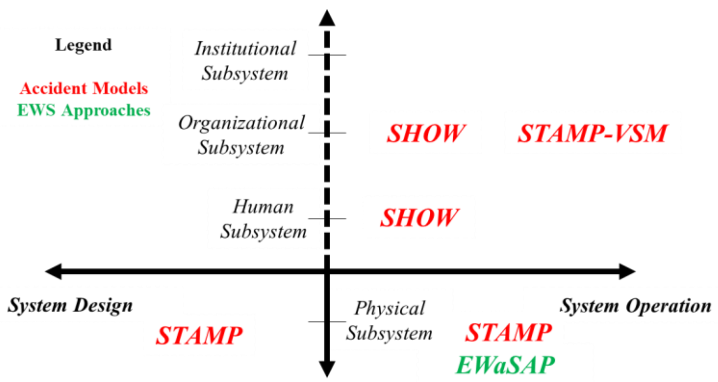


Figure 2-15 Applicability of accident models and EWS approaches

Prepared by author, based on the literature review

However, the accident models developed so far have not had an acute focus on institutional factors. Figure 2-15 shows the applicability of various accident models and EWS approaches, and it can be clearly seen that the current accident analysis approaches have not been generally extended to the institutional subsystem. Since the scope of the current thesis involves studying interactions between the regulator and the TOC, the general applicability of the existing accident models in analyzing such relationships should be checked. If needed, a new accident model, particularly catering to such interaction, needs to be developed.

While STAMP has been sometime criticized for its acute focus on the physical subsystem, the general limitations posed by STAMP for its application at the organizational level are expected to be overcome by the application of SHOW or the STAMP-VSM accident models. Further, STAMP has been applied in many fields, including for analyzing organizational and institutional factors for HSR in the USA (Kawakami, 2014a) and in China (Dong, 2012). Such applications for STAMP at the institutional level suggest that it may be appropriate to use STAMP based accident analysis or hazard analysis tools at the institutional levels as well.

2.7.2 Applicability of the EWS study

One of the objectives of this thesis is regarding proactive safety management in Japanese HSR at the organizational and institutional levels. However, Figure 2-12, make it clear that the current approaches to for proactive safety management, such as leading indicator management programs, focus only at the physical subsystem level. Clearly, there is a necessity to develop EWS approaches for organizational and institutional subsystems. Such a research gap has also been highlighted by (Leveson, 2015) and an attempt to develop such an approach will be made in the current thesis.

2.7.3 Applicability of the Reporting Culture

The literature review presented in this chapter suggest that dynamic interactions among various causal factors may be necessary to explain the employee’s reporting behavior in an organization. The behavior of various system components is also a topic of concern for the system-safety approaches. In that, various studies were reviewed in the present study that had utilized SD to model the behavior and organizational level dynamics. The review thus suggests that the usage of SD can be explored to develop a generalized theoretical model that can qualitatively explain the reporting culture of an organization and help identify the focus areas of improvements becomes essential, and an attempt will be made in this study for the same.

2.8. Summary

This chapter provided an overview of the state-of-the-art safety theory for complex systems, including an overview of various accident models, methods of hazard analysis, reporting culture and structural and behavioral dynamics affecting safety, etc. The review helped in clarifying the suitability of the existing methods for achieving the objectives of this study as well as identify areas that will need further improvements. While fulfilling the objectives of this study, the thesis will also contribute to advancing the academic discussions in safety theory for complex system on the following topics

1. A generalized leading indicator approach for organizational and institutional sub-systems.
2. A reporting culture model that considers the interaction between various factors affecting the reporting behavior of the employees in an organization.

In addition to the contribution to the safety theory for complex systems, the thesis will also contribute to highlight the safety-critical aspects of the organizational and institutional level for an ultra-safe complex system of international importance, i.e., Japanese HSR.

In the next chapter, a review of the current RM and Reporting Culture related practices used by the Japanese HSR TOCs is presented. Such a review will be helpful in identifying the gaps in the existing practices in HSR TOCs and the corresponding state of the art safety theory.

Chapter 3. Shinkansen Safety Management: Current Practices

This chapter will provide an overview of the current practices of safety management prevalent in Japanese HSR TOCs. Although at present, 5 different TOCs exist in Japan that operate HSR services in different parts of the country[5] (Figure 3-1) and their practices could differ from each company. However, there exist a lot of commonality among the practices of the different companies, mainly because of the common origin of technology, and a common parent organization before privatization. To clearly differentiate the commonalities and difference in the practices, the chapter first discusses the origins of the HSR system and operation in Japan and highlight the practices that exist across all the operators. Then practices at 4 of the 5 TOCs are taken to discuss the practices related to safety management at an organizational level. The information about these practices was obtained using the official documents published by the company, published literature, and in some cases, a site visit and various unstructured interviews with the company officials.

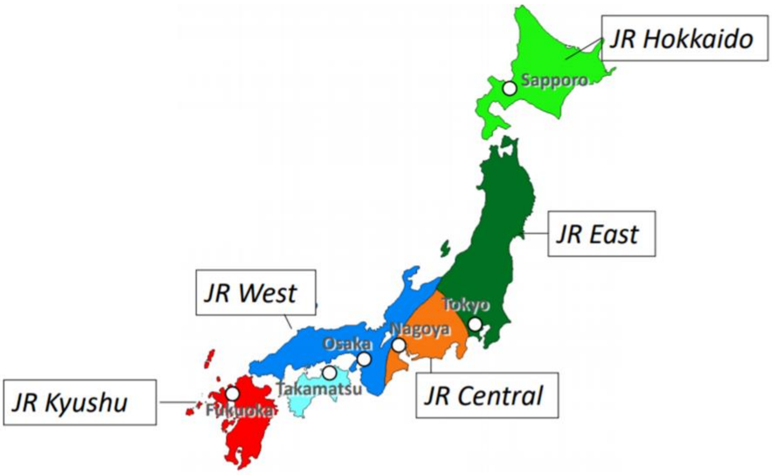


Figure 3-1 HSR operating TOCs in Japan

Adapted from [1]

3.1. Safety promotion activities common to all TOCs

3.1.1 Principle of technological development

The philosophy behind the Shinkansen system development was to remove as many risks as possible. Measures such as the development of an exclusive grade-separated system, minimization of human errors, maximum use of computers, use of tested technology, and implement fail-safe mechanisms in critical parts are some of the technology-related manifestations of this early safety philosophy (Hancock, 2015). These manifestations are clearly known to have a significant impact on the safety performance of HSR (Hancock, 2015). Shinkansen has had zero incidents related to a collision with other trains or to over-speeding, compared to such fatal accidents in Spanish and Chinese HSRs (Kawakami, 2014a). Japanese TOCs are known for the continuous evolution of their technical subsystems catering to their needs. These new technologies go through an extensive regime of test-trials using life-sized prototypes. Only the technologies that are proven in the field are then implemented for passenger service. For example, JR East has unveiled its plan for a new high-speed train called ALFA-X, capable of operating at a commercial speed of 360 km/hr, 40 km/hr more than its current predecessor. The ALFA-X trains will face an extensive 10-year trial period[6].

[5] https://www.ihra-hsr.org/data/_pdf/15.pdf
[6] https://en.wikipedia.org/wiki/ALFA-X

3.1.2 Synchronized evolution of the technical system

As much as the original design of the system is necessary, system evolution is essential in ensuring safety under ever-changing demands put on the system. One of the core principles of system evolution in Shinkansen is the synchronous evolution of various sub-parts.

The integration of core-system while system evolution is one of the principles diligently followed by the Japanese TOCs. The new type of rolling stock designs has always promoted harmony with the existing fixed infrastructure systems such as the tracks and the power supply. The braking systems, the signaling systems have all been upgraded "in-sync" to the technology evolution. Figure 3-2 traces the evolution of various aspects of the shinkansen technical system, and the synchronized evolution is immediately visible, as the introduction of most new technologies coincides (Hancock, 2015).

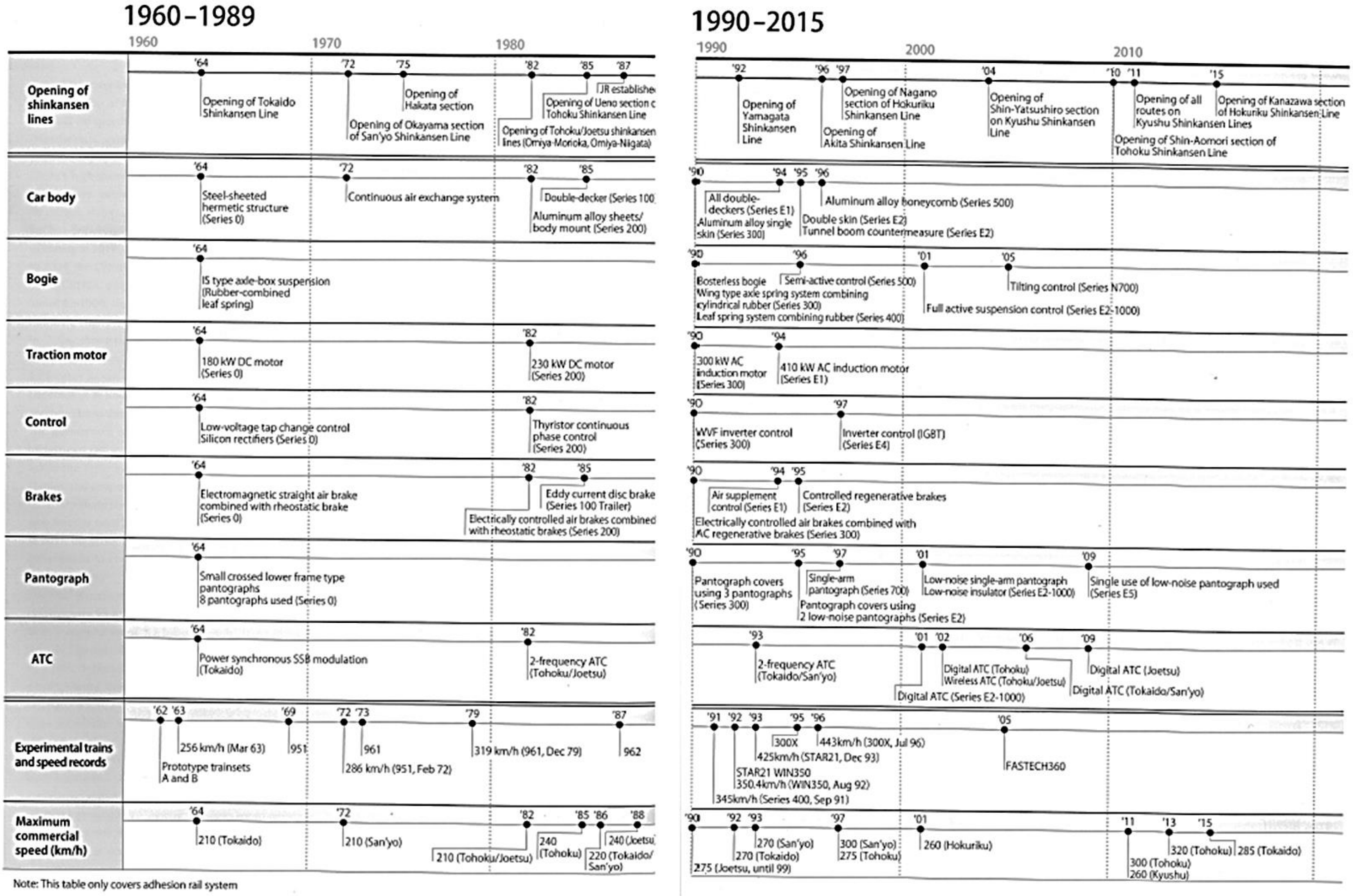


Figure 3-2 Evolution of Shinkansen technology

Source: (Hancock, 2015)

3.1.3 Focus on asset maintenance

The dedicated lines for HSR create an opportunity for high-capacity rail transportation. In Japan, the HSR network is often heavily utilized. For example, in the peak time, both JR East and JR Central operate trains every 4 minutes, a level which is close to 80% of the theoretical capacity of the system. Such high utilization leaves very little scope for further service enhancement. Under such high utilization, the maintenance of the system, i.e., both fixed and moving assets, becomes essential.

Realizing the need for regular maintenance, all HSR TOCs in Japan, have dedicated a fixed time window of 6 hours, starting midnight, for maintenance activities. Train operation commences only after maintenance activities of the day are completed. All major HSR operators have dedicated extensive resources to maintenance activities, as evident from Table 3-1. Although, the data reported in Table 3-1 refers to the respective JR Company as a whole, including the conventional railway lines, however, the generalized importance of maintenance is still evident.

Table 3-1 Operating cost structure of the major HSR TOCs in Japan (data from (Yasutomi, 2016))

Maintenance head	% of the total operating cost in FY 2012		
	JR East	JR Central	JR West
Track/Overhead	21%	22%	18%
Other asset	3%	4%	3%
Rolling Stock	7%	9%	10%

Further, fundamentally new approaches to maintenance have also been devised at HSR TOCs in Japan. Over the years, all TOCs have shifted from conventional time-based maintenance (TBM) to ***Condition-based maintenance (CBM).*** In time-based maintenance, repair works are conducted based on the pre-agreed reference or inspection target schedules. However, under the new regime of CBM, sensors can be mounted on trains in operation, which can then collect a wide range of information from tracks while under operation. Example of data that these train mounted sensors collect includes rail alignment or current collection performance from overhead electric wires etc. Under CBM, the maintenance resources are then optimally allocated to the parts of assets which require them. Moreover, such extensive inspection data proves helpful in detecting the potential problems pro-actively, and hence, different maintenance strategies can be planned accordingly (JR East Group, 2018).

Many of the operators have developed specialized trains, that are capable of running at regular operating speeds of HSR and are mounted with equipment to collect data about the track structure. These trains are then operated during the regular service hours and can collect data on a large number of track condition parameters. In JR Central, such trains are called as Doctor-yellow[7], and JR East such trains are called as East-i. Similarly, for rolling-stocks, a combination of TBM and CBM strategies is adopted. The bogie inspection cycles are pre-determined, whereas the bogie status is continuously monitored. Appropriate maintenance interventions are made when deemed necessary [8].

3.1.4 Training system for Human Resource capacity development

While the technical system of HSR in Japan is determined such that safety is not compromised despite human-errors, nevertheless, the Humans are considered an integral part of the overall safety and reliability of the HSR operation and maintenance (Hood, 2006). Consequently, skill and capability development for their employees is an integral part of all HSR company's management.

While the specific methods for training may differ significantly, a few common elements are as follows. First, app Japanese HSR TOCs have adopted a system of life-long continuous training for their employees. All employees necessarily receive experiences of the key operational aspects within the railway operations. Periodically the employees receive basic training, refresher courses, and skill-up training and develop their skill-set equivalent to professionals. Further, an inter-functional rotation scheme for employees is adopted where employees of employees across move across the organization verticals and enhance their understanding and experiences of all works in the company (Saito, 2002; Hood, 2006).

Second, all Japanese HSR TOCs have adopted similar training methodologies. Japanese HSR companies usually categorize their training in three types, namely, on-the-job (OJT) training, self-improvement training, and group training (Suyama, 2014). During, OJT, each member is assigned to some tasks regarding practical actions that they are expected to perform during the normal system

[7] https://www.ihra-hsr.org/data/_pdf/09.pdf
[8] https://www.ihra-hsr.org/data/_pdf/08.pdf

operations. Follow-up and close guidance provided by the manager is then helpful in the improvement of the skill for an employee. In the era of portable smart devices, education by correspondence plays a vital role for the self-improvement of the employee. They can revisit the training materials at their convenience using smartphones. However, apart from individual training, Group training supplement the OJT. Various group training centers are located at the headquarter level as well as geographically divided field offices. These training centers serve essential local and universal training needs for the employees. The focus here is to impart training on issues that reflect the climate, environment, or other features in each region. These training centers provide training using the replicas of the tools that are used in operations. Hence the training conditions are very similar to the actual potential situation at the site. To further support the real experience during training, technology such as Virtual Reality, etc. are used in simulators. These simulators can reproduce experiences of typical operations and accidents related to maintenance works (Suyama, 2014; JR East Group, 2018).

While engaging in safety training, the long-term focus of the HSR TOCs in Japan not only is to impart knowledge to all the young generations but also is to create the next generation of safety trainers. In this aspect, the training facilities, responsibilities for the appointment of the trainers, etc. are deeply ingrained in the organizational structure of the companies. An example, of the safety training system at JR East, is shown in Figure 3-3 (Bugalia, Maemura, and Ozawa, 2019). Other HSR TOCs in Japan also have similar hierarchical structures supporting training for employees (Central Japan Railway Company, 2017; West Japan Railway Company, 2017).

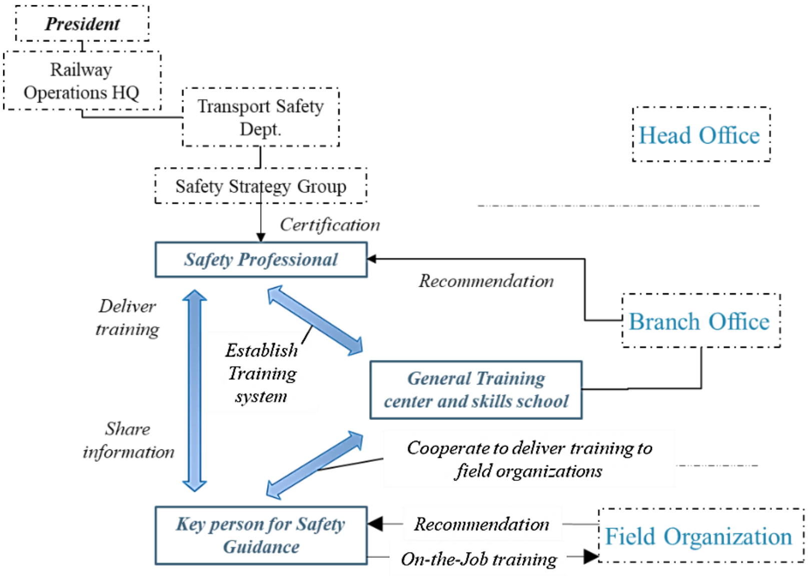


Figure 3-3 Safety Training System at JR East

Created by author, published in (Bugalia, Maemura and Ozawa, 2019b)

3.1.5 Integrated planning

In Japan Development of comprehensive traffic control systems that pay sharp attention to issues such as staff management, maintenance management, customer information dissipation management, along train operations demonstrates the importance of synchronous evolution in Japanese Shinkansen (Akita and Hasegawa, 2016). The importance of synchronous evolution for ensuring safety for complex systems such as Shinkansen has been well demonstrated in academic literature (Leveson, 2004; Ota, 2008). In this regard, JR East has implemented a large-scale, comprehensive data management system called Computerized safety, Maintenance & Operational Systems for Shinkansen (COSMOS). All the information collected from various sensors monitoring various natural disasters is readily analyzed and shared with the other 6 components of the COSMOS, i.e., Electrical System Control System, Transport Planning System, Traffic Control System, Yardwork management system, Rolling Stock management, and Maintenance work management system. The information collected through various sensors is then also helpful in determining the accurate levels of utilization for components necessary for effective train operation. Such information will then be necessary for calculating the required resources for executing the long-term train operational plans. Alternatively, the long-term operational plans could be revised based on the true-performance of the system, thus reducing the gaps between the planned demand and real-supply and reliving the system from the pressures emanating from such mismatches (Akita and Hasegawa, 2016). Systems similar to COSMOS also exist for JR Central, JR West, and JR Kyushu (Hancock, 2015).

3.1.6 Summary

Based on the factors described above, it is clear that technology plays an important role in assuring safety for HSR. The Japanese HSR technology has been designed to consider the human-deficiency and yet achieve safety. Only proven state-of-the-art technical components are used for Shinkansen in Japan and are maintained as much as possible. Moreover, the focus is on the "in-sync" evolution of core-technologies. At the same time, humans continue to be an integral part of the HSR system, and in Japanese HSR TOCs, the emphasis has been given on the long-term skill development for all human resources under real conditions as much as possible. Both the development of human-capacity and technology is further integrated with the long-term organizational planning, so as to ensure

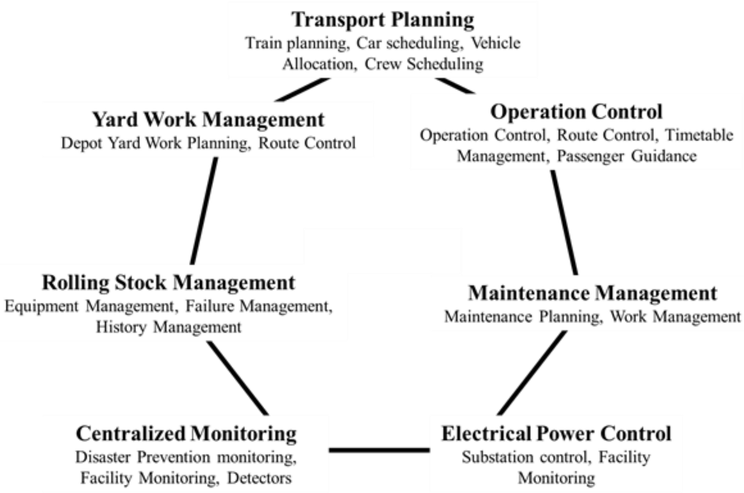


Figure 3-4 Overview of the COSMOS system

the effective balance between the demand for services and supply of resources in the organization. In the next section, a deep dive is presented on the concepts of safety management at an organizational level. A case of JR East is presented, and an attempt has also been made to highlight the similarities or the differences in these practices of safety management. The next section is organized on the basis of concepts of the Safety Management System, as explained in Figures 1-5 and 1-6.

3.2. Factors affecting railway business

While safety is an important priority area for HSR TOCs in Japan, they are also private entities, and hence, once aspect of sustainability is also related to the financial sustainability of the business. Early HSR lines in Japan had achieved high-passenger volume and enjoyed rapid growth. However, similar passenger levels were not observed by other HSR lines. Further, after a period of initial rapid growth, the passenger volumes have plateaued for almost all HSR lines in Japan. With the socio-economic issues such as aging and declining population, HSR lines in Japan are expected to have very moderate growth in passenger volume, suggesting strained conditions for passenger revenues. Figure 3-11 shows the relative ridership for different HSR lines in Japan. All figures have been normalized with respect to the ridership of the first full year of the operation, since service commencement. The normalizer values in a million passengers per year are also shown in Figure 3-5.

While passenger-revenues are expected to show moderate growth or even decline, the HSR TOCs in Japan are allowed to diversify their businesses as well as do not cross-subsidize their transport business. Consequently, a number of HSR TOCs have taken measures such as station area development, the opening of retail space, office space in the station, etc. Figure 3-6 shows the share of transport incomes and non-transport incomes for various HSR TOCs in Japan. The share of revenues from non-transport sources has been gradually increasing for all companies. Such is the extent that, for JR Kyushu, more than 50% of its total revenue came from the non-transport sector.

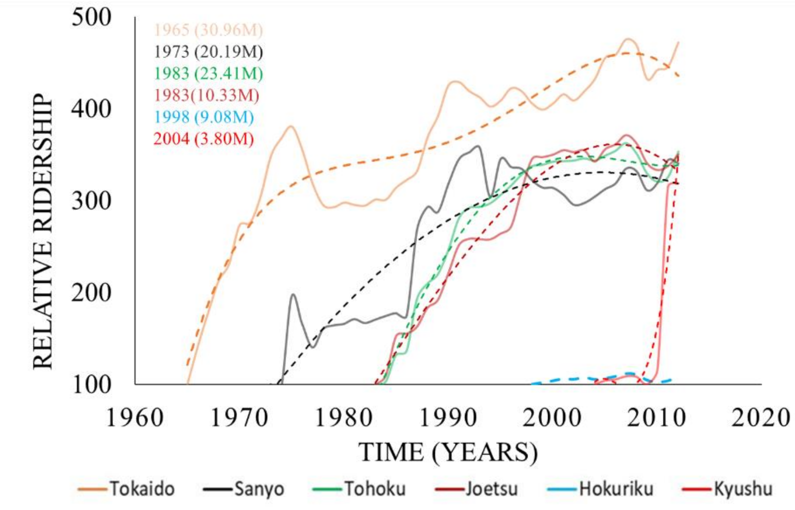


Figure 3-5 Passenger ridership for various HSR lines in Japan

Created by author, based on official statistics

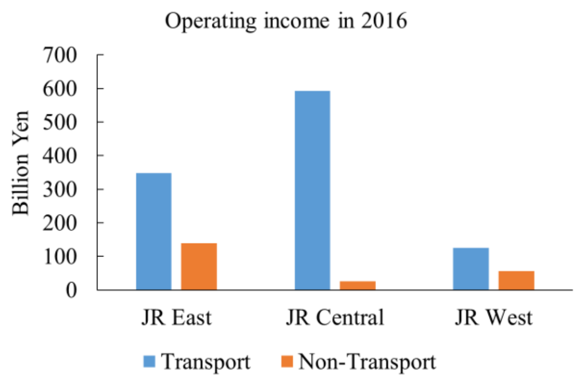


Figure 3-6 Operating income profile for various HSR operators in Japan

Source: Annual reports

While the revenue streams are getting strained, the maintenance expenditure of the fixed assets is likely to go up as for many HSR TOCs, the infrastructure is aging, and the railway usage has been increasing.

Also, the age distribution of employees within the railway company is changing rapidly. A large proportion of the HSR TOCs employees (~20%) are now 55 years or older. Because of the strained hiring in the immediate years after the privatization, now various companies are also facing issues of lack-of middle management and are facing difficulties in passing on the knowledge to the younger generation of employees (Central Japan Railway Company, 2017; West Japan Railway Company, 2017).

3.3. Safety Management System – Case of Japanese HSR TOCs

3.3.1 Safety Policy

An analysis of the various official reports published by the HSR TOCs in Japan suggests that customers are considered as one of the most important stakeholders in all JR Companies. All HSR operators also emphasize assuring compliance with various statutory and regulatory requirements (Central Japan Railway Company, 2017; West Japan Railway Company, 2017; JR East, 2018). Consequently, for all HSR TOCs, safety is stated to be the top priority.

Safety policy is developed to achieve certain goals and, in turn, determine the priority areas of management within the organization. For JR East, since its inception, the priority areas has been to take preventive measures for safety, including the promotion of voluntary and independent actions from employees. Further, priority areas for safety-related investments have been identified, such as the strengthening of the physical infrastructure to reduce the risk from natural disasters, including earthquakes, wind, tsunamis, etc. Other priority areas include the installation of safety doors on platforms (JR East Group, 2018). The priority areas for JR East have been achieved through the development of mid-term (5-years) safety plans. An overview of the focus points of various 5-year safety plans at JR East is shown in Table 3-2.

Table 3-2 Overview of the 5-year safety plans at JR East based on (JR East Group, 2018)

Name and Year	***Overview***
1989-93	Priority investment plans for safety equipment
Safety Basic Plan (94-98)	The overall plan for both Hardware and Software
Safety Plan 21 (1999-2003)	Prevention of major accidents and improvement of transport quality
Safety Plan 2008 (2004- 08)	Go back to the root and review safety
Safety Vision 2013 (2009-13)	Think and Act by yourself to achieve safety
JR East group safety plan 2018 (2014-18)	Extend skills for each individual employee and improve safety through teamwork

Similar, mid-term safety plans also exist for JR West (West Japan Railway Company, 2017) and JR Kyushu (Kyushu Japan Railway Company, 2019a). JR West's current mid-term safety plan focusses on promoting think-and-act-by-yourself strategy, where the focus is on reflecting the experiences from previous serious accidents and conduct risk-assessments from multiple-angles to improve safety. For JR Kyushu, safety is not immediately reflected from its business values, and the focus is on promoting the revenue activities of the group based on the transportation business. However, a deep dive into its safety policies immediately reflects its core priority areas that are similar to other JR companies. Currently, JR Central does not develop such a mid-term management plan but believes that safety is an everlasting goal and hence, the focus of JR Central is on improving safety through installation of derailment prevention guards, earthquake countermeasures, and providing practical training to all employees (Central Japan Railway Company, 2017).

3.3.2 Safety Culture (Reporting Culture)

Safety culture is a concept for which academic consensus has not been reached even for a definition; however, organizational communication has been inarguably recognized as one of the important aspects of it. JR East describes five cultures that the organization strives for, these are Correct Reporting culture (prompt and proper reporting), Recognizing culture (recognition and sharing information), Discussing culture (open and honest discussions), Learning culture (continuous awareness) and Acting culture (Think and act by yourself) (JR East, 2017). Consequently, JR East's top-management has taken numerous initiatives to promote the above-mentioned cultural values. These activities include holding safety meetings regularly among employees and between employees and top management. Accordingly, the incentive structure has been revised where the focus is on "praise to encourage" rather than "punish to correct." Hence, numerous activities have been taken where award ceremonies are conducted for people who took positive safety actions and produced favorable results. Under the challenge for safety campaigns, employees take part in various emergency response drills and carry-out activities in the field. Employee's awareness is also supported by continuous training. In addition, to provide employees experience of the atrocities of the accident, the various accident exhibition hall has been set up where employees can visualize the importance of safety.

Very close to the activities of JR East, are the activities promoted by JR Kyushu. Where the explicit focus has been given on improving the near-miss reporting through by developing a system of near-miss reports. JR Kyushu's management then has established awards that promote the reporting behavior and safety activities of different kinds. JR Kyushu's management is further committed to reinforcing the employees reporting behavior by taking tangible actions on employee's suggestions. Examples of these include changing the height of the emergency stop button to improve its visibility on crowded stations or take actions to reduce work-place hazards for different employees (Kyushu Japan Railway Company, 2019b). Figure 3-7 shows the trends of the near-miss reports in JR Kyushu, collected through its reporting system.

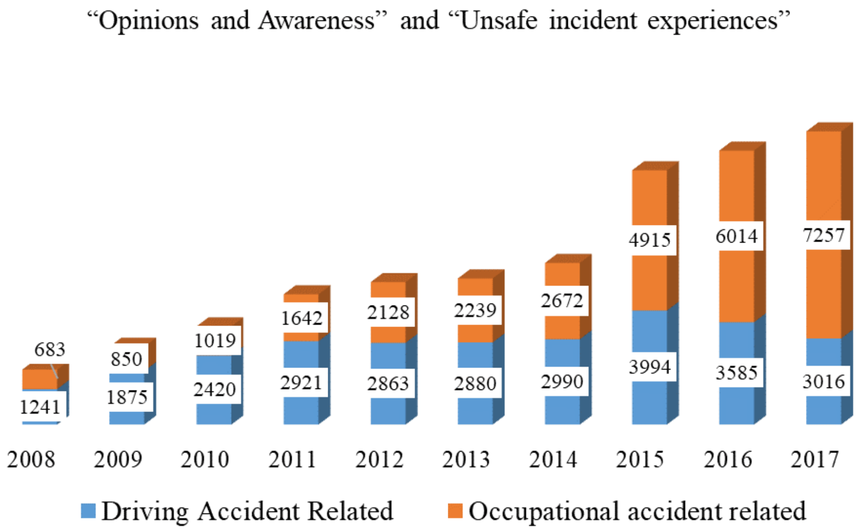


Figure 3-7 Trends of reporting in JR Kyushu

Data from (Kyushu Japan Railway Company, 2019b)

Similarly, JR Central also carries out activities to promote the reporting culture. JR Central has established a whistleblower system in their organization, where employees can report anonymously within or outside the organization (Central Japan Railway Company, 2018).

The safety report of JR West also lists a number of activities that the group is taking to improve its employees understanding of the think-and-act-by-yourself concept. The company has launched an integrated safety management system, where a summary of organization-wide reported incidents can be seen, although this system is not anonymous. Further, JR West claims to have no punishments for people who report; however, the safety report does not indicate the presence of a reward system or group activities similar to other JR companies (West Japan Railway Company, 2018).

3.3.3 Risk Management

3.3.3.1 Accident analysis

Hazard identification is an important step for improving the safety of safety. Even in Japanese HSR, the path of system evolution has been guided by the identified hazard as, over the years, the technical system is getting robust to manage as many hazards as possible.

In Japan, "Learn from the Past" so as to stop the recurrence of the same hazards, has been a key strategy for all HSR TOCs. Accordingly, there has been an acute focus on accident analysis using multiple perspectives. For example, for JR East, accident investigation is considered a priority area post-privatization (JR East Group, 2018). The whole focus of JR West has been to never able to repeat an accident similar to the tragic Amagasaki accident on the conventional line. Hence, many of JR West's current activities are centered around improving accident reporting and accident investigation (West Japan Railway Company, 2018). In fact, the ability of Japanese HSR TOCs to learn from the accidents and improve the system has been considered as an essential means to enforce safety by many (Saito, 2002).

An overview of the few of the popular accident models in Japanese HSR TOCs is presented here. Information on accident models is obtained only through publicly accessible information. The first accident analysis model, adopted by JR East, is called the 4M4E model (JR East, 2017). "M" here refers to perspective or point of view. Hence, in 4M4E model, accidents are analyzed from 4 perspectives namely *Man* (Human; psychological factors; physical factors; technical factors; knowledge factors), *Machine* (Machine; facility; equipment status, design; quality), *Media* (Information; Environment; information acquisition and exchange; communication), and *Management* (Education; administrative factors, organizational factors; status of education and training; rules and manual factors). Then, "E" refers to a number of perspectives on countermeasures. Hence, in 4M4E model, countermeasures are proposed from 4 perspectives namely *Education* (Training; knowledge; awareness; technology education; training), *Engineering* (technology; equipment and facility improvement), *Environment* (Background; improve physical working environment), and *Enforcement* (Strengthen; thorough; implementation of operations, standardize the manuals, etc.).

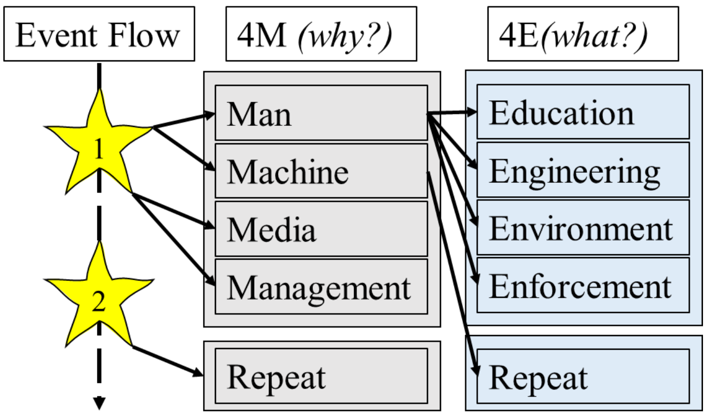


Figure 3-8 Schematic of 4M4E accident analysis model

Based on (JR East, 2017)

4M4E model is an event-chain accident analysis model. To apply, 4M4E, events leading to accidents are arranged in the order of their occurrence. Then, for each error, 4M perspectives are analyzed. Then, for each M perspective, countermeasures from 4E perspectives are analyzed. The overview of the 4M4E model is shown in Figure 3-8.

JR West adopts an accident analysis model named "m-shell," specially designed for Human-errors. An overview of the "m-shell" model is shown in Figure 3-9 (JR West, no date). In m-shell model, "S" refers to *Software* such as Procedures, manuals, rules, etc., "H" refers to *Hardware* such as equipment, facility, structure, etc., "E" refers to *Environment* and "L" refers to *Liveware* or the human, and "m" refers to *Management* such as policies, safety management, etc. The "L" in the middle refers to the person who was directly involved in the accident, and the second "L" refers to non-party teams or colleagues, etc. The unevenness around each of the elements indicates the limits of those elements. Hence the accident occurs when these irregularities do not match. Like, 4M4E model, the m-shell model is also an event chain model, and for each event, various pairs of interactions such as L-L, L-E, L-S, L-H interactions are analyzed to generate practical safety recommendations.

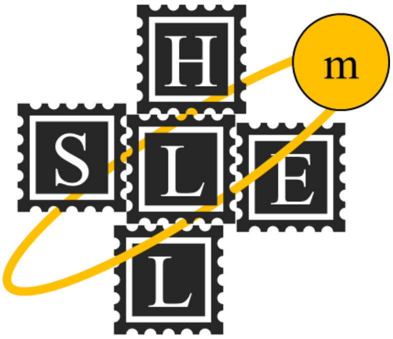


Figure 3-9 Schematic of m-Shell accident model

Further, details on the m-shell model are also useful in understanding the basic philosophy of the Japanese HSR TOCs in understanding human-errors. MIYACHI (2008) has described the process of such management in detail. In such an analysis, the first step is to define a set of "Desired Actions," which are deemed suitable by the TOCs management for successfully executing a given task. Then, by comparing the actual actions taken by the staff, a "Deviation" from the "Desired" can be obtained. These *deviations* are then arranged in a time-series. Once the deviation has been identified, a "why" analysis can be conducted to obtain the factors that contributed to the *deviation*, and accordingly, measures can be obtained to improve the situation. The *deviation* here is equivalent to an event, which can then be analyzed using an m-shell taxonomy developed for railway (MIYACHI, 2008). Further, the m-shell model is a "deductive approach," where the *deviation* is defined as a top-event, and the factors can be identified on how can this top-event occur (Ota, 2008). Figure 3-10 shows the typical process of a "why" analysis. The "why" analysis can be created for each of the links in the model, such as the L-L, L-E, L-H, and L-H links. When the issue for each of the links can be identified, the actions for "m," i.e., Management, can be generated.

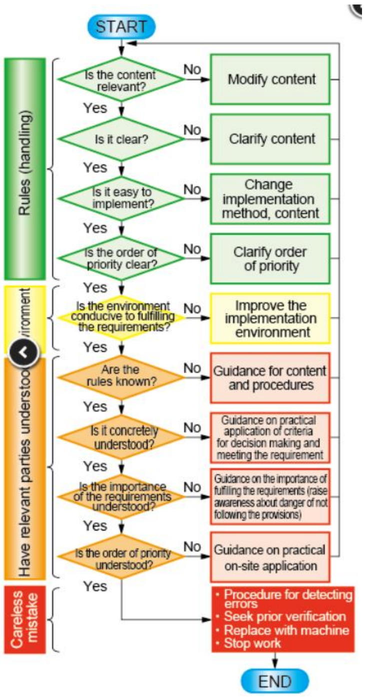


Figure 3-10 The process for Why analysis in m-shell model

Source: RTRI website

One important observation regarding the management of the human-errors from the m-shell model can be made. In the m-shell model, the key assumption is that the management's role is mostly attributed to improve the organizational procedures (S) and improve hardware (H), but not the direct cause of the human behavior, e.g., the modeling of m-L relationship is not emphasized. Hence, while there is an acute emphasis on modeling the interactions among system components at the physical level, and the physical human level, the full interaction of the human-factors from the organizational perspective is not considered. Further, the definition of the "Desired" is also set by the management, and the accidents could also occur when the "Desired" state of the system itself is incorrect (Pariès *et al.*, 2019). However, the current m-shell model does not consider the possibility of the incorrect desired state, to begin with, thereby masking the organizational factors in safety. Such information was further confirmed through an interview with the JR West official, where, as per the personal opinion of the person interviewed, JR West focuses on the "psychological" perspectives of the Humans to control for safety rather than more organizational factors.

3.3.3.2 Hazard Analysis

Accidents offer valuable learning opportunities; however, learning from accidents is considered a reactive approach. In this regard, hazard analysis, which can identify potential accident causal factors in advance, is considered a proactive approach.

In Japan, however, the approach of "learning from the past" also manifests as a means of hazard analysis. As explained before, the Japanese way of hazard analysis is based on accumulating long-term operating experience, through running tests for real prototypes, before the technology is used for commercial purposes. In this aspect, a number of issues can be detected and corrected before the real system operation. In many aspects, such an approach is also defined as a proactive approach to hazards analysis (Saito, 2002).

In any formal approach to risk analysis, configuration management is considered an essential component. Configuration management refers to identify and document the functional and physical characteristics of a configuration item, control changes to those characteristics, record and report the changes while verifying compliance, etc. However, for Japan, such business writings are considered to be simple and often vague (Ota, 2008), thus indicating that formal methods of risk identification are often not adopted in Japanese HSR.

The anecdotal evidence, as obtained from the expert-interviews from ex-officials from JR Central, points out that Japanese HSR TOCs are also not fond-of quantitative risk assessments based on failure probability and event-severity estimation. In fact, a number of risk-assessment methods, as we see in the next section have qualitative risk acceptance criteria, which is in accordance with the ide of vulnerability as proposed by the state-of-the-art system safety theories.

3.3.3.3 Risk Analysis and Risk Assessment

Once the hazards have been identified, usually they are analyzed for their probability of occurrence, and severity (i.e., impact if the hazard were to be realized). An acceptance criterion is then defined for determining the strategy that is adopted for managing the risk. A typical example of risk analysis and risk assessment is shown in Figure 3-11. Based on the set criteria, numerous risk-management strategies such as accept, avoid, minimize, mitigate or transfer, etc. can be adopted.

Numerous practices for risk management exist in Japanese TOCs. For example, JR East and JR Kyushu adopt a risk-management strategy based on Heinrich's law. As per Heinrich's law, every serious accident is usually preceded by 29 minor troubles (incidents), and, in turn, these are preceded by nearly 300 "near misses" (small signs). Hence if, countermeasures can be taken for 300 "near misses," then the minor troubles and one serious accident can be avoided (Ishii, Xu and Seetharam, 2019). Figure 3-12 shows the risk-management scheme adopted by JR East using Heinrich's law. Similarly, the triangular hierarchy also exists for JR Kyushu (Kyushu Japan Railway Company, 2019b).

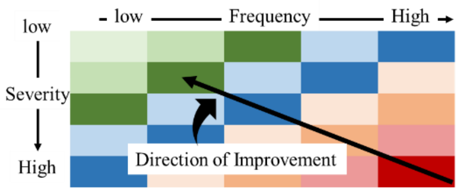


Figure 3-12 A typical method of Risk Analysis and Risk Assessment

JR Central's approach for the risk-management is slightly different. JR Central has assigned a level of criticality (importance) to each of the components in the HSR system, based on their functionality in the overall HSR operation safety. An example classification of the signaling system is shown in Figure 3-13. Aim of the risk-management is such that all risks must be eliminated as soon as possible for all the functions and equipment that are classified as "vital." Subsequent components receive a lesser priority. Such activity is then conducted for all technological systems to ensure the safety of the overall system. Even in this case, the lessons from past form a basis of estimating incident occurrence frequency.

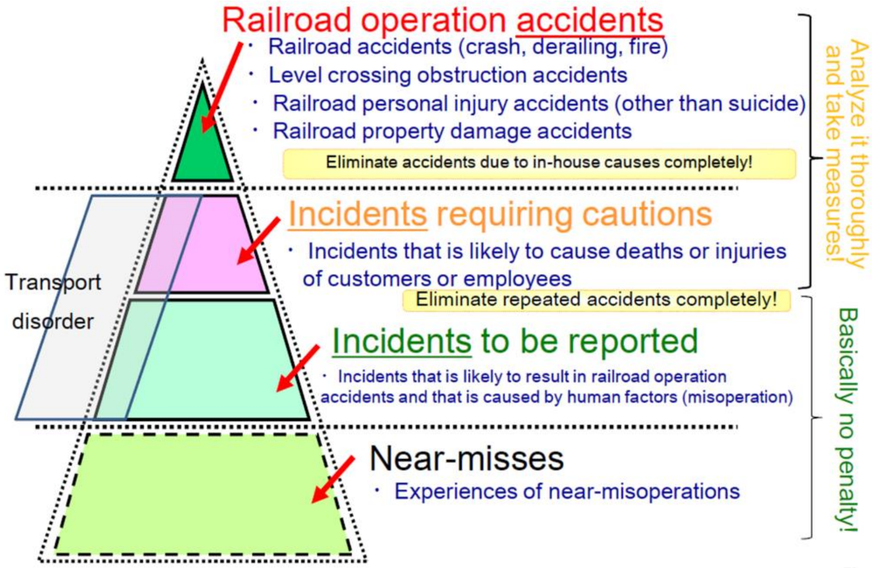


Figure 3-11 Risk Management scheme at JR East

Figure taken from the presentation obtained during interviews with the JR East officials

However, while the Risk-Management approaches in Japan consider the occurrence frequency of the several types of incidents, the management approach is still qualitative, and not completely quantitative. As per the interview with the experts in JR Central, the absolute accident frequency has no meaning in Japan, but the relative frequency of the different types of events is considered important. In Japanese HSR TOCs, the focus is not on the frequency of the failure of the individual components, but rather the relative frequency of the top-events, such as the wheel-climb derailments, etc. (JR East, 2017). Such a qualitative approach is thought necessary in order to ensure that the safety management should not be driven by the short-term quantitative goals of managing individual components, but rather qualitative goals to ensure the system performance.

3.3.4 Safety Assurance

Activities related to safety assurance relate to the monitoring of safety performance in an organization. Hence, the specific activities involve safety performance monitoring, management of change, and continuous improvement of the safety management system.

In this regard, no specific information could be obtained from the review of the official documents, except for the common philosophy of adopting cycles of Plan-Do-Check-Act for continuous improvement in the safety management system, as mandated by the Japanese law (MLIT, 2017b). Although, MLIT evaluates the performance of each HSR TOCs on 14 dimensions, and a number of those dimensions relate to continuous improvement, performance monitoring, etc. (Figure 1-8). Safety surveys are surely adopted by each of the organizations to confirm the reach and understanding of safety policies, organizational policies, etc. among all employees; however, specific methods and the related data are not a public information.

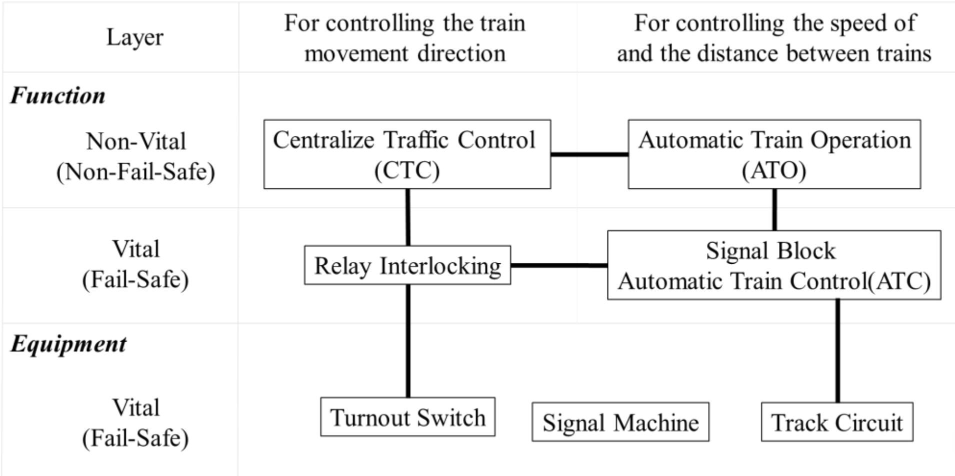


Figure 3-13 Functions layer and classification of the signaling system (JR Central)

3.3.5 Safety Promotion

Activities related to safety promotion are safety training and safety communication. A review of safety training related activities has already been presented in section 4.1.4. Further, the status of safety communication can also be inferred from the information presented in section 4.2.2. Each of the HSR TOCs takes extensive communication activities to increase the reach of their respective safety policies, goals, and other organizational policies. In some cases, the top management has an overt and visible role for safety promoting activities. For example, in each of the JR Central, JR East, and JR Kyushu, top-managers often participate in safety-related discussions, promote safe behavior through a reward system, and match their commitment through real actions such as high-priority to safety investments. Communication channels have also been established for employees to discuss among themselves and take safe actions. For example, JR West has established a company-wide reporting system, where everyone can access the reports and see the trends. Safety promotion activities are present in all the TOCs; however, the current information is inconclusive about the effectiveness of the safety promotion programs.

3.4. Risk-Management at the Institutional level

This section describes the current risk-management practices at the institutional level for Japanese Shinkansen. A publicly available document on technical, regulatory standards on Japanese Railways is used as a reference is this analysis (Railway Bureau, 2001). The standard is generic to be applied for all types of railways in Japan, including on the Shinkansen. The key features of the standards are described as follows.

In Japan, MLIT sets "Approved Model specifications," that provides standard interpretations, and quantified requirements of the Ministerial ordinance of the MLIT, which is expected to contribute to the promotion of public welfare. The model specifications details on the structure, maintenance, operation and handling of various fixed and moving infrastructure within the railway system, in order to ascertain that any danger capable of posing a risk to each and all persons and objects involved in the train operation is minimized considering the technical feasibility and the economic efficiency of the proposed solutions.

In this regard, the Japanese regulatory system does not emphasize on having an acceptable level of risk, and instead the focus is on minimizing the risk, given the financial and technical constraints (Ota, 2008). In that, often, a consensus has to be reached between the operator and the regulator to determine what is acceptable and what is not on a case by case basis.

On the other hand, the approved model specifications do not preclude any other specifications necessary for achieving the safety of the system. Indeed, the Japanese system allows each operator to set its own implementation standards that should conform to the approved model specifications. Figure 3-14 showcases the process of the specification development and approval in Japanese Shinkansen. Each of the operators drafts its own standards in coordination with the District Transport Bureau, and Engineering Planning Division of MLIT and seek approval from the MLIT before implementing them in their work. Figure 3-14 also provides detail on the approval process. A standard is approved if the conformity with the model specifications can be readily proven. If such conformity is not readily proven, MLIT coordinates the information across its various bureaus as well as the Engineering Planning Division. The criteria to determine the conformity itself evolves as the knowledge from previous experiences accumulate, or the technology and other systems evolve. For example, one of the criteria adopted by the MLIT to check the conformity of a new standard is to compare it with similar systems developed and adopted by other operators. Thus, MLIT relies on industry-wide knowledge management for approving the standards and specifications, etc.

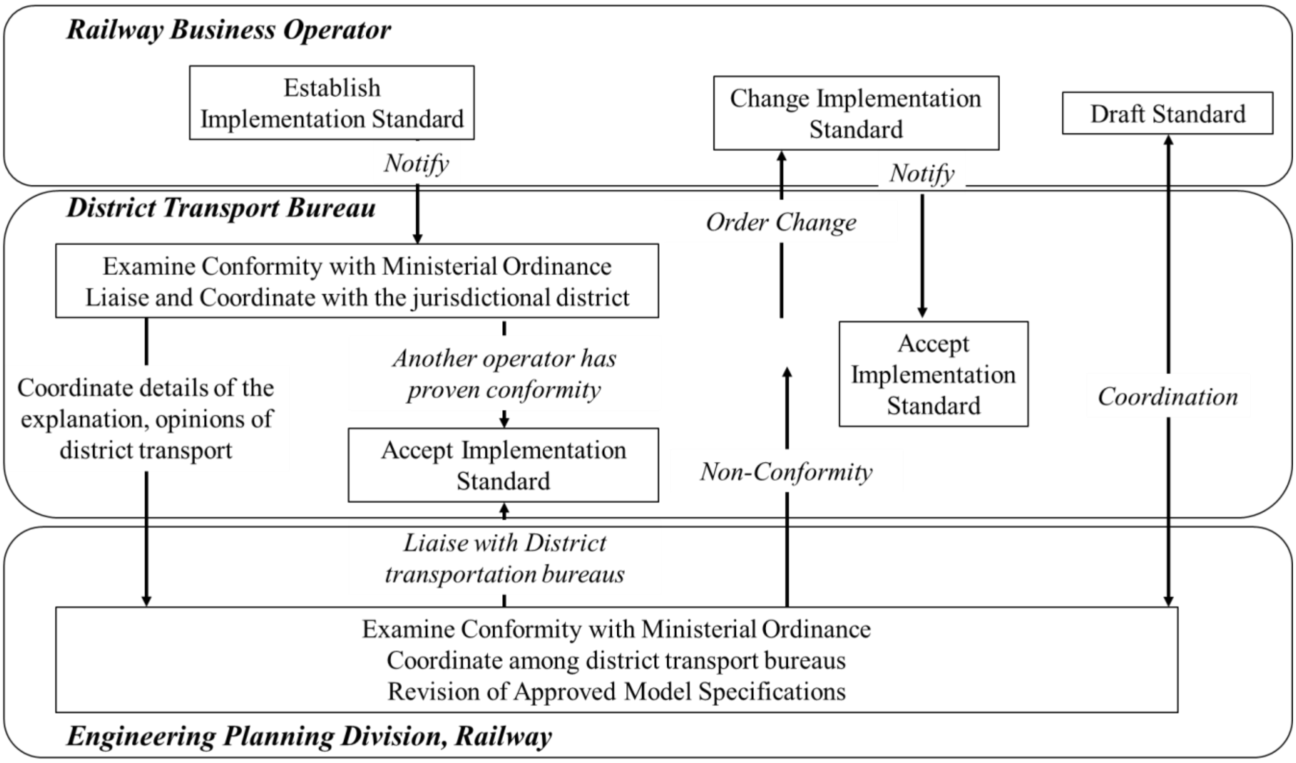


Figure 3-14 Process of Standard development and Approval in Japanese Shinkansen

Adapted from (Railway Bureau, 2001)

Like RAMS, the approved model specifications for Japanese HSR also specify several factors that it considers important for safety. Good emphasis is given on Human factors, factors related to railway facilities, infrastructure, rolling stock, train operation, maintenance of rolling stock as well as of facilities, etc. However, the Japanese approved model specifications generally do not specify any of the specific risk evaluation procedures and are performance-based in its true sense, as they value the ultimate outcome of safety more than the individual processes. Hence, generally, it is argued that the Japanese standardization process is based on the principles of system-thinking, where the focus is on system-level properties and system-integration rather than the individual components. Consequently, these specifications do not differentiate between systemic factors and random failures and emphasize the importance of all in preventing safety-related issues.

For example, guideway related specifications for the ministerial ordinance are:

Article 12: Gauge shall be able to maintain the safe and stable car operation, given the structure of rolling stock, the maximum design speed, and other relevant factors into consideration."

The corresponding approved model specification suggests that the Gauge of the Shinkansen shall be 1.435m; however, such an approved model specification does not preclude any operator from having gauge other than the 1.435 m as long as they can prove conformity with article 12 of the ordinance. By keeping the language utilized in the ministerial ordinance generic, Article 12 is able to emphasize on systemic factors such as the design speed, and the curve radius, as well as on the random failures such as the non-uniform settlement in the track for safety.

However, because of the lack of a formal RM approach at the regulator level, the configuration management of the Japanese HSR TOCs is considered to be simple and often vague (Ota, 2008). In any formal approach to risk analysis, configuration management is considered an essential component. Configuration management refers to identify and document the functional and physical characteristics of a configuration item, control changes to those characteristics, record and report the changes while verifying compliance.

3.5. Suitability of integrated framework for analyzing Japanese HSR

While, the integrated framework being utilized in this study (Figure 1-8), was proposed for a general railway company, now sufficient information is available to assess whether such a framework is suitable for analyzing Japanese HSR.

As highlighted in the previous chapter, no complex socio-technical system is either perfectly centralized or decentralized. Each system has its own characteristics to optimize for its needs. However, Japanese HSR TOCs can be identified as fairly centralized systems in which key-decision making is made closer to the top of the hierarchy. For example, since the railway reform of 2006 proposed by the MLIT, all Japanese HSR TOCs have established safety officers close to the top-management, providing them a similar level of a priority compared to other business-related activities (JR East Group, 2018).

Similar to the organizations described in the integrated framework (Pariès *et al.*, 2019), Japanese HSR TOCs have an acute focus on learning from the past and not on repeating the mistakes. Conventionally, Japanese HSR TOCs have adopted a rule-based management style where strict enforcement of the rules is considered as essential for ensuring safety (Saito, 2002). Such characteristics match the characteristics of the organization described in (Pariès *et al.*, 2019) for railway companies. Where the objective of continuous learning is not to empower the front-end employees for decision-making in any complex situation, however, is to change the system such that it should stay within the boundaries of the safe operations.

Pariès *et al.* (2019) describe the characteristics for such an organization in developing standardized skills for their human-resources, such that any particular human can easily be replaced by any other with equal skills. Such characteristics are also visible through the training methods adopted by Japanese HSR TOCs.

Over the years, especially after the 2006 reform, the policies adopted by the HSR TOCs in Japan are gradually changing. While strict enforcement of the rule is still considered as an essential principle of safety management, the focus is also given to promote independent thinking by the front-line staff for managing safety during unusual situations. Consequently, incentive schemes are put in place within the organizations where the safety-related initiatives taken by individuals are rewarded in the company. Systems are put in place to promote reporting of the near-misses, etc., and the practices of the punitive actions are gradually fading away.

However, such a decentralized characteristic does not necessarily negate the importance of the integrated framework being utilized in this study. A few of the academic studies have looked at the issue related to the excessive centralized control in the railway industry, such as the increasingly large number and complex rules (Hale, 2000; Hale and Borys, 2013b, 2013a). These studies have argued more empowerment at the front-end staff level for improved safety performance. While others have not necessarily supported the idea of removing the rules altogether, as they are often seen as helpful in complex decision-making (Bourrier, 2017). Leveson *et al.*(2009) have provided a balanced perspective on the issue by highlighting the importance of system-level information in decentralized decision-making. As per (Leveson *et al.*, 2009), decentralized decision-making will result in safe operations only when the decentralized controller bases his/her decisions on the system-level information and not otherwise. They provide an example of the runway *Go Around* operations in the airline industry. While the pilot of an aircraft may assess the situation to be too dangerous for a safe landing. In such a situation, the pilot often may not have enough time to discuss the issue with all the controller above him and may make a quick decision to go around to avoid any accidents. However, such locally safe operation may not always be safe at a system level. At a busy airport, the decision to go around by one aircraft may lead to a collision with another aircraft taking-off from crossing runways. Here, a new type of hazard materialized while averting the risk of avoiding of another kind. Under such situations, it is the responsibility of the controllers at the top to provide system-level information to the decentralized controllers, essentially through a certain type of centralized control.

Even the Japanese HSR operators share the characteristics of the air traffic management described above. The training-system prevalent in Japanese HSR TOCs also show characteristics of both a centralized as well as a decentralized system. While the General training center located at the HQ identifies general training needs for all employees and accordingly plan its activities to deliver the training. Region-specific or task-specific training needs are also identified and delivered by the training centers at a lower level in the hierarchy. The characteristics of the “on-the-job” training are such as that each individual receives training as per his/her own competences and performance, allowing the trainers to deliver highly customized training suitable to the needs of an individual (Figure 3-3). Further, the Japanese HSR operators emphasize on providing training using the real-equipment, thus enabling the employees to gain familiarity with as many system-level information as possible.

Hence, while Japanese HSR TOCs are gradually promoting management policies to strengthen the abilities of their front-line employees, they can still be categorized as the organizations executing a high degree of centrality, which is often considered essential in ensuring safety for such a complex system. In this regard, the proposed integrated framework in this study is also deemed suitable to be applicable for analyzing Japanese HSR.

3.6. Summary

This section summarizes important conclusions from the review of the safety management practices in various Japanese HSR TOCs.

a. **Safety Goals and constrained business environment:** From the review of the Japanese HSR TOCs, safety is stated as the highest priority for most of the organizations. However, whether it is actually true or not, can only be understood from a deeper study of the actual work process as practiced in the companies. Further, all Japanese HSR operators are going to face challenges from a constrained business environment, and thus the pressure to make -short term performance gains at the cost of safety are expected to be very high on Japanese HSR TOCs. This is an important trend to be vigilant in the context of Japanese HSR.

b. **Visible commitment from Top-Management in safety promotion-** Visible commitment from the top-management is seen important from the perspective of safety communication and safety promotion activities. From the review of Japanese HSR TOCs, it is clear that safety-related investment receives a significant priority, thus suggesting that actions of the top-management match their stated commitment. However, in some of the companies, such as JR West, overt involvement of top-management is not visible, for example, in all the HSR TOCs except JR West, the top-leaders directly participate in safety-related communication at the real-work level or are directly involved in safety promotion activities such as social-recognition or rewarding the good safe behavior of the employees.

c. **The increasing importance of near-miss reporting -** All HSR TOCs in Japan rely on learning from the past to improve the system. In the absence of frequent accidents in Japanese HSR, the emphasis now is on promoting near-miss reporting among employees so that potential safety-related gaps can be identified. Many HSR operators thus have established the system and necessary incentive structure to promote employees near-miss reporting behavior.

d. **Risk Management –**The summary of the current RM approaches in Japan are summarized in Table 3-3. In Japan, HSR TOCs adopt qualitative methods of risk assessment and management, and safety is not driven by short-term quantitative targets. The emphasis is given on the integration of the system in assuring the safety, rather than focus on improving the reliability of an individual component (Section 3.3.3.3.). However, the consideration of the system interactions is rather bottom-up and not top-down, and there is a possibility that the role of organizational factors affecting human-factors, etc. are not considered adequately (Section 3.3.3.1). Further, the approach for Risk-assessment at both the operator and the regulator level is often described as being unsystematic (Ota, 2008), as both operator and the regulator do not follow a systematic practice of detailed component documentation etc. (Section 3.3.3.2). Finally, while the regulator in Japanese HSR does not prescribe the use of any specific accident model, the usage of event-chain models is prevalent among HSR TOCs (Section 3.3.3.1).

Table 3-3 Summary of the RM practice in Japanese HSR

<table>
<tr><th>Factor</th><th>Accident Model</th><th>Risk Assessment</th></tr>
<tr><td>Organizational Level (HSR TOCs)</td><td>Event-Chain models</td><td rowspan="2">Qualitative and Unsystematic approach.

Partial consideration of System interactions (Top-Down interactions are missing)</td></tr>
<tr><td>Institutional Level (Regulator)</td><td>None specified</td></tr>
</table>

Chapter 4. Risk Management challenges in Japanese HSR

Based on the review of the state-of-the-art safety theory and methodologies applicable for analyzing organizational and institutional factors in chapter 2 and a review of the current organizational and institutional RM practices of the Japanese HSR in Chapter 3, this chapter presents three important analyses to identify challenges and suitable improvements in the current risk management practices in the Japanese HSR. The three analyses are as follows.

1. In the first analysis, multiple accidents in Japanese HSR are considered, and a taxonomy for the causes of accidents is generated using principles of system and control theory. The results of this analysis are helpful in establishing the relative prominence of the Organizational and Institutional factors affecting the safety of the HSR. The results are also helpful in identifying the common organizational and institutional level risks.

2. In the second analysis, a comparison of the state-of-the-art safety theory (reviewed in Chapter 2) and the current RM practices in Japanese HSR (Chapter 3) is made, to confirm the suitability of the current Japanese HSR practices in explaining the complexity of the accidents in the railway system. Further, the comparison reveals the scope of improvements in the current RM practices at the organizational and institutional levels.

3. In the third analysis, the focus is shifted towards analyzing the first "Serious Accident" in the history of Japanese HSR. STAMP is used for this analysis, which reveals an accident mechanism (Archetype) about the relationship between the regulator and the operator. Multiple examples from the Japanese HSR confirm to the archetype that is generalizable to the Japanese railway context. The archetype is then helpful in identifying suitable improvements in the current RM practices of the Japanese HSR system at the organizational and institutional levels.

4.1. Methodology

For accident analysis, selection of methodology is very important, as often you learn what you seek for. In this regard, methods combining the concepts of both System engineering and Control theory, that are able to systematically consider interactions among a wide range of technical, human, management, cultural and environmental factors, have been proven to be useful for analyzing the case of complex systems such as HSR (Ota, 2008; Kawakami, 2014a).

However, the process of deriving lessons from an accident in a complex system is challenging for multiple reasons. Accidents are rather Infrequent in such systems, for example in HSR, or in Aircraft. In the absence of a large number of previous accidents, common failure patterns across multiple accidents must be identified, and accident taxonomies can thus be of help. On the other hand, analyses based on system-control theories are often complicated and time-consuming, limiting their practical applications (Li, Zhang, and Liang, 2017). Thus, for simultaneously analyzing multiple accidents, a method that can provide a consistent and detailed accident factor classification scheme with the ability to consider a sufficient number of contributing factors in a simplified and communicable manner becomes necessary. Li, Zhang, and Liang (2017) have compared 7 system-control engineering accident analysis methods, and for the criterion-mentioned above, the Accident Causation Analysis and Taxonomy (ACAT) (Li, Zhang, and Liang, 2017) is found to be suitable for developing a failure taxonomy using multiple HSR accidents in this study.

Also, for an in-depth analysis, the System-Theoretic Accident Model and Processes (STAMP) is thought to be suitable for its ability to showcase a complete understanding of the complex systems in a consistent and communicable manner (Leveson, 2004).

4.2. Data Collection

Two schemes of data collection are used in this study, one each for the ACAT and STAMP analysis. For the ACAT taxonomy analysis, the official railway accident investigation reports published by the Japan Transport Safety Board (JTSB) are used. JTSB was formed in 2001, and since then, a total of 6 accident cases for Shinkansen are observed. These accidents have resulted in passenger or crew injury or death or injuries of five or more passengers, or these were likely caused by railway officers or by management errors.

A STAMP analysis on the case of the bogey frame crack detected in December 2017 was conducted using facts obtained from the official JTSB accident investigation report (Japan Transport Safety Board, 2019) and investigation report by the Bogey Manufacturer (Kawasaki Heavy Industries Co. Ltd., 2018). In addition, STAMP also requires information on the functional relationships between various controllers in a Safety Control Structure (SCS). Previous applications of STAMP in the Japanese railway (Ota, 2008), the information provided in chapters 1 and 3, and successive interviews with Japanese HSR practitioners were useful in obtaining such information. The interviews were not recorded, but the notes were taken, which were approved by the interviewees.

For the comparative study for the RM practices, the review of the literature has already been shown in chapter 2 and Chapter 3. Here the suitability of the Japanese HSR RM practices will be confirmed for a previous accident in Japanese Railway, for which the information was obtained from the field visit to JR Kyushu.

4.3. ACAT Analysis

4.3.1 Overview of the method

ACAT method uses a combination of subjects and their functional characteristics to classify accident causes while reducing analysis subjectivity. In ACAT analysis, there are a total of 6 subjects, i.e., Man, Machine, Management, Information, Resources, and Environment. The codes used in this study for denoting these subjects are M1, M2, M3, I, R, and E, respectively.

For HSR, Man refers to frontline staff such as train operators, maintenance workers, or field supervisors; Machine is related to technical components within the railway system such as fixed assets including tracks, or the moving assets such as rolling stock; Management refers to decisions made by managers, companies, or the government; Information relates to existing rules, procedures, work-standards, or job-description within the railway company; Resource refers to both Human and Financial resources. Finally, Environment refers to the safety culture within the HSR company of the related stakeholders.

In the ACAT method, there are 4 functional characteristics of each subject, namely Actuator, Sensor, Controller, and Communication. In this study, the codes used to denote these functions are A, S, C, O, respectively. An Actuator executes commands; a Sensor monitors the output; a Controller compares output performance with references and gives commands, and Communication connects elements and conveys information. Each combination of a subject and function refers to one-element in the accident taxonomy (or classification). For instance, a combination of Man and Actuator (M1A) refers to incidents where a human operator fails to take effective actions.

4.3.2 Process of Taxonomy development

In a complex system such as HSR, multiple hazards can be associated with a single accident. The broader objective of safety research thus is to prevent all hazards from occurring. As per the definition used by MLIT, accidents are linked to both the damage to assets as well as to passengers. To account for the broader perspective on accidents, our analysis focuses not only on identifying causes of the main event in an accident, but also other events such as the spread of damage as well as its impact on passengers.

The detailed accident report from JTSB is available only in the Japanese language, and public translation software was used for translating these reports in English. Key interpretations were confirmed with native Japanese speakers by referring to the original text. Further, a tree diagram was used to list the critical causal factors mentioned in a report to produce accident causation diagrams. The JTSB reports do not follow a standard approach to identify root-causes of the accident, and the depth of analysis varies for each identified factor. For example, for several technical factors, probable underlying management factors are not discussed in the report, while for many other non-technical issues, they are considered. To maintain consistency in the analysis, the data from the official report alone is used and included in our study. The generalized ACAT classification is applied to each of these causal factors to generate taxonomies. In this way, each of the causal factors in a sequence of causal factors can be classified. The approach is consistent and similar to the original ACAT study to which we referred (Li, Zhang, and Liang, 2017).

The results of the qualitative analysis described above must be checked for researcher bias and subjectivity from relying on translation software. The detailed process of how the reliability of the developed taxonomy was increased is shown in Figure 4-1. Person 1 generated the causal tree-maps, which were useful in summarizing the complex, unstructured, and lengthy documents to be presented and checked by Person 2. The clarifications sought from Person 2, a communication expert with native Japanese language ability, allowed authors to reconfirm the interpretations for some of the causal factors through reference to the original Japanese text.

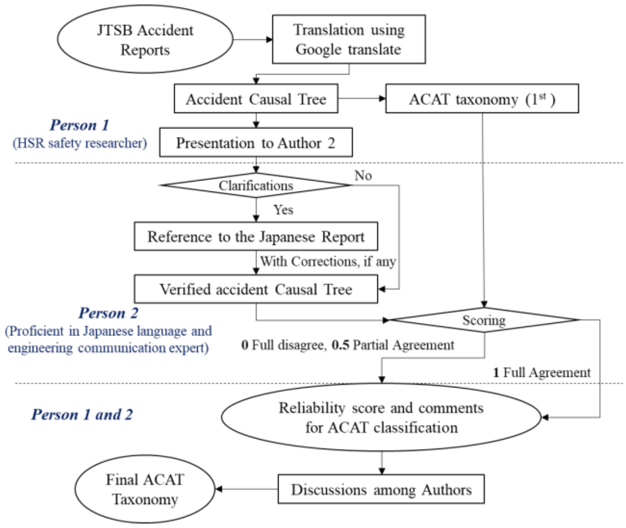


Figure 4-1 Process adopted for developing ACAT taxonomy

4.3.3 Details of accidents in Japanese Shinkansen

Table 4-1 Accidents in Japanese Shinkansen

Year	**Line**	**Short Description**	**Proposed Taxonomy** *(#no of factors in the same category)*	**Sources**
2004	Joetsu	Derailment due to a strong earthquake	*M2A(2)*	(Japan Transport Safety Board, 2007)
2011	Tohoku	Derailment due to a strong earthquake	*M2A(1), IA(1)*	(Japan Transport Safety Board, 2013)
2015	Sanyo	Plate falling accident	*M1A(1), M1O(1), M3A(1) M3O(1), IA(2), IS(1)*	(Japan Transport Safety Board, 2016a)

2015	Tokaido	Passenger fire accident	*IC(1), RA(2)*	(Japan Transport Safety Board, 2016b)
2016	Kyushu	Derailment due to a strong earthquake	*M2A(3), IA(1), IC(1)*	(Japan Transport Safety Board, 2017)
2017	Sanyo	Crack in bogey frame	*Operator- M1S(1),M1O(1), IS(1), IC(1), RA(1), EA(1) Manufacturer – M1S(1), M3O(1), IS(1), IC(1), IO(1), EO(1)*	(Japan Transport Safety Board, 2019)

An overview of the accident taxonomy generated for all the 6 accidents in Japanese HSR is shown in Table 4-1. In this section, a detailed accident description for each accident is given, along with information on how the classification for each of the accident causal factors was decided.

4.3.3.1 Earthquake related derailment for Joetsu Shinkansen (2004)

In 2004, *Joetsu Shinkansen* train derailed after a strong in-land earthquake. Figure 4-2 provides a summary of the causal factors discussed in the original accident analysis report. The boxes in green represent factors that were found to have satisfied existing safety performance expectations, whereas the factors in red denote the potential accident causes. Factors leading to the train derailment, the

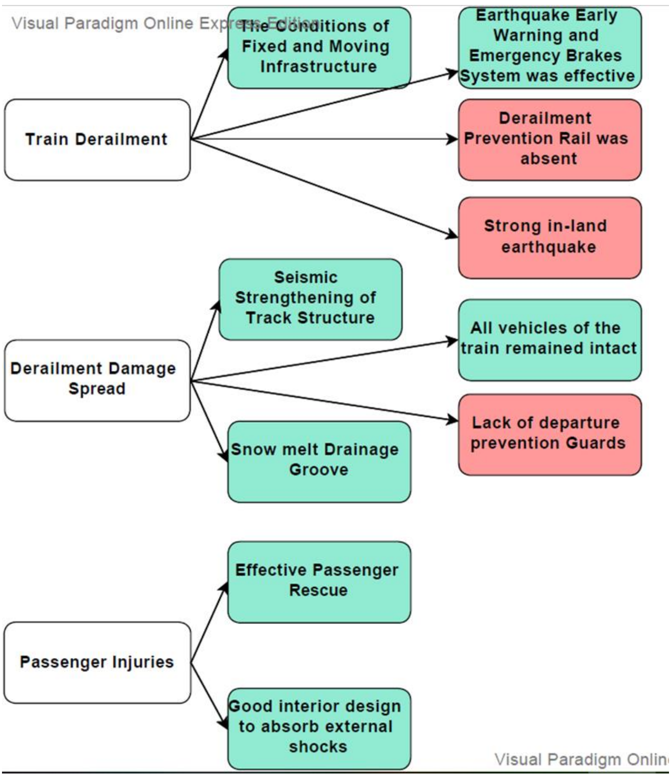


Figure 4-2 Accident causal map for 2004 Joetsu Shinkansen derailment

damage spread, and passenger injuries are all considered here as per the broader definition of accidents described above. The arrowhead points to potential factors of a specific event. In this case, the report establishes that derailment occurred because of large lateral vibrations caused by the strong in-land earthquake, which is a factor external to the railway system.

Nonetheless, the report identifies the absence of measures such as derailment prevention rails that could have been in place. Similarly, the lack of departure prevention guards was deemed to have contributed to the spread of damage to other assets. The report does not provide any further information about why such measures were not taken before the accident. Hence, strictly utilizing the data available from accident reports, the absence of derailment prevention rail as well as departure prevention guard, both were classified as a *design deficiency*, i.e., Actuator failure for Machine or *M2A.*

4.3.3.2 Earthquake related derailment for Tohoku Shinkansen (2011)

On March 11, 2011, a test train traveling at a speed of 72 km/hr, suddenly felt a strong jolt. The drives had applied brakes and stopped the train. It was found that that 2 axles of a bogie had derailed. The accident analysis report suggests that deviation prevention countermeasures were effective in stopping the train to deviate. However, the derailment prevention rail was absent from this train. The accident report provides no further report for the same, and hence it was categorized as design deficiency or M2A. The emergency brakes applied in a timely manner had reduced the speed to about 14 km/hr at the time of derailment and were thus considered effective. A possibility of amplified vibration because of the "Resonance" phenomenon of the bridge, on which the train was traveling, was considered as the probable cause of the derailment. "Resonance" is a complex phenomenon that is still not very well understood. Hence, this causal factor was classified as *Inadequate information* or IA (Table 4-1). The accident causal map is summarized in Figure 4-3.

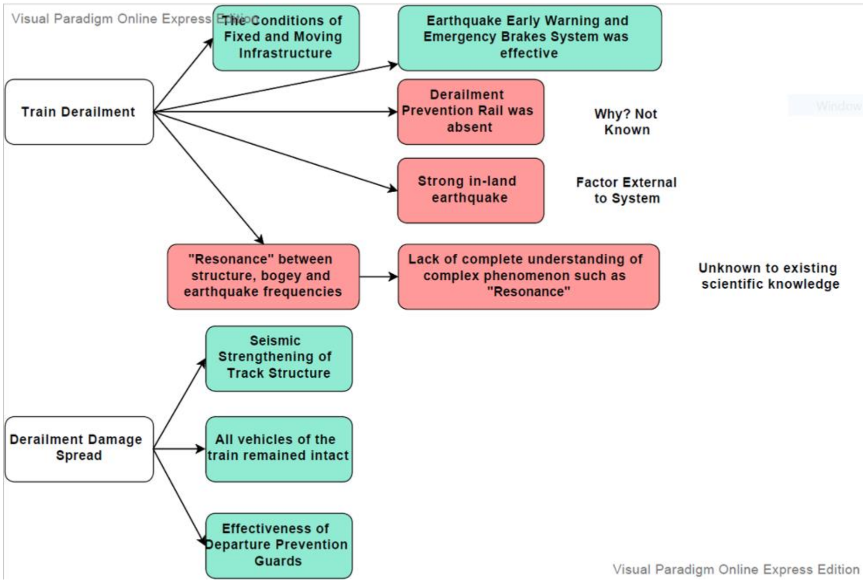


Figure 4-3 Accident causal map for the derailment of Tohoku Shinkansen (2011)

4.3.3.3 The fire caused by the passenger, Tokaido Shinkansen (2015)

On June 30th, 2015, on a Shinkansen bound to Osaka, a passenger sitting in the first cabin had poured gasoline on himself and light fire. The passenger himself was dead along with 1 co-passenger. In addition, 25 passengers and the 2 members of the crew, including the driver, were injured. One passenger putting himself on fire was the only reason for fire ignition. For the purpose of this analysis, this is considered as an external event and thus is not classified.

However, our analysis focuses on damage spread from smoke and fire as well as causes to passenger injuries. There were multiple factors that affected the extent of smoke and fire damage spread. Following the operational protocol, the train had stopped outside a tunnel, so that firefighting activities were quickly carried out. All the crew members on-board had received training for firefighting and were aware of their responsibilities clearly. Such training was effective for controlling the damage of fire and smoke. Following the operational protocol, the train's AC was quickly turned off, further stopping the spread of the smoke. All the material inside the car was either fire-retardant or fire-resistant, helping to contain the fire damage from spreading. In addition, the TOC responsible had carried out the public-awareness campaign for a long time; hence, passengers were quick to inform about the incident to the crew members, helping in decreasing the time spent before the firefighting could begin.

Even after such effective measures, the smoke from car 1 still filled in car 2 and affected the crew's response time to firefighting. The reason for this was identified as follows. The passengers evacuating from car 1 had gathered in the lobby area between cars 1 and 2. Instead of evacuating further, a few passengers had stopped for taking pictures. However, such a gathering of people had caused the automatic door to remain open, and thus smoke was still filled in other cars. The accident report surely considers that lack of effective passenger evacuation guidelines had contributed to such damage spread. For ACAT, such an activity should be classified as *Failure in establishing information* or IC.

Such passenger behavior was in-part also affected by poor-evacuation guidance provided by the crew; however, a deeper analysis in the report identifies that the crew did not have sufficient time for such a response. One of the contributing factors for the same is that the crew did not have any monitoring devices, such as images from the camera installed inside cars, that could help the crew to assess the situation faster. As per the ACAT classification, this is a *lack of equipment (resource)* and thus is classified as RA. This delay from the crew to assessing the situation had also contributed to the increase in passenger injuries. On the other hand, the accident report highlights that the train crew had also lacked sufficient protective equipment, thus limiting the effectiveness of their rescue efforts. As per the ACAT classification, this factor is also classified as a lack of equipment and thus is classified as RA. Figure 4-4 shows the complete causal map for this accident.

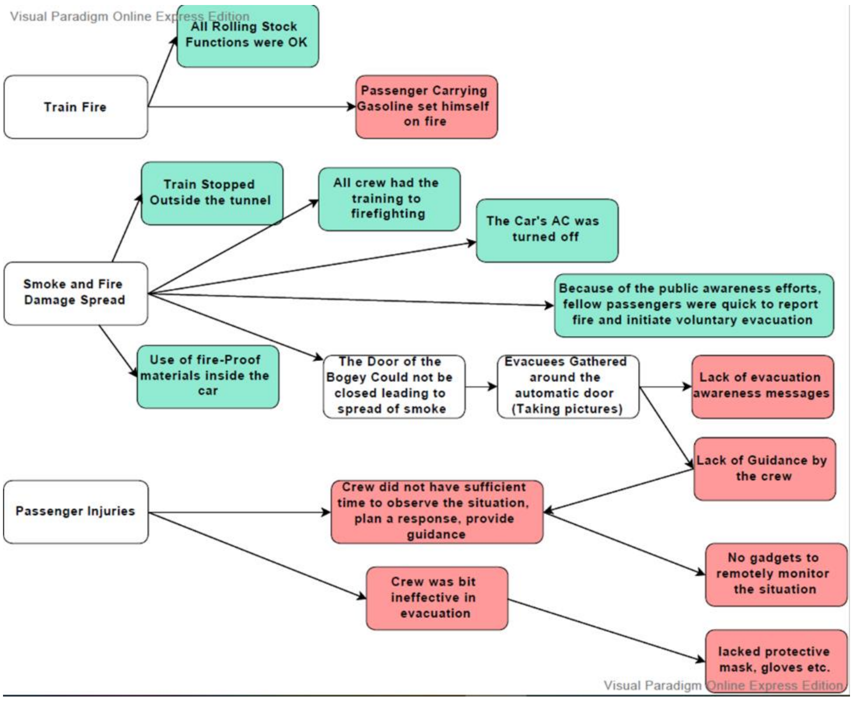


Figure 4-4 Accident causal map for fire in the train, Tokaido Shinkansen (2015)

4.3.3.4 Plate falling incident, Sanyo Shinkansen (2015)

On 8th August 2015. a metallic plate from the bottom of the coach, 2nd from the front, had detached on a train traveling at 290 km/hr and hit the glass window in coach 3rd from the front, causing passenger injury. Later the accident investigation revealed that the bolts holding the concerned metallic plate were tightened with force equivalent to "Manual Tightening" during an incidental work related to installing a few sensors in the train (Conducted on 21-24 July 2015).

The whole event could be analyzed with respect to two events. On August 7th, the train had gone through routine operational checkup. It is clear that the routine check-up was not effective in identifying the loosened bolt from the sensor installation work conducted on 21-24 July. The accident report identifies two main contributing factors for the same. First of all, the testing methods for routine check-ups were not standardized for all the personnel involved. It was discovered that a discrepancy existed between the approved-procedures (by the regulator) and the procedures as practiced in reality as well as taught during the training for the staff. As per the ACAT classification, this is a case for *Fail to monitor or update the information* or IS. Further, the report also proves that the testing method approved for the routine check-up was unsuitable in detecting the hand-tightened bolt (tightened 9 or 10 times by hand). As per the ACAT classification, this is a case of *inadequate information* and thus be classified as IA.

Further, the accident report has analyzed the process of sensor installation work, along with running tests. The case of removing the side-plates and then tightening them involves multiple bolts, and hence to identify that the bolts have been correctly tightened, JR West uses a system of making a mark on the bolt and the surrounding plate, for the tightened bolts. With this simple mark, if the mark on the bolt is aligned with its surrounding plate, the chances are that the bolt is tight. For creating an understanding of the accident, we have further divided into three-tasks, i.e., removal of the plate, installation of plates, and the running test.

While removing the concerned plate, the existing bolts must be cleaned for their marks from the previous tightening, so that new marks can be made when the bolt is tightened again. The report highlights that the two workers involved discussed cleaning the bolts, but neither of them did it. The official accident report classifies this as a human error; however, as per the ACAT analysis, this causal factor is classified as a Lack of effective coordination between the two personnel, i.e., M1O.

When the removed plate is reattached to the body of the train, there are 6 steps involved that must be performed in sequence, e.g., put the boards, tighten by hand, tighten by machine, inspection, etc. The accident report highlights that there was a lack of coordination between all the 6 different workers involved in the same process. This was partly because the manager of the task failed to give appropriate directions, thus classified as a human failed in *taking effective actions* M1A. The lack of coordination was also attributed to the fact that all of these 6 people were belonged to 6 different departments in the organization and were brought together to work specifically for this task. This is seen as management's failure in effectively managing the workers and is thus classified as M3A.

Also, during the installation work, the scope of the work had changed from the original plans at the last moment. The department responsible for the work did not use the "check-sheets," a method prevalent to manage similar work in other departments of the organization, as it was not clearly written

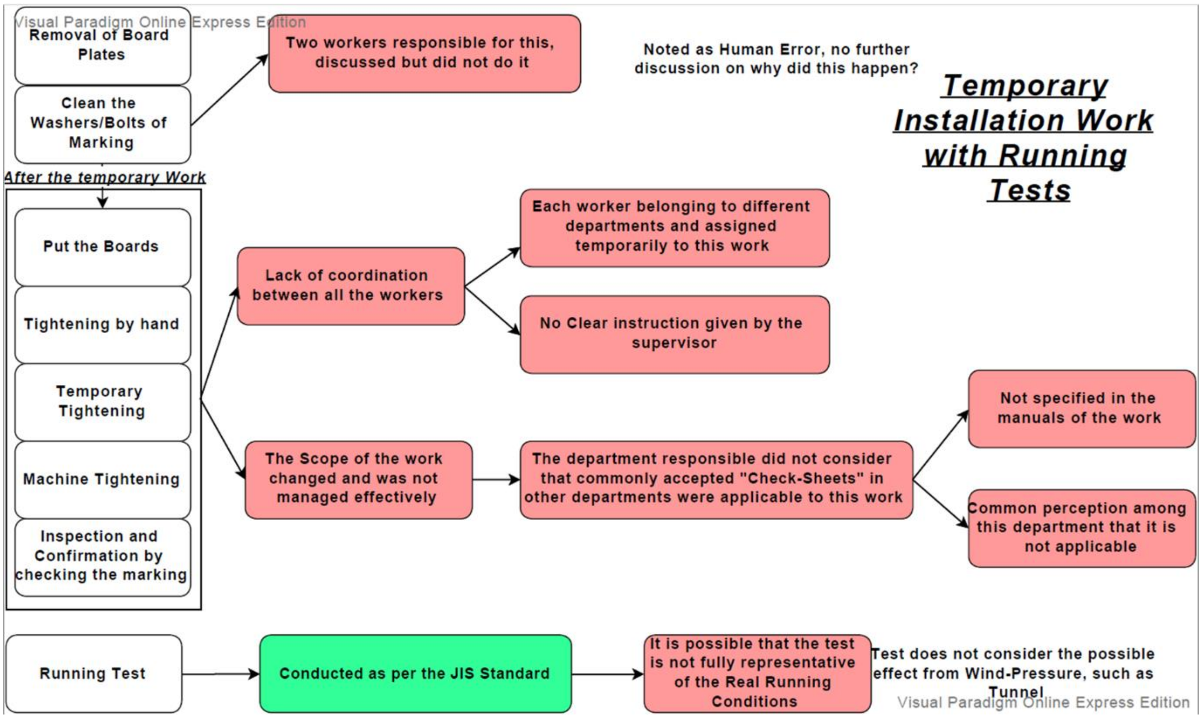


Figure 4-5 Causal factors for plat falling accident, Sanyo Shinkansen (2015)

in their working manuals. In fact, the common perception among the manager performing the current task was that such "check-sheets" were not applicable to their work. From the perspective of ACAT classification, this is categorized as the lack of communication between the decision-levels of the management, i.e., M3O.

Finally, the sensor installation work was also followed by a train running test. In this test, the train was put on a testing facility and had a full-speed running test for a few hours. In this test, no loosening of the bolt was detected. The accident report identifies that the wind-pressure caused by high-speed train operation in a tunnel could have caused such an incident, implying that the lab-test was not a true representative of the real conditions. As per the ACAT analysis, this a case of inadequate information, i.e., IA. Figure 4-5 shows the causal factors for the accident.

4.3.3.5 Derailment due to earthquake, Kyushu Shinkansen (2016)

On April 14, 2016, a Shinkansen was operating in a deadhead operation near Kumamoto station traveling at 78 km/hr. The driver of the train felt strong vertical jolts and applied emergency brakes immediately. He found that all 6 vehicles of the train had derailed. There was no injury. The accident analysis report considered a possibility of ground amplification leading to the rolling of vehicles when the powerful Kuma moto earthquake occurred. The interaction between the ground motion, the structure, and the rolling-stock is a complex phenomenon and is still not well understood. As per the ACAT analysis, this factor can be classified as *Inadequate information*, i.e., IA.

On the other hand, it was found that the derailment prevention rail was not installed in the tracks where the accident occurred. As per the ACAT classification, this would count as equipment issues such as M2A. However, it was also found that JR Kyushu, had not installed such rails, because the risk from earthquake damage was undermined. JR Kyushu had installed such prevention rails for areas that were directly above the already listed earthquake fault planes. In the current situation, the location of the derailment was just 10 KM away from the focus of the earthquake and had suffered significant damage. As per the ACAT analysis, this factor was classified as a failure in establishing information, i.e., IC.

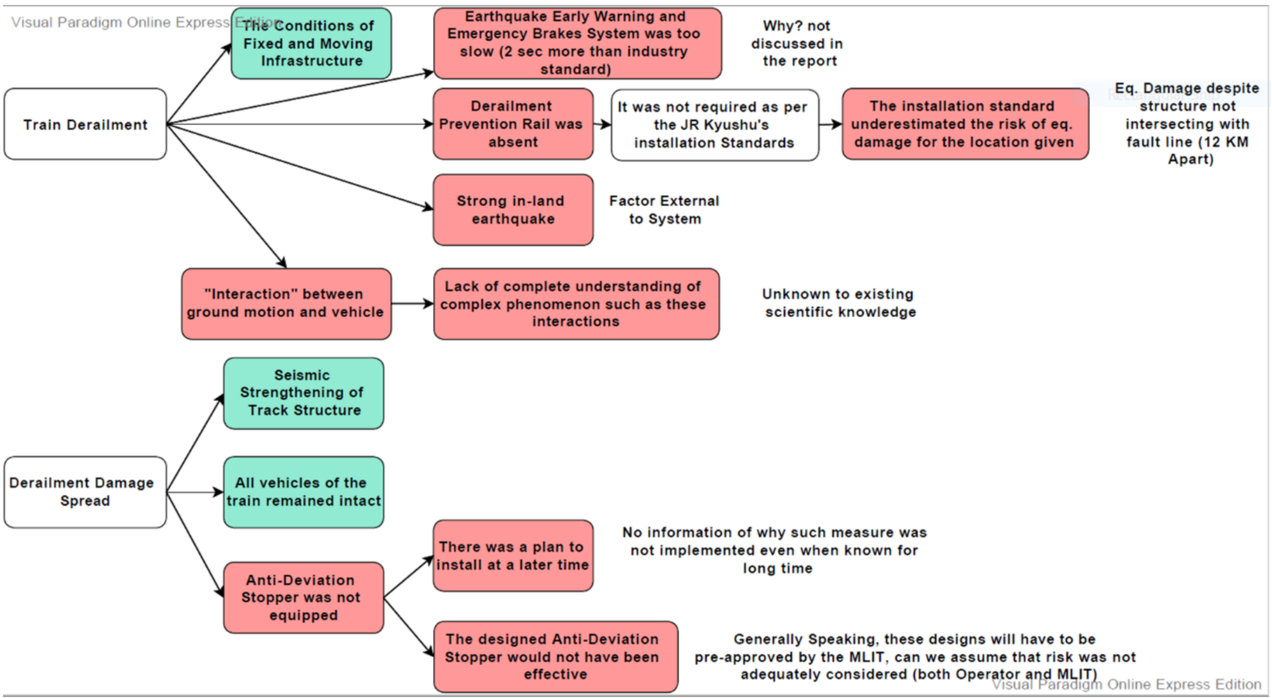


Figure 4-6 Causal factors for derailment due to earthquake in Kyushu Shinkansen (2016)

Further, it was found that the response time for the emergency braking system during an earthquake was not even as fast as other industry-wide practices, and thus was not effective. As per the

ACAT classification, this was also considered as a design deficiency, i.e., M2A. No further information on this design deficiency could be obtained from the official accident report.

When it comes to a derailment, the equipment that can control the damage spread should also be considered. In this case, there was no departure prevention guard installed on the train affected. This factor is classified as a design deficiency, i.e., M2A. Although, official accident report goes even further to highlight that even if the departure prevention guard approved for the company would have been installed, it would still not have been effective. However, since the guard was not installed, this factor is not considered as a causal factor in this accident. Figure 4-6 provides an overview of the accident causal factors for this accident.

4.3.3.6 Crack in Bogey frame, Sanyo Shinkansen (2015)

On December 11, 2017, A Shinkansen owned by JR West, started from Hakata for Tokyo. Immediately after leaving the Hakata terminal, the crew noticed an offensive odor and noise from below the floor. But they operated the train to Shin-Osaka and handed over the responsibility to the crew of JR Central without mentioning the abnormal odor and noise. The vehicle operated further 100 KM, and finally, an oil-leak was found. The service was canceled, and later a crack in the side bogey frame was detected. The crack had penetrated deep into the depth of the frame and could have led to disastrous consequences. This accident was termed as the first “serious accident” in the history of Shinkansen.

The accident is analyzed from three perspectives. The first is related to stopping the train as soon as the abnormality was sensed. The second is related to the detection of crack during the vehicle inspection. The third perspective is linked with issues during manufacturing that led to the generation of cracks in the first place. The causal factors for each of these 3 perspectives are analyzed here.

The train driver, despite noticing the abnormal odor, sound, and vibration, did not reach the conclusion that the train should be stopped. The report identifies the following causal factors for the same. Firstly, the abnormality in the train was intermittent. Also, the driver did not have access to information from certain tangible sensors. The accident report demonstrates the possibility of making such information from various sensors already installed in the train. The absence of such sensors is thus classified as a lack of equipment, i.e., RA as per the ACAT classification. In addition, the abnormal conditions were not clearly defined in drivers, possibly leading to a situation where it was difficult for the driver to classify the situation as abnormal. This is classified as a failure in updating information, i.e., IS. The accident analysis report also highlights the long history of behavior where it became normal

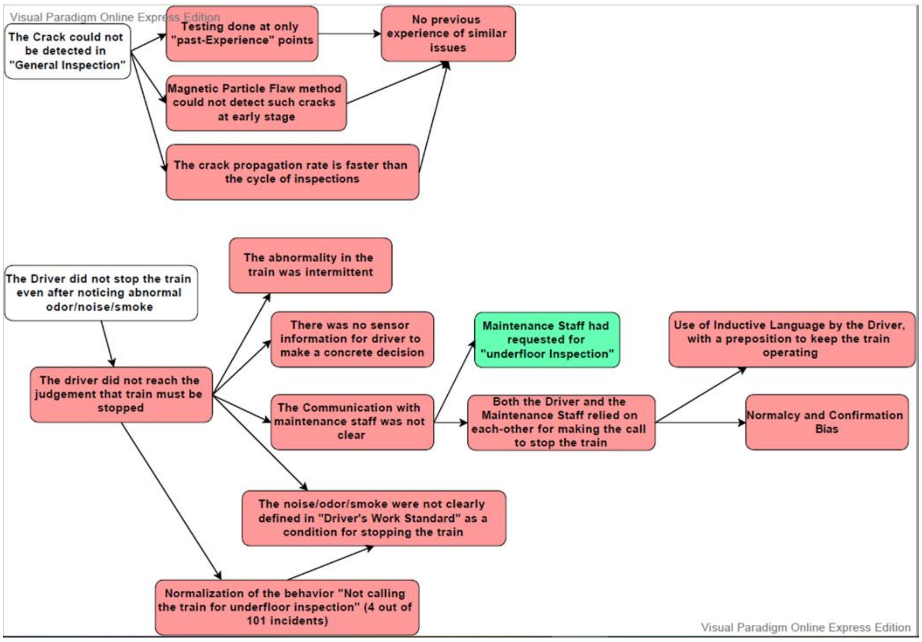


Figure 4-7 Causal factors, bogey frame crack, Sanyo Shinkansen (2017)- Part 1

to not call the train for inspection, even when such abnormalities are discussed. This issue is related to *ignoring the warning from previous accidents*, i.e., EA.

The accident analysis report also provides a detailed account of the communication between the train driver and the onboard employee of the rolling-stock maintenance division. From the communication, it was concluded that both the driver and the rolling-stock engineer had engaged in communication and had relied on each other to take safe action, but neither took the lead. This lack of communication is classified as a lack of effective communication, i.e., M1O. The accident analysis reports identify that the train driver may have suffered from normalcy bias and the confirmation bias. Such factors affected the driver's ability to sense information and are thus classified as M1S.

The report also provides a detailed description of the related inspection procedures that were adopted by the TOC. In this case, all the inspections were carried out as per the pre-approved inspection methods (by the regulator). In the report, it was found that the method, frequency, and the location was such that the crack could not have been detected. However, the above-mentioned parameters were not in violation of the pre-agreed inspection procedures. One of the prime reasons for this factor was that all the inspection parameters were determined based on "past" experiences, and there was no history of such incidents for this operator. Thus, this factor can be classified as a failure in establishing information, i.e., IC. The accident causal factors identified from the first two perspectives are shown in Figure 4-7.

Finally, a third perspective, i.e., the issues encountered during the manufacturing process of the bogey, is analyzed. The report highlights that the bottom plate of the bogey frame that is attached to the seat of the spring was excessively grinded (4.6mm instead of 8 mm). Further, excessive surface welding was also conducted, which resulted in micro-crack development and fast propagation. Further, the bogey had undergone the train running test and fatigue test but was found to be ok.

Similar to the inspection tests adopted by the operator, the train running test during the bogey handover from the manufacturer to the operator, was also inadequate in detecting the issues described above. The accident analysis report states that the same happened because the inspection procedures etc. were all based on "past" experience, and such a problem had not happened before. Thus, this factor can be classified as a failure in establishing information, i.e., IC.

Excessive welding had resulted because the workers at the site did not fully understand the risks of a large quantity of such welding. Thus, the information was not communicated or was well interpreted, leading to such failure, i.e., IO.

There were multiple causal factors that ultimately resulted in the excessive grinding of the bogey frame bottom plate. First, the supplier of the part had changed. The new supplier had used a part different in dimensional accuracy than the original part, that workers were used to working with. The change in supplier was not communicated to the shop-floor manager. Such lack of communication can be classified as a lack of communication within decision levels, i.e., M3O. Further, the shop-floor manager had given the order to grind without checking the dimensions of the parts that were supplied. It was partly because he was not aware of the change in supplier but also because of the failure in sensing real condition by the shop-floor manager, i.e., M1S. The training provided to workers in the past had also normalized the excessive cut as normal behavior, and thus, the workers also proceeded with grinding without realizing that the current situation could be different from the normal situation. This was a failure in updating the information as the part supplier had changed, i.e., IS. An overview of the causal factors involved from the third perspective is shown in Figure 4-8.

4.3.4 Analysis of ACAT Taxonomy Results

Summary for ACAT taxonomy for each accident in Japanese HSR is shown in Table 4-1. On the other hand, Table 4-2 summarizes the ACAT classification of accident causal factors from all the 6 cases analyzed in previous sections. In total, 31 causal factors were classified, including the 6 factors belonging to the rolling stock manufacturer company in the bogey frame crack accident of 2017.

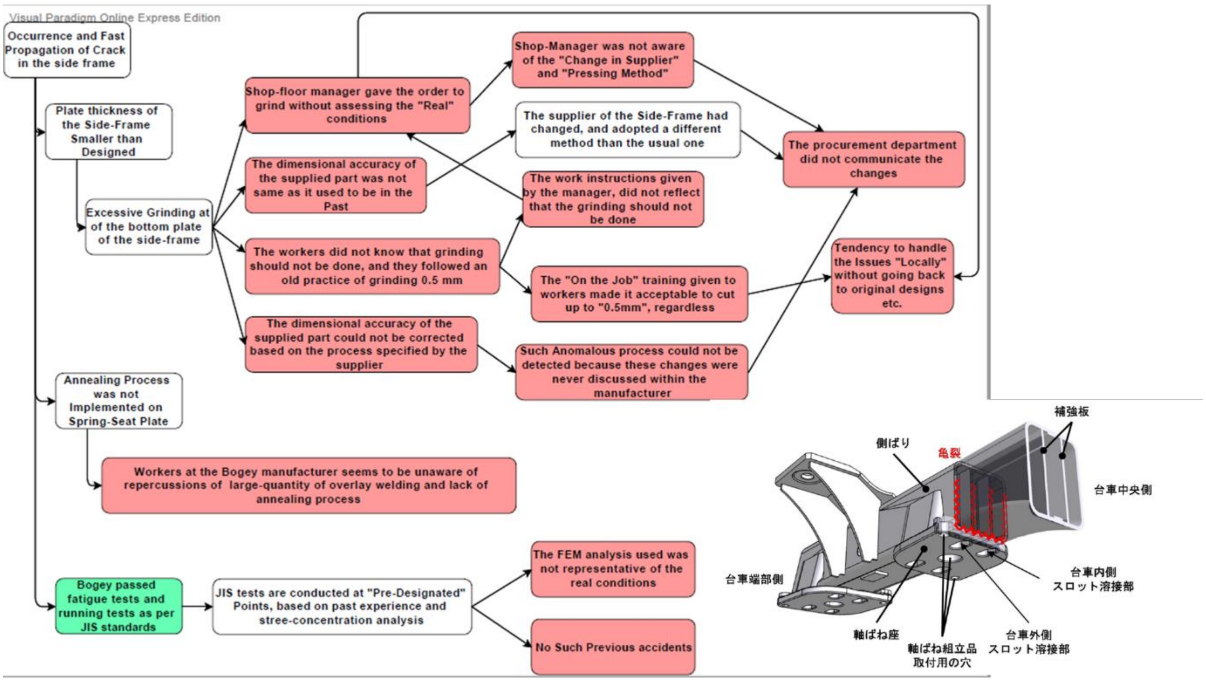


Figure 4-8 Causal factors, bogey frame crack, Sanyo Shinkansen (2017)- Part 2

Table 4-2 Summary of ACAT taxonomy for accidents in Japanese HSR

	Actuator	Sensor	Controller	Communication	**Total**
Man	1	2	0	2	5
Machine	6	0	0	0	6
Management	1	0	0	2	3
Information	4	3	4	1	12
Resource	3	0	0	0	3
Environment	1	0	0	1	2
Totals	25	9	5	7	31

Figure 4-9 provides an overview of relative contributions from different agents for accidents in Japanese HSR. Further, Figure 4-10 and 4-11 describe the contribution by *Information* and *Man*,

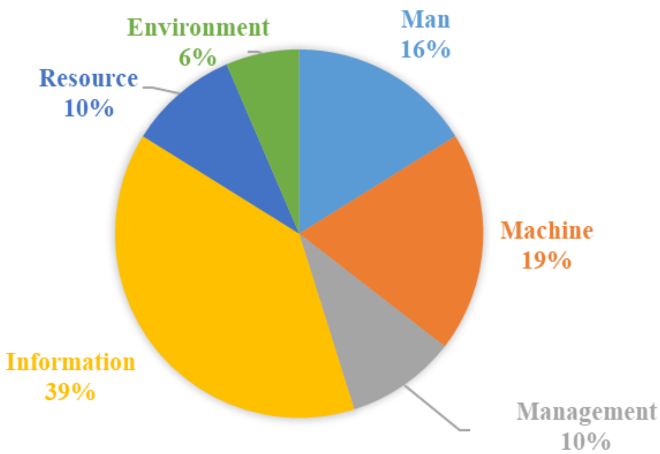


Figure 4-9 Failure-factor Chart (by agents)

Obtained from the ACAT analysis

respectively. The results of ACAT analysis provides many interesting insights into the safety management of Japanese HSR, which are summarized as follows.

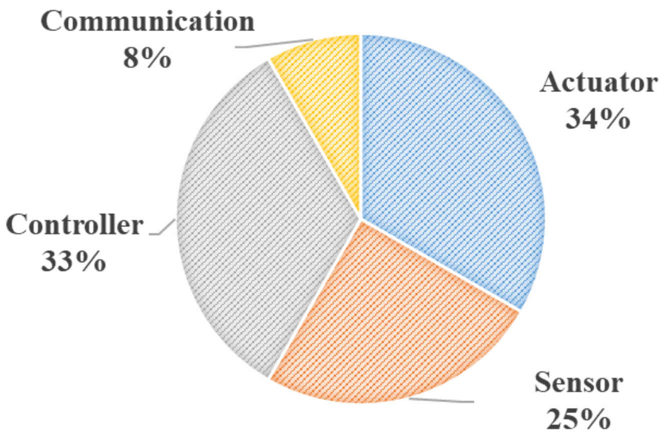


Figure 4-10 Causal factor classification (Information)

Obtained from ACAT analysis

First of all, despite having achieved remarkable progress on the technical front and even being claimed as perfect (KASAI, 2000), the **technical system of Japanese HSR does experience issues**. JR Kyushu's experience in the earthquake demonstrates that even the well-established technology of earthquake detection and braking was not sufficiently effective, and hence, technology adoption to new HSR projects must be carefully investigated.

The ACAT analysis reveals that **a majority of accident causal factors for Japanese HSR are not equipment failure or the human-error type**, which is in contrast with the popular view (Saito, 2002). Technical failure and human errors constitute about <40% of the total accident causes, while approximately 60% of accident causes are, in fact, related to organizational factors (such as poor decisions, issues in resource allocation, safety culture, etc.). In fact, a few machine-related failures will also have corresponding organizational factors, but the information on managerial decisions is often not included in official reports, and thus, it is not reflected in the data here.

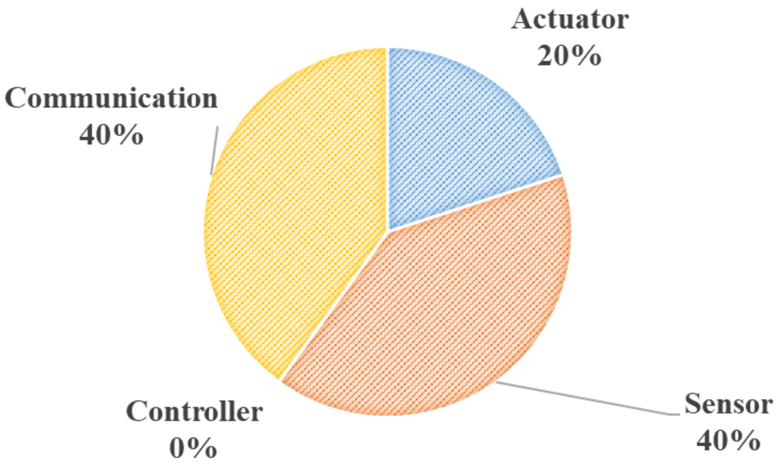


Figure 4-11 Causal factor classification (Human)

Obtained from ACAT analysis

Trends observed in the Information failure chart (Figure 4-10 and 4-11) also reveal some critical issues with the current safety management practice of Japanese Shinkansen operators, which are otherwise not highlighted in individual accident reports. Some common accident causes include the **failure to sense degradation in Information** (procedures, programs, methods, or knowledge), **failures in confirming the applicability of Information to the situation**, and **failures to establish Information based on thorough risk assessments**.

For the two accidents experienced by JR West, important contributing factors show how procedures being followed at the workshop level had gradually omitted some important aspects of the process, allowing individual judgments to jeopardize the safety of the overall process. For example, the visual inspection method to confirm the looseness of the bolt "as practiced" did not specify any methods or actions to check the bolt looseness, whereas the method "as approved" had done so. Hence, the method adopted differed from each individual and could have contributed towards the non-detection of loosely fastened bolts. The mechanisms of such information degradation should be studied further, and their implications should be considered in the reports.

The other contributing factors to the two accidents experienced by JR West highlights that the applicability of the Information to the situation was not confirmed. For example, various inspection tests meant for assuring quality, such as visual inspection tests for detecting hand-tightened bolts, or the rolling stock running tests after temporary installation, were not a true representation of real operational conditions, and hence their efficacy is cast in doubt. However, the report does not suggest improvements to these standards.

An example from JR Kyushu reveals how some HSR operators (or relevant stakeholders) did not consider risks adequately. The accident report states that JR Kyushu's internal standard to install derailment prevention rails (after the 2004 earthquake) did not consider derailment risk sufficiently despite being located very close to an active fault line. Similar arguments were made in an accident where a fire occurred in the train compartment. Staff operators were deemed not to have sufficiently considered passenger behavior in their response planning. The investigation does not examine the reasons why such risks were not accounted for or how they should be incorporated into system development and system evolution.

4.3.5 Limitations of ACAT

The results of the qualitative analysis described above must be checked for researcher bias and subjectivity from relying on translation software. The detailed process of how the reliability of the developed taxonomy was increased is shown in Figure 4-1. Person 1 generated the causal tree maps, which were useful in summarizing the complex, unstructured, and lengthy documents to be presented and checked by Person 2. The clarifications sought from Person 2, a communication expert with native Japanese language ability, allowed authors to reconfirm the interpretations for some of the causal factors through reference to the original Japanese text.

Further, to ensure consistency in developing the ACAT taxonomy, Person 2 was asked to critically evaluate and score the 1st version of the taxonomy prepared by the author 1 (while using the verified causal tree for each accident). Person 2 assigned a score of 0 for full disagreement; 0.5 for partial agreement; and 1 for full agreement for each of the taxonomical classification generated by the Person 1, along with additional comments explaining the rationale behind scores of 0 or 0.5 to any specific factor. The average of the scores assigned by Person 2, for all causal factors, is 0.89, showing a high degree of agreement between the accident taxonomies generated by two persons independently. Such a high score ensures confidence in the results of the qualitative analysis performed in this study as well as the generalizability of applying ACAT taxonomy to a complex system such as HSR.

A limitation of the ACAT classifications is their reliance on the quality of information obtained. Obtaining more details around a factor can alter classifications. For example, in a plate falling accident of 2015, the visual inspection method to test hand-tightened bolts during routine checkups was found to be ineffective in detecting loose bolts. As per the original ACAT classification, this could well be a case of Inadequate Information, thus classified as an information-actuator problem. However, if additional information were to be found about the history of the development of these inspection methods, the same factor could also be classified as an information-sensor issue. Therefore, if this technique would be applied to a large dataset using algorithm-based classifications, caution must be warranted about the data quality.

The second limitation refers to the interpretation of the agents themselves. The authors observed difficulties in justifying Information, Resource, and Environment as agents in their strict sense. For example, failing to establish Information is termed as an Information-Controller failure as per the original ACAT classification; however, the authors often obtained information that such failures were, in fact, due to Management decisions. Such difficulties then lead to a problem of identifying unique classifications for individual factors, and further discussions with multiple analysts will undoubtedly strengthen the classifications.

While the issue of reliability of the ACAT classification itself can be partly resolved through independent assessments from multiple analysts, the overall validity of the output is nevertheless dependent upon the quality of the input. The issue of analysis reliability and output validity has been discussed in detail in (Underwood and Waterson, 2014). The results from ACAT can only offer limited lessons by utilizing official accident reports, as the reports themselves do not contain information about management decisions or institutional factors. However, in this study, the validity of the analysis does not undermine the necessity of further emphasizing the organizational and institutional factors affecting *Shinkansen* safety, as obtained through the ACAT analysis. The results of the ACAT analysis in its current form support the argument that organizational and institutional level factors are prominent in affecting the safety of Japanese HSR. The authors expect that with additional information about organizational and institutional level decision-making, many of the current technical factors will have more *Management* and *Information* related causal factors, thereby further increasing their proportion in overall causal factors, and further supporting the key conclusion of the ACAT analysis.

Although the ACAT analysis results are based on a limited number of accident cases, the results are comprehensive as the cases are not a sample per se, but are in fact, an exhaustive analysis of publicly available information of reasonable quality on authentic accident cases. The general conclusion of the ACAT analysis is also supported by a detailed examination of specific cases, where organizational and institutional factors are highlighted from official reports that have primarily summarized only technical factors, e.g., JR Kyushu Derailment.

4.3.6 Comparison of ACAT method with models as practices by Japanese HSR TOCs

While ACAT has been shown to be an effective accident taxonomy for its application in multiple-Japanese HSR accidents, a comparison should also be made with the prevalent practices of the accident investigation/classification. Table 4-3 summarizes the comparison between the ACAT model, and the current methods of accident analysis used by the Japanese TOCs, such as the “m-shell” model and the 4M4E model. Like m-shell and 4M4E models, ACAT is also an event-chain model. However, ACAT adopts the structure of system-control theory and thus provides a meaningful way for the organizations to be integrated with their current accident-analysis and gradually moves towards full-scale systemic interactions analysis. The comparison, as presented in Table 4-3, is useful in highlighting the advantages of using the ACAT method in the context of Japanese HSR.

Table 4-3 Comparison of ACAT method and the current Japanese accident models

	m-shell	**4M4E**	**ACAT**
Type of model	Event-chain		
Type of Agents	Man, Machine, Management, Information, Environment	Man, Machine, Management, Media	Man, Machine, Management, Information, Resources, Environment
Interactions between Agents	Yes (no structure)	No	No
Functional responsibility of Agents	No	No	Yes
Hierarchy among Agents	Only for a few types	No	Partial

4.3.6.1 ACAT vs. m-shell

There are numerous commonalities between the two models. Both are event-chain models, have common agents, and focus on analyzing the interactions among various agents. However, there are various important differences which are shown to be crucial for the context of safety in Japanese HSR.

First, the factors related to the adequateness of resources has been identified as a separate and important agent in ACAT model. Resource allocation is an important issue that can undermine the safety performance of a system and is considered as an important responsibility of the management. In addition, management has other important responsibilities, such as monitoring organizational failure, manage change, and facilitate coordination. In this regard, the separation of resources from that of other management functions increases the importance of both the resource-related issues as well as the other safety management related management responsibilities. A focus on only the safety management activities without allocating proportionate resources for the same would also undermine the safety risk reduction. For example, even in Japanese HSR, where safety-related investments are among the top priorities of the TOCs, equipment helping in rescue operations was not allocated in sufficient quantities, and it affected the response time of the crew members in 2015 JR Central fire accident.

There are important differences in the two-models with respect to another agent, i.e., Environment. The m-shell model considers both the conditions of the environment within the organization, such as worker overload and outside the organization, such as external weather and technical factors, etc. Whereas the focus of the environment in the ACAT model is on factors within the organization. The difference lies between the perspectives adopted for the accident analysis. In the "m-shell" model, the focus is to analyze the effect of the external factors on human errors, while in the ACAT models, the focus is on identifying organizational traits related to safety culture and communication culture within the organization. In this regard, the perceptive of m-shell can be assumed as a subset of the broader perspective adopted by the ACAT model. Hence, the ACAT model could serve an important accident analysis model for focusing on organizational factors for Japanese HSR TOCs.

Another important difference between the two models comes from their consideration of interaction among and within various agents. The ACAT model adopts a structure that is helpful in analyzing the problems related to the interactions within an agent in a more objective manner. For example, coordination within the management group, which was found to be an important factor for the 2015 JR West plate falling accident as well as for the 2017 JR West bogey frame crack accident, could be considered because of the taxonomical structure proposed by the ACAT model. In the m-shell model, such an intra-agent interaction is considered only for the human agents. On the other hand, the m-shell model is more comprehensive for consideration of intra-agent interactions, at least with respect to the human-factors when compared to the ACAT model. However, the interactions considered in the m-shell model are not considered in a systematic and structured manner; for example, the interactions between software and hardware and their impact on human errors are not considered in the m-shell model. In this regard, the basic control-feedback structure, as adopted by the ACAT model, could easily be extended to provide a structure for intra-agent interactions. Depending upon the position that various agents acquire in a control-feedback loop, the ACAT model can then be further modified for considering the interactions highlighted above.

However, both m-shell and ACAT models have a common limitation, i.e., they give limited attention to consider the full hierarchical structure and their interactions to identify accident causal factors. In the m-shell model, only management as an agent is considered above all other agents. For the ACAT model, the full hierarchical structure is not considered. In this regard, for further detailed analysis considering the full systemic view, both the models are found to be unsuitable. However, the control-feedback structure model adopted by the ACAT model makes it easier to be extended for the full hierarchical structure for any HSR organization.

4.3.6.2 ACAT vs. 4M4E model

A comparison of both of these models is also presented in the original paper delineating the ACAT model (Li, Zhang, and Liang, 2017). It was reported that the ACAT model was superior to the 4M model for its generality, communicability, integration, consistency, failure taxonomy, and completeness, while the 4M model was found to be simpler when compared with the ACAT model.

A few of these issues are discussed here once again, with specific examples from the analysis of HSR accidents. Both of these models are event-chain models. In the 4M4E model, the environment is not considered as an accident agent explicitly but is combined in a broader perspective, i.e., Media. Although both the models have similarities in their interpretation of Environment, as they both refer to the environment internal to the system or organization. Similarly, resources do not receive explicit mention in the 4M4E model as compared to the ACAT model.

One of the biggest differences between the two models is related to their consideration for the interactions among various agents. In the 4M4E model, the interactions between the agents are not considered; consequently, there is no hierarchy among the various agents. However, the ACAT model considers a detailed structure for considering interaction within an agent level and if-needed can be extended to the consider the interactions between the agents

4.3.7 Summary of ACAT analysis

In this section, an accident taxonomy was generated using the ACAT taxonomy from 6 reported accidents in Japanese HSR. The official accident analysis reports were used as a primary data source.

ACAT taxonomy adopts a method based on the principles of system-control theory and is proven to provide an important structure for accident classification. The taxonomical classification generated by this method was found to be highly consistent against the personal biases of an individual analyst.

ACAT analysis is not a perfect method and has its own limitations. For example, the analysis results are dependent upon the quality of the information input. In Japan, all the accident investigation reports do not follow a structure for fact collection, etc. Thus, in the absence or presence of additional information, it is likely that the classification provided by the ACAT taxonomy may change.

However, when compared to existing accident analysis models adopted by the Japanese industry (such as m-shell model or the 4M4E model), ACAT was found to be superior in many aspects such as an explicit focus on a number of agents such as resources, environment, and information, etc. Further, the control-feedback structure adopted by the ACAT method helps in analyzing the intra-agent functional interactions and is found to be useful for accident cases in Japanese HSR. In other aspects, the ACAT method is found to be inferior compared to the “m-shell” model, e.g., for inter-agent interactions. However, the control-feedback structure adopted by the ACAT method can easily be extended to consider such interactions.

The results obtained from the simultaneous analysis of multiple accidents reveal several interesting trends for organizational factors that are not observed in an individual accident report. First, despite having achieved remarkable progress on the technical front, the technical system of Japanese HSR does experience issues. Further, the ACAT analysis reveals that a majority of accident causal factors for Japanese HSR are not equipment failure or the human-error type, which is in contrast with the popular view (Saito, 2002).

Further, the results from ACAT analysis reveal that the most prominent accident causes are indeed related to the practices of RM at the organizational and institutional levels. Factors such as failures in confirming the applicability of Information to the situation, and failures to establish Information based on thorough risk assessments, hints the gaps in the RM at the organizational and institutional level in Japanese HSR. Further, another prominent common accident cause is related to the failure to sense degradation in Information (procedures, programs, methods, or knowledge), hinting the presence of the issues in the safety assurance and reporting behavior of the employees, which needs to be examined further. The results obtained from ACAT analysis, thus provides conclusive evidence of the issues at the organizational and institutional factors in the Japanese HSR, as highlighted through the integrated framework adopted in this study (Figure 1-8).

4.4. Comparative analysis for RM practice in Japanese HSR vs. system-safety theory

The results from the ACAT analysis, confirm the possibility of the issues in current RM related practices of the Japanese HSR operators at the organizational and institutional level. In this section, a comparative analysis of the state-of-the-art safety theory for complex systems, as well as the current practices in the Japanese HSR system, is provided. Table 4-4 provides an overview of the factors considered in both the safety theory as well as the corresponding practice in the Japanese HSR operators. A detailed analysis is presented for accident models and the RM practices at the organizational and institutional levels.

Table 4-4 Status of Safety Management System across HSR TOCs in Japan

Factor	***System Safety Theory***	***JR Central***	***JR East***	***JR West***	***JR Kyushu***
System-Goals	Priority to safety Non-conflicting goals	Safety is assigned as first priority			Business promotion with HSR as basis
Business Overview		Moderate growth for passenger revenues, an aging workforce, expected financial constraint from increasing maintenance burden			
Role of top management	Process safety is centrally controlled	Visible commitment from top management		--	Visible commitment from top management
Accident Analysis	Control-System engineering-based models for complex system	Event-chain models			
Hazard Analysis	A systematic and comprehensive approach	Simple and rather unsystematic procedure for hazard analysis			
Risk Assessment	Qualitative targets	Qualitative targets			
Safety Assurance	Synchronous evolution, Leading indicators	Partial Consideration			
Safety Training	-	Extensive focus on OJT, individual and group training			
Safety Communication	-	Information inconclusive to assess the effectiveness of communication practices.			

4.4.1 Comparison of the accident models

All Japanese HSR operators currently use event-chain accident models, which describe the accidents as a sequence of events. Accident prevention can be done when if any of the events in the sequence can be stopped from happening. Further, the event chain models see accidents arising due to failures in several defenses. These defenses are not only at the technical and human level but also considered at the organizational level.

On the other hand, system-control engineering-based accident models see the accident as a control problem, where the accident happens because of loss in control. In these models, the control loss happens because of the dysfunctional interactions between several components. Component failure is one of the several causes of dysfunctional interactions, but often the accidents occur because of poor information coordination between various system components.

While both methods have been prescribed to be useful for their applications at the organizational and institutional levels, there are several important gaps between the two. While the academic literature has also discussed the difference between the two approaches, in this study, the key differences between the two for their applicability at the organizational and institutional level are considered using the examples of the accidents in the Japanese railway (not necessarily HSR).

4.4.1.1 *Kagoshima main line accident on 22 February 2002*

Railway accidents often involve cases where certain parts of the physical or human systems did not function as they should have done, leading to accidents. It is rather rare to obtain an example in the railway industry, where the accidents occurred even when there was no failure in the functioning of the components per se. One such example is the Kagoshima main line accident on 22 February 2002, where a speeding train had collided with a stationary train. Figure 4-12 shows the schematic of the accidents obtained from (Sato, 2002). The accident happened at a curve, where a repeater signal was placed (block B). A repeater signal is a signal that repeats the status of the signal status of the fixed block ahead of the signal (in this case, the repeater signal placed in block B shows the condition of the block A). In this accident, the driver of the front-train had applied brakes after the train had passed the position of the repeater signal but had still not entered the fixed block ahead (block A). The driver had applied brakes because he had heard a loud voice coming from the rear end of the train and had topped to check the condition of the train as per the standard operating procedures of the company. Because of the stopping position of the front train, the repeater signal has shown a green aspect, correctly as there was no train the fixed-block A ahead.

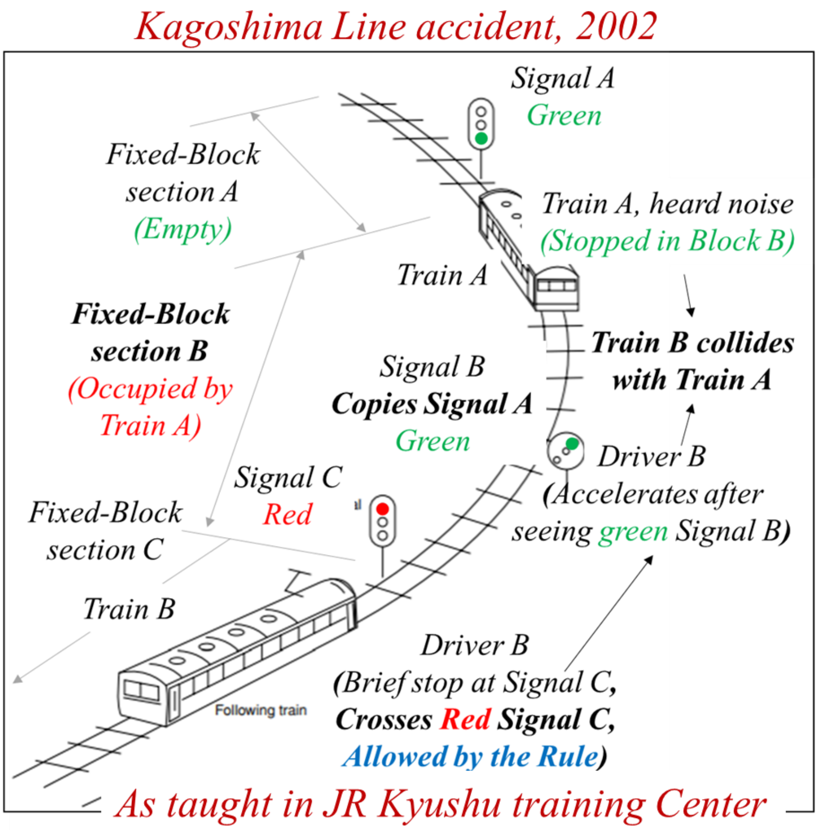


Figure 4-12 Train collision on the Kagoshima Mainline

Adapted from (Sato, 2002)

Further, the train signal at for the rear train (at the boundary of block C and B) had correctly shown "Red," as the front train had stopped in Block section B. Indeed, the rear train had stopped at the red signal between B & C, for 1 minute, and then had proceeded ahead with certain speed restrictions (as part of standard operating procedure of the company). When the driver of the rear train, noticed the green aspect of the repeater signal, he then sped up the train (again as per the standard operating procedures of the company), only to discover the stopped train ahead. Even though brakes were applied, it was impossible for the train to stop in time, and hence, the rear train collided with the train in front.

4.4.2 Limitations of the event-chain models

One of the main arguments explaining accidents for the event-chain models is that events occur due to failure in components, e.g., technical failure or human errors. However, in the case of the Kagoshima main line accident described above, none of the components failed, and they all performed as they were either designed or instructed to do. For example, the signals displayed aspects exactly as they were designed to do. Even the act of moving ahead at the red signal by the driver of the rear train, was part of the standard operating procedures of the company, whereas it is well known that the Signals Passed at Danger are one of the leading causes of train-related accidents around the world. Clearly, the conventional notion of event-chain leading to the accidents cannot explain the accidents described here. Despite the obvious limitations, the TOC, in this case, continued to treat this accident as an event-chain model and had come up with solutions catering to each of the events in the causal chain.

During a field trip to the respective TOC, I had an opportunity to discuss the case with the safety experts in the respective TOCs. The proposed countermeasure for this accident was all addressed to stopping the specific events in the accident causal chain from happening. One of the proposed solutions after this accident was a revision in the operating procedures for the drivers about the decision to move ahead at the red signal. Instead of one operator making the decision, the rule was revised for the two operators on the same train to decide whether to move ahead at the red signal.

Another limitation of the event-chain models is their ability to consider the effect of systemic factors, and interactions among various components (Center, 2006). Systemic factors refer to the factors that could affect multiple components simultaneously, whereas the interactions refer to the changes in one part of the system affecting the functioning of the other parts (Stringfellow, 2010). However, in this case, none of the safety experts were worried about the fact that such a rule of crossing a red-signal is acceptable, where the signals passing at danger are clearly dangerous and are in contradiction of the fundamental principles of the fixed-block signaling system. This rule clearly had a major role to paly in this accident.

Upon further inquiry during the field visit, I found that such a rule was made to control the delays of the trains and was made during the pre-privatization days of JNR. It is a well-known fact that several lines had become crowded and reaching near capacity during the JNR days (Hancock, 2015), and indeed the reduction in the waiting time at the red signal will lead to higher capacity utilization of the tracks using the fixed-block system and thus reduce the delays in the preceding trains. Here, the changes made to accommodate delays had introduced a rule that is clearly shown to faulty.

However, not all the sections of the JNR lines had faced similar issues; nevertheless, a standardized rule was developed to be followed across the JNR. Further, the same rule was never revised, or its suitability reconsidered, even after the railway privatization. The safety experts interviewed during the file visit agreed, that in their understanding, such a rule was not necessary for their operations, as the Kagoshima line was not heavily used. Nevertheless, the rule was never considered for revision. Clearly, several contextual factors had interacted in this case, leading to inadequate formation of rule, and not being revised under changing context.

Form the example described above, it is clear that several factors had interacted with each other in this accident, and such factors are rarely considered in the event-chain models (Center, 2006). On the other hand, the control-system based safety theory can be adequately applied. From the STAMP's perspective, there were several occasions of asynchronous evolution at the organizational level contributing to the accidents. First, in order to minimize the effect of delays, the procedure had systematically allowed violating a fundamental safety constraint of not passing the red signal. Such an operating procedure seems to have been developed from the perspective of delay-management alone, and its effect on safety may not have been examined thoroughly. A more systemic solution of the same problem would have been to revise the block-length or shift to a moving-block system, which allows the safety constraint to be maintained while solving the problem of the delay. Nevertheless, any such systemic solution would have been costly, as it is not easy to change the signaling system in a railway context.

Second, even when the management had changed during privatization, such existing procedures and knowledge were not thoroughly examined. The operating conditions for each of the newly privatized entities could have been significantly different from their parent company. In this context, the new operating context should have been examined thoroughly by each of the new operators. However, such was not the case, thus leading to practice, being prevalent, even when it was not necessary.

Another solution proposed after the accident involved removing the repeater signals from everywhere. Such removal surely allows the train operators to operate under speed restrictions, and potentially contribute to eliminating the accident risk, however, as long as the rule to pass the signals in red exist, the system is vulnerable to failure in situations where the operator is not able to control the speed adequately.

From the example described above, it is evident that in the railway system, an accident can happen due to the dysfunctional interactions between system components, and the event-chain models have limited applicability in examining such dysfunctional interactions.

In addition, the event-chain accident models were found to inadequate for their application at the organizational and institutional levels for several other reasons. Often, analysis of underlying accident causal factors at the organizational and institutional level in these cases can then be subjective to the analysts, especially when analyzed with various event-chain models. For example, the 2004 Amagasaki accident in Japan has been analyzed by several authors, each of them highlighting the different causal factors at the organizational level. While the official accident report has provided information on the practice of punitive actions, creating a negative safety culture within the organization (Atsuji, 2016), other analysts have gone ahead to attribute the cultural competition between the Japanese people in western and the eastern part of Japan as one of the contributing factors to the accident (Niwa, 2009). The example highlights the lack of a systematic structure to objectively identify the multiple-accident causal factors, especially at the organizational and institutional levels, when the event-chain accident models are used. On the other hand, the development of the SCS in STAMP allows the analyst to systematically analyze the accidents at the organizational and institutional levels.

Further, the event-chain models offer only limited objective recommendations when the information is not sufficient (as demonstrated in the ACAT analysis), while the systematic structure developed in STAMP prompts the analyst to often seek more information to base their recommendations, thus keeping the accident analysis as objective and blame-free as possible (Underwood and Waterson, 2014).

In addition to the observations made in this study, many other academic studies have examined the applicability of the event-chain models for analysis in complex socio-technical systems. Stringfellow (2010) demonstrates that the event-chain models assume independence of failure-event in multiple defenses and thus do not identify the systemic factors that push the entire system into a high-risk state. As an example, the reactor meltdown of the Fukushima Dai-ichi nuclear reactor after the 2011 Great East Japan Earthquake can be considered. In this nuclear reactor, multiple defenses against the meltdown existed. However, the percolation of the tsunami water in the plant rendered multiple defenses in-effective simultaneously. The effect of such systemic factors is not considered in the conventional event-chain models, and hence they are deemed unsuitable for application in the complex systems such as the HSR.

4.4.3 Comparison of the Risk-Management practices at the Organizational level

A number of risk-management strategies discussed in previous chapters, including the Japanese practices, rely on the estimation of the failure frequency for adequate risk management. The safety theory suggests that the event frequency-based failure probability estimation has a few drawbacks. First, with the advent of technology, the electro-mechanical components do not fail as often, making it difficult to get a reliable estimate of the failure probability at the physical subsystem. Further, the operational environment of the technology may differ significantly from that of the conditions assumed during the product testing; thus, the real failure rates are significantly different from what is anticipated from the lab-tests (Leveson, 2004). Further, Stringfellow(2010) had discussed the limitations in estimating the failure frequency at the human, organizational, and institutional levels. The complex interactions affecting the safety, are impossible to assign a failure probability value. The state-of-the-art accident theory, thus calls for a more qualitative approach to accidents, introducing the concept of vulnerability for all types of system components. Vulnerability is defined as the possibility that a component/system will fail in its given lifetime. Answer to vulnerability thus is whether it is yes or a no (Leveson, 2015). Thus, a more pessimistic view on safety is assumed, and focus has been on developing accident models which can comprehensively consider a wide-range of factors.

Another important dimension in conventional risk-management practices is related to the estimation of the associated impact of a given hazard. As per Leveson (2004), estimation of impact on losses from a hazard is also highly erroneous. The impact of a hazard also depends on certain environmental or external factors. For example, in the Bhopal gas leak, the damage was much worse because of the wind condition on that day. For the 2004 Japanese HSR derailment in the earthquake, the train had overturned, and there was a possibility that it could hit the trains coming from the opposite direction. Hence, a hazard classification considering the extent of damage should also be calculated carefully. In this regard, the Japanese approach of RM at the organizational level is different from conventional RM approaches. In Japan, importance is provided to those components or subsystems that are safety-critical. For example, in HSR, any problem in the ATC system has to be dealt with immediately, as it does pose immediate safety threats, whereas the error in the centralized control system is given relatively less priority, as the system is not safety-critical. Such an approach can be considered in synergetic with the principles described by the system safety approach for the complex system.

4.4.4 Comparison of the Risk-Management practices at the institutional level

Table 4-5, gives an overview of the current RM practices at the institutional level in Japan, compared to the requirements identified in (Ota, 2008). The summary of the Japanese approach is developed based on the information described in section 3.6.

Table 4-5 Comparison of the Japanese approach with respect to requirements for the Complex system

Risk assessment requirements for Maglev Systems		*IEC 62278*	*Japanese Approach*	*STAMP*
6.	Hazard analysis must emphasize Qualitative analyses over Quantitative (Ericson, 2015)	✓	✓	✓
7.	Deductive analysis (*How can*) over Inductive analysis (*what if*)	-	✓*	✓
8.	Ability to identify future hazards resulting from asynchronous evolution	✓*	✓*	✓
9.	Ability to consider human errors	✓*	✓*	✓
10.	Focus on the severity of accidents, rather than probability	✗	✓	✓

✓- Strictly true, ✗ - Strictly not-true, ✓* - Partially true, - - NA

The approved model specifications and the ministerial ordinance are based on the performance criteria, where the focus is on qualitative and in-depth hazard analysis considering multiple perspectives rather than any quantitative methods. A similar observation was also made by (Ota 2008). As discussed in section 4.4.2, safety theory for complex systems also vouches for utilizing a qualitative approach rather than the quantitative methods.

Further, the Japanese approach does not adopt a reliability-based approach where the focus is on identifying the failure probability of an event and then determine its potential impact (inductive approach). Instead, the Japanese model specifications provide guidance on some potential events to avoid and then emphasize the factors that could result in such potential events. An example model specification is helpful in illustrating the point described above.

Article 14 of the ministerial ordinance describes that the *Radius of curvature shall be set in order not to impair safe car operations, taking the performance capability of negotiating a curve, the* *operation speed, and other relevant factors into consideration* (Railway Bureau, 2001). Further, the approved model specification describes the situations in which could affect the radius of curvature, e.g., a rolling stock with the capacity to negotiate the sharp curves or a critical ratio of the lateral and vertical wheel ratio. However, such deductive descriptions are not available for all subsystems, and the current Japanese approach does not provide recommendations about any systematic approach to considering such risks comprehensively. A limitation of the deductive reasoning related to consideration of human-factors was also highlighted in section 3.6. In Japanese HSR RM practices, there is an acute focus on considering the bottom-up interactions, but not top-down interactions, such as the effect of organizational decisions on the human and technical factors.

Like IEC 62278, the Japanese model specifications also highlight the necessity of the risk-analysis when the part of the system is changed. For example, reapproval is necessary for any minor or major changes in specifications or design while developing a new rolling stock; however, like IEC 62278, the Japanese model specifications also do not provide any systematic approach to assess the full impact of system changes in all other parts. Although such a principle has been long recognized by the HSR TOCs in Japan, such full integration is often based on past experience and not on a systematic risk-assessment. Further, because of the utilization of the event-chain models, the interactions among various system components are not adequately considered, hence, making it difficult to analyze future hazards. On the other hand, the STAMP based safety theory is often useful in future risk-assessment.

While the issue of Human-factors receives an explicit mention in the Japanese approved model specifications, it is limited to the specification of training programs and aptitude assessment for the associated humans. Emphasis is also given on ergonomic designs of the technology. However, a detailed assessment of potential stressors during the train operations and their full interactions with various organizational factors, etc. are not fully considered. Further, as the case of Kagoshima's mainline accident suggested, that the accident, which could not be explained using the conventional event-chain models were still being taught as such. Through the use of such event-chain models, the organizational factors could systematically be masked from the organizational knowledge.

4.4.5 Results of the comparative analysis

In this section, a comparison between the current RM practices at the organizational and institutional level in Japanese HSR and the state-of-the-art system-safety theory-based RM practices is made. While the ACAT analysis in the previous section was helpful in identifying potential limitations about RM practices in Japan, the comparative study of this section was instrumental in identifying specific limitations in the RM practices in Japanese HSR.

The comparison first revealed that the HSR TOCs in Japan, still rely on rather obsolete accident models based on event-chain principles. Event-chain models see the accident as a sequence of events resulting from the failure of the existing defense system. However, such event-chain models cannot describe the accidents where there is no component failure, and all systems worked exactly they were designed to perform. The Kagoshima railway accident of 2002 is an example where the accident happened not because of any component failure but rather due to the underlying systemic factors, which led to an asynchronous evolution of the system leading to accidents. Such accidents can then only be explained by the system safety theory-based accident models such as the STAMP. Over the years, the railway system has become complex, while the technology is getting more and more reliable. Under such a context, railways are now prone to such systemic accidents (e.g., Amagasaki accident in Japan (Ota, 2008), HSR accident in China (Dong, 2012)), which cannot be explained using the event-chain models popular in the industry. Such systemic accidents are now likely to happen in the Japanese HSR, and hence, there is a necessity of improving the understanding among Japanese HSR TOCs on how accidents occur.

Another important dimension that the System-safety theory-based accident models consider is the possibility of systemic factors rendering multiple defenses ineffective simultaneously. In the conventional event-chain models, the failures in multiple defenses are considered independent of each other. However, the review of the cases in Japanese HSR and the Kagoshima Main Railway Line provides evidence that the systemic factors can have important implications for accidents in complex systems. For example, in 2015, passenger fire accident in JR Central, the behavior of the passengers (accumulating near the auto-door at the end of the car), not only allowed the smoke to spread but also contributed to a slower response from the crew. Thus, one common factor affected multiple defenses simultaneously. In complex systems, such interactions must be considered systematically, and hence, there is a further necessity for the HSR operators to move beyond the conventional event-chain models, and use system-theory based models such as the STAMP.

In addition, the comparison provided in this section revealed the limitation of the event-chain accident models in objectively analyzing causal factors at the organizational and institutional levels. While the accident models utilized by the Japanese HSR TOCs such as the 4M4E and the m-shell models emphasize on analyzing the accidents from multiple perspectives so as to identify organizational factors contributing to safety. The analysis presented in this section reveals the potential subjectivity in such analysis, as none of the event-chain models provide a systematic structure to analyze the interactions at the organizational and institutional levels. In the absence of a systematic accident model, information about such potential causal factors at organizational and institutional factors is not collected even in the official accident reports (as highlighted in the limitations of the ACAT analysis) and could lead to masking of such factors from further consideration. The subjectivity in the analysis can often lead to the issue of attributing blame without giving due consideration to the contextual factors that governed the interactions among the system components, a situation that is described to be harmful to achieving the goals of system-safety (Leveson, 2004).

On the other hand, the comparative analysis was also useful in highlighting several positive aspects of the Japanese RM practices at the organizational and institutional levels. In Japan, the emphasis is on qualitative risk assessment methods as opposed to quantitative risk assessment methods prevalent in the HSR industry around the world (Rao and Tsai, 2007). The system-safety theory highlights several limitations in the quantitative estimation of both the probability of accidents occurring as well as their impacts. Hence, the decision-making based on quantitative estimates can often mask the vulnerability and the potential severity of the accidents in a complex system, leading to poor resource prioritization. In Japan, there is an acute focus on system-integration both at the organizational and at the institutional level, leading to the realization of the important difference between reliability and safety. However, the qualitative methods prescribed by the system-safety theory often require more comprehensive documentation about system-level details, hazards, etc., whereas in Japan, such details are often found to be vague and incomplete (Ota, 2008). In this regard, the system-theory based systematic risk assessment methods could be of good help. The overall merits and the demerits of the current RM approaches in Japanese HSR will then be useful in deriving implications for improving the RM practices of the Japanese HSR.

4.4.6 Summary

In summary, the current RM practices in Japan at the organizational and institutional levels are very comprehensive and have adopted principles that are suitable for managing the safety of the complex system that an HSR is. However, in the current Japanese system, the principles adopted are not always supported by adequate tools necessary to analyze the complexity of the HSR system, especially at the organizational and institutional levels. Given the limitation of the prevalent event-chain models in systematically analyzing various organizational and institutional factors affecting safety, the next section presents the analysis of a recent accident in Japanese HSR, using the system-safety theory-based method, called STAMP. Such an analysis is helpful in further identifying challenges and their solutions in the current RM related practices in Japanese HSR at the organizational and institutional level.

4.5. STAMP Analysis

In the previous section, simultaneous analysis of multiple accidents was performed, which revealed important trends in organizational factors prevalent in Japanese HSR TOCs. However, there are important limitations in the ACAT method, such as lack of consideration of the full hierarchical safety structure as well as extreme reliance on the accident report; hence, detailed accident investigation using the STAMP, a state-of-the-art accident analysis method for a complex system is adopted. The accident analysis method using STAMP is known as CAST, and the description of the steps involved is shown in Table 2-1. In this thesis, CAST analysis is conducted for the only "serious accident" in the history of Japanese HSR, i.e., the 2017 crack in bogey frame accident. The detailed accident analysis is discussed in subsequent sections.

4.5.1 Background of the Accident

On December 11, 2017, a bogey crack was detected on an N700 series Shinkansen owned by JR West. The crack was located on the side frame and was 146 cm deep, which could easily have resulted in a fatal accident. The accident investigation revealed that the crack originated from a welded joint connecting the side frame and spring seat. The physical cause of the crack initiation and rapid propagation was due to the insufficient thickness of the welded plate (4.6 mm as opposed to the design thickness of 8 mm) and the absence of an annealing process, a necessary means to releasing additional thermal stress generated during the manufacturing process.

The chronology of events leading to the accident is as follows.

- A new subcontractor was nominated to provide the side-frames by the bogey manufacturer in June 2006. The sub-contractor adopted a different pressing method than the previously used method.
- The changes involving subcontractors and pressing methods were not discussed in manufacturing process review meetings conducted in October 2006 by the purchasing department of the manufacturer.
- In June 2007, the workshop manager issued a command to grind the surface of the frame, not knowing or being able to observe that the pressing method had changed. This resulted in a reduced plate thickness of 4.6mm and is thought to have contributed to a fast crack propagation rate.
- Further, there was excessive overlay welding, in part, concerned. Such excessive welding is thought of as a reason for crack propagation.
- The bogey in question still satisfied the MLIT approved test criteria and had been regularly inspected by the HSR operator using methods pre-approved by MLIT.
- There was no evidence to doubt the quality of the periodic maintenance and inspection work within the operator company (as per the specifications pre-approved by MLIT).
- On December 11, 2017, the crack was detected.

4.5.2 SCS and System Hazards

System hazards in this accident were identified as the operation of a train with a crack in the bogey structure. The system-level constraints are that cracks must not be generated in the bogey structure, and if produced, the cracks must be detected and adequately dealt with. The safety control structure (SCS) should enforce these safety constraints (Figure 4-13). The SCS is divided into two parts, a) System Development and Integration, and b) System Operations. In Japan, rolling stock is jointly developed by the railway company and the manufacturer. Conventionally the specifications and technical standards regarding HSR technology are developed by operators through joint research programs with various public, private, and academic bodies. Manufacturers oversee production, and the assets are operated and maintained by the HSR operator themselves. Each operator receives a pre-approval on detailed technical specifications, inspection methods, and maintenance methods from the MLIT. MLIT then uses these pre-approved specifications as a basis to regulate the integration and operation stage. When an operator seeks approval for new working-level standards, MLIT often assures its conformation by comparing if any other operator has successfully implemented similar standards (Railway Bureau, 2001).

4.5.3 System Development (Quality of produced bogey frame by the Manufacturer)

As mentioned before, the foundation for crack generation and its fast propagation were laid during the manufacturing of the rolling stock. The most important safety constraint for the rolling stock manufacturer was to ensure the quality of the produced bogey by first developing the design standards for the bogey and then by manufacturing a quality product as per the original design. In this analysis, a macroscopic perspective on the Manufacturer is taken, and the manufacturer is taken as one single organization; however, the manufacturer can be further divided into multiple parts who had various responsibilities related to enforcing the above-mentioned safety constraints.

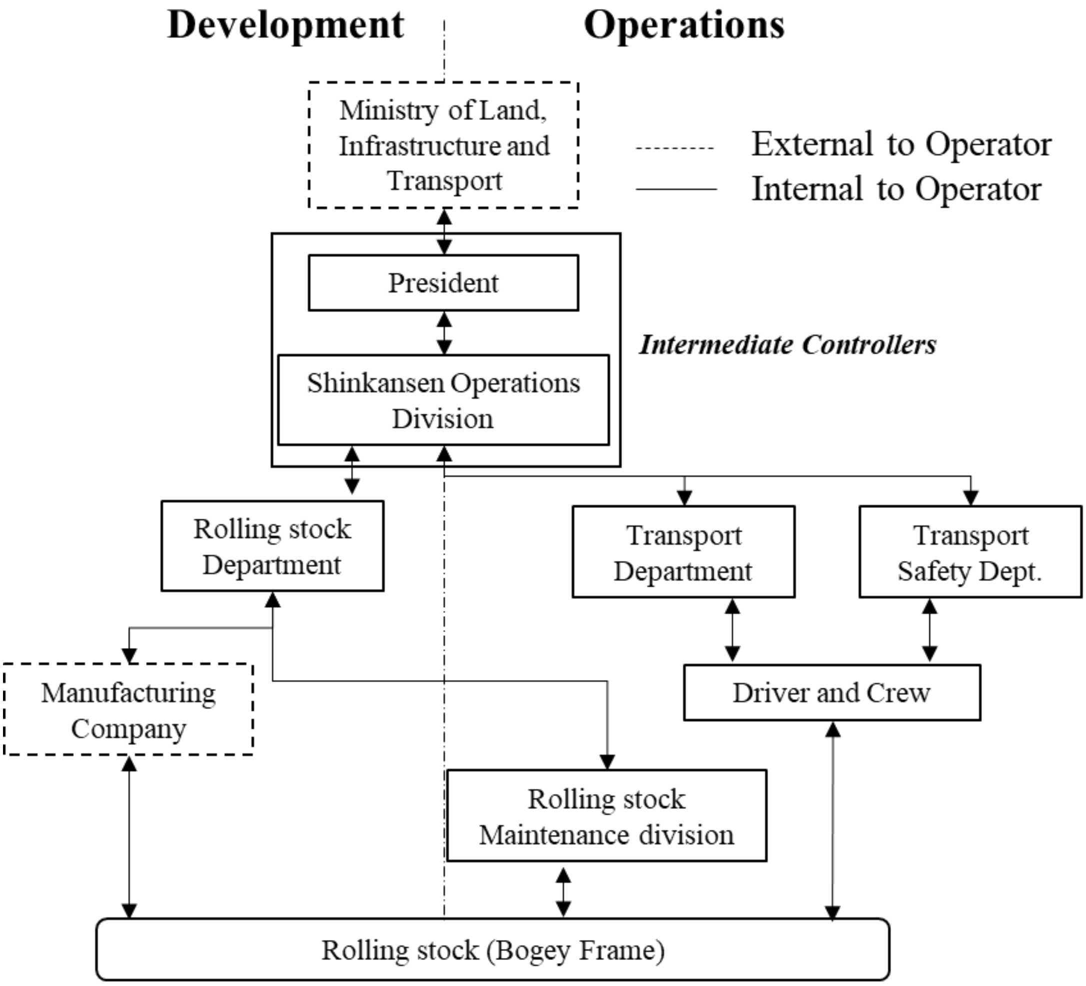


Figure 4-13 Safety Control Structure for Japanese HSR (Bogey frame crack, 2017)

The official statement of the manufacturer (Kawasaki Heavy Industries Co. Ltd., 2018) provides detail on the processes internal to the manufacturer. Within the manufacturer, the design department's role was to come up with technical specifications for the bogey frame. Then, the responsibility of the production department was to ensure the quality of the product as per the specifications in the shop-floor. The manufactured product is jointly tested with the TOCs as per the pre-agreed tests by the quality assurance department. In addition, the role of the marketing department in the manufacturer company is to procure the necessary material through sub-contractors, etc.

4.5.3.1 The design team of the manufacturer

As mentioned above, the responsibility of the design team is to develop specifications for the rolling stock while working in coordination with the rolling stock department of the TOC. In turn, these design specifications are approved by the MLIT.

As per the official accident report, the design of the bogey structure was found to be adequate in preventing the fast propagation of the crack. Although the design of the bogie frame was found to be adequate, the design process served another important function. The use of numerical simulation in the design stage can also be useful in identifying the areas of potentially high-risk during the construction.

However, the analysis scheme adopted by the manufacturer was found to be inadequate in detecting the high-risk at the location where the crack was thought to be originated. Any numerical scheme is based on assumptions. The official accident report demonstrated that if some variations in the underlying assumptions were considered, the high-risk for the said location could be obtained. However, there are no specifications regarding performing the numerical simulations, and hence in the strict sense, there was no violation of any pre-determined safety constraint.

Hence, this is a case of missing safety constraints where the design process itself be reviewed for its underlying assumptions. Such safety constraints should be enforced for future accidents.

4.5.3.2 Shop-floor of the manufacturer

The two main triggers of the accident, i.e., excessive grinding and welding, both originated during the fabrication stage of the bogey frame at the shop-floor of the manufacturer. The shop-floor manager should enforce the constraint that the produced part is as agreed in design, which the shop-floor manager failed to do.

The shop-floor manager had provided the unsafe control action in the form of an order allowing excessive grinding. However, the context under which such an unsafe control action was given must also be understood. The given unsafe control-action from the shop-floor manager was in response to the feedback received from the shop-floor workers about the misfit of the two parts that needed to be joined. The misfit had occurred because the dimensions of the part concerned were different from the parts that are usually supplied to the shop-floor. The part concerned had been provided by a different supplier than the usual, who used a different method of manufacturing the part leading to change in its dimensional accuracy. However, the shop-floor manager was not aware of the changes in part supplier and had wrongly assumed the situation to be a normal variance instead of special one (*faulty process model)* and provided an unsafe action without checking the actual dimension of the product. Not checking the actual dimensions of the part supplied was another faulty control-action by the shop-floor manager that led to a situation of missing feedback and, thus, a faulty model of the process.

In addition to excessive grinding, excessive overlay welding was also found to be an important factor in a crack generation. The official accident report could not identify the reason for such welding; however, it clearly highlights that the workers had not clearly understood the risk of cracks due to excessive overlay welding (*faulty control-algorithm*), and hence, had carried out such an activity (*unsafe control action*).

4.5.3.3 The marketing department of the manufacturer

The prime responsibility of the marketing department at the manufacturer is to ensure the supply of the raw materials or the parts. Thus, the safety-related constraints are to draw the procurement specifications that do not jeopardize safety. Hence, the prime responsibility of the marketing department was to involve various shop-floor managers, designers, etc. in setting up the specifications of the part supplied, and in-turn, thoroughly discuss the changes with the above-mentioned departments. However, the official statement from the manufacturer highlighted that such cross-department coordination was not implemented correctly (unsafe control action) and was made in a hurry. Specific details are not known, but such a hurried preparation from the marketing department hints at the possible conflict with other performance goals of the marketing department, which should be analyzed in detail.

4.5.3.4 The quality assurance department

After the fabrication stage of the bogey, each bogey is subjected to certain tests to check its quality. The testing procedures and test locations etc. are jointly decided by the design team of the manufacturer and the rolling-stock department of the TOCs. Such testing procedures and test locations are all then approved by the MLIT.

The test location was determined using the potentially high-risk areas determined using the numerical simulation method. As discussed in section 5.4.3.1, the adopted scheme of numerical simulation was inadequate in identifying the location from where the crack originated. Thus, an expected control action, of conducting the test at the vulnerable location, was not provided (*missing control action).* The exact context responsible for such missing control action is not discussed in accident reports. However, a general lack of coordination between the design stage and the manufacturing stage was deemed responsible for the same as per the report of a working group set-up by MLIT (MLIT, 2018) as it leads to a belief that the current design process was adequate. The discussions made so far have been summarized in Figure 4-14.

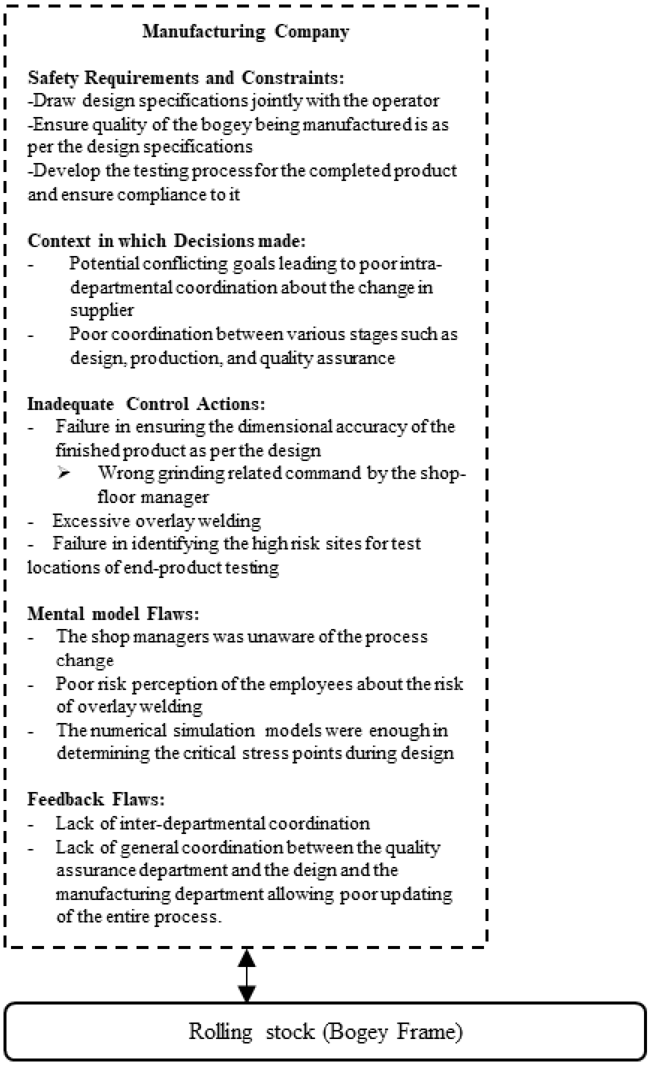


Figure 4-14 Rolling stock manufacturer component for the bogey frame accident of 2017

4.5.4 System Integration

It is the responsibility of the rolling stock department to test the quality of the finished bogey frame before using it for commercial operations. In this regard, the rolling stock department had set up a few tests and had received approval from the MLIT on the same.

The official accident report highlights that the tests were conducted as proposed, and the bogey in concern had been approved only after all the necessary tests were conducted. However, it is important to discuss whether the test method was sufficient in ensuring the safety constraints that the quality of the bogey should confirm to the original approved design.

The bogey had already passed strength tests through methods pre-approved by MLIT. As per the survey conducted by an MLIT working group, for parts not visible to the naked eye, fatigue strength is checked only at the c*ritical points* using the testing procedures as agreed by Japanese Industrial standards. The manufacturer and the Rolling stock department had identified these *critical points* as a result of numerical simulation models and based on information from previously reported crack locations and available data of running tests. The accident report clearly established that the scheme of numerical simulation adopted is not a standardized analysis demonstrating that some vulnerable locations could fail to be identified as a *critical point.* Moreover, cracks from this location were not reported in the past. Hence, the location of crack origin, in this case, was not designated as a *critical point,* and proceed through the thorough tests and evaluations at handover. However, the accident report highlighted that slight changes in the numerical simulation model parameters could lead to different results, demonstrating that a systematic risk-assessment approach could have been meaningful for safety improvement in this case.

From the testing procedure described above, it is clear that the test process did not involve checking the dimensional accuracy of each of the parts in the bogey, rather the testing procedure had tested the performance of the overall system. The long-term performance was checked only for predesignated points, which had failed to detect the issues involved in this particular bogey frame. Hence, the testing procedure adopted in this case was faulty *(inadequate control algorithm),* leading to missing control action of checking the dimensional accuracy of the produced bogey system.

From the discussions presented in the official accident report, it is clear that the testing procedure for the quality control had relied extensively on the previous experience of similar incidents or accidents and had not taken a pro-active approach of conducting a systematic risk assessment.

4.5.5 System Operation (Maintenance)

While it is clear that the faults during the bogey manufacturing stage were the main cause of the cracks in a bogey, at the same time, these cracks were not discovered during the train operations and had grown to become close to being a fatal crack. Hence, it is important to analyze why such cracks could not be detected during system maintenance.

Rolling stock maintenance department in the TOC is responsible for maintaining the vehicles as per the procedures set up by the Rolling stock department. Yet again, it was found that the rolling stock maintenance department had fulfilled its responsibilities as per the pre-approved testing procedures and methods. However, still, the crack could not be detected, thus suggesting that the control-algorithm was inadequate (the testing procedures) to begin with, as described below.

The three crucial decisions that must be made when maintaining rolling stock are the inspection methods, location, and frequency. The rolling stock maintenance department uses a magnetic particle flaw detection method for critical areas, and visual inspections for other locations to detect cracks. The survey conducted by the working groups suggests that operators have an estimation of the crack propagation rate (based on extensive data collected during operation and past accidents), and it is used to determine the frequency of the general inspection. The inspection cycle is such that it would detect a common crack propagating at a slower rate.

However, the accident analysis report discusses the rate and mechanism of crack propagation in further detail. It was observed that once a crack reaches a location where it becomes observable using magnetic particle flow detection, the crack quickly propagates to full depth (potentially fatal) in less than one year. This one-year period is undoubtedly shorter than the existing frequency of inspection, which was scheduled every 3 years. The report thus describes how the rolling stock maintenance division did not correctly understand the crack propagation rate.

The accident report gives some information on the context under which the control-algorithm could have been inadequate. According to the analysis conducted in the official accident report, if the plate width would have manufactured as designed, the time taken for the crack at becoming visible would have been of the order of over 20 years, which is longer than the average service life of rolling stock in Japan. Over the years, the Japanese rolling stock manufacturers have delivered a wonderful quality of the product, and hence, such lapses in the quality of the manufactured product are very uncommon. Hence, with a lack of experience, the location of crack origin could not have been designated as a *critical point*. Under the limited resources available, the operator had adopted a policy to inspect only the critical parts, and hence, such decision-making practices (control-algorithms) were not adequate.

In summary, the control algorithm of the Rolling stock maintenance division was faulty in that their existing inspection methods were not enough for detecting the cracks within the scheduled frequency of inspections, leading to a control-action which was not sufficient in detecting the crack in due time. The control algorithm was based on past experiences, and in the absence of the past-experience, had become inadequate for this particular case. The summary of the discussions in sections 4.4.4. and 4.4.5. has been shown in Figure 4-15.

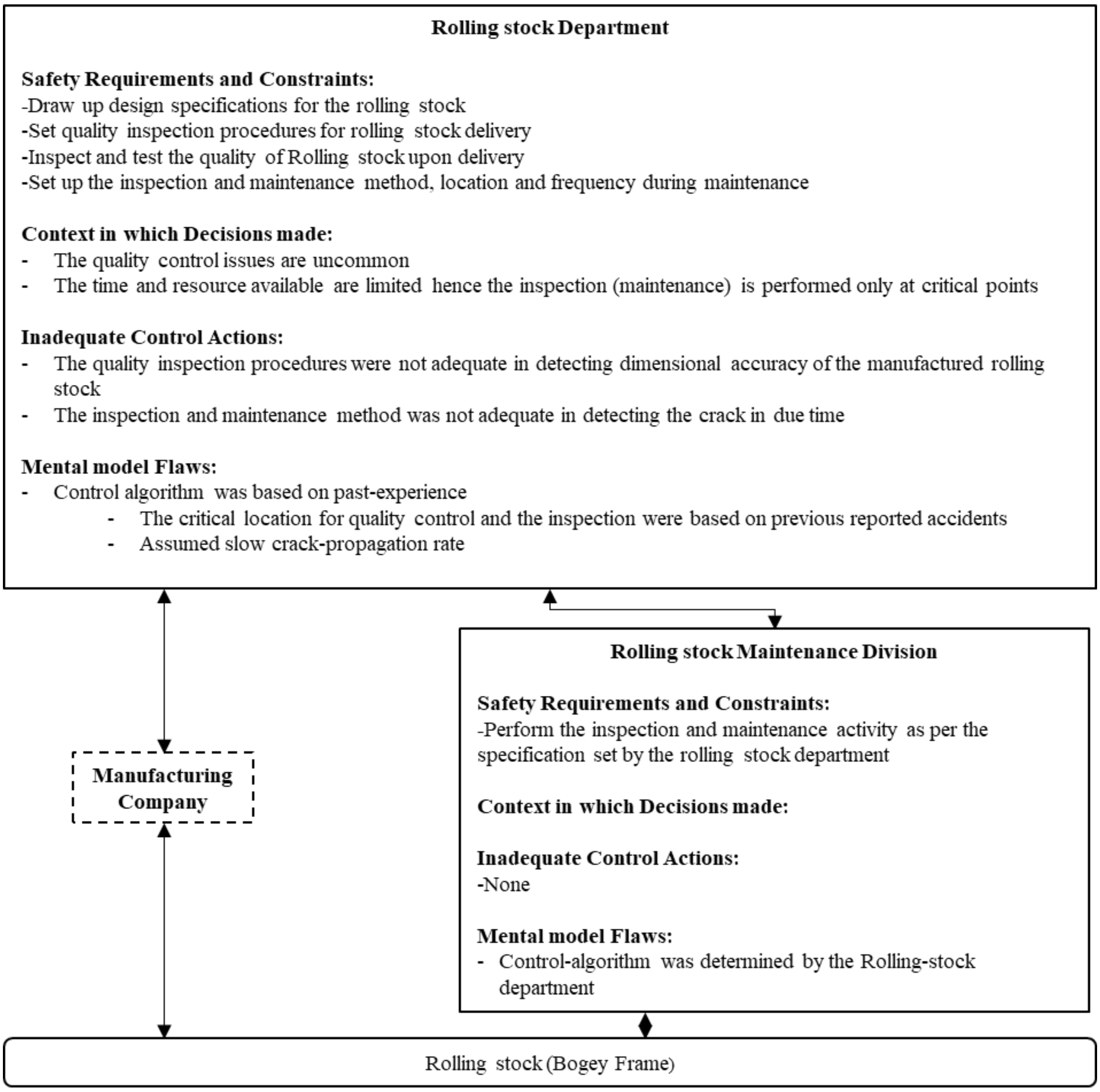


Figure 4-15 System Integration and Maintenance (Bogey frame crack accident in Japanese HSR)

4.5.6 Specification approval

As mentioned above, all the related procedures, such as design procedures, quality inspection procedures, as well as the maintenance procedures, have been pre-approved by the MLIT, the chief regulator for the railway industry.

Based on the detailed description of the facts presented so far, the various inspection methods used at various stages of the product are found to be inadequate. However, these methods were duly approved by the MLIT. Thus, a review of the approval process becomes important. The official accident investigation report, do not discuss the approval process of the testing procedures, etc. However, the ministerial ordinance of MLIT provides a brief overview of the approval process (Railway Bureau, 2001).

MLIT receives a number of reports from Railway company across Japan and collects data to identify potential risk causing factors. From time to time, MLIT organizes various conferences to disseminate information about such high risks.

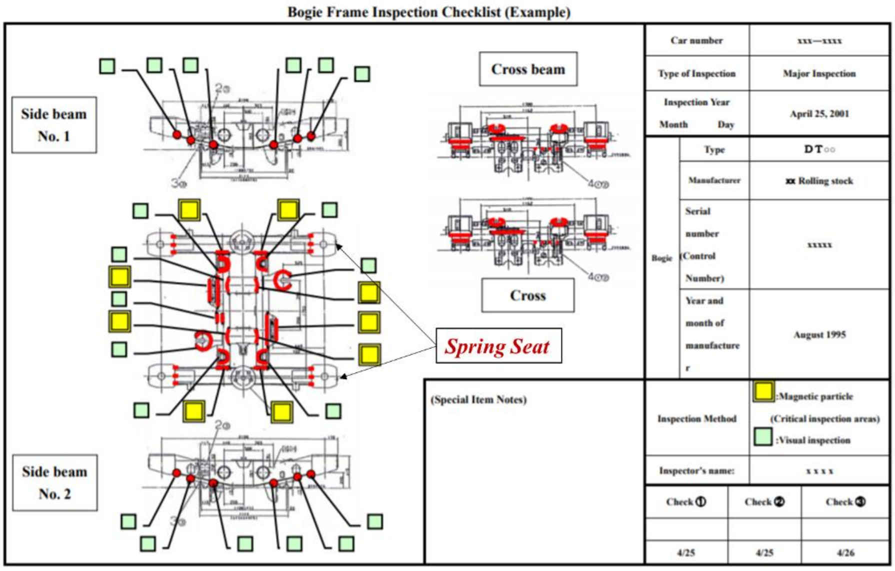


Figure 4-16 Approved model specification for crack inspection in bogey frame

Source: Approved model specification from the MLIT ministerial ordinance (Railway Bureau, 2001)

Based on the accumulated experience, MLIT has prepared an approved model specifications (Railway Bureau, 2001). These model specifications serve as a benchmark for approval of detailed procedures to be adopted by various train operators. The TOC seeking approval of its new set of standards has to notify the MLIT about its intent and also specify the rationale behind the implementation standard if it is not in accordance with the approved model specifications. The district transport bureau of MLIT examines the conformity with the approved model specifications while coordinating with the Engineering Planning division of railways. One of the most important factors for granting approval is if some other operator has already obtained proven conformity with similar specifications. However, the approval process does not designate any formal method for risk-assessment (Railway Bureau, 2001), and the confirmation process is largely derived from the accumulated experience.

In this context, the Side-beam crack propagation has been identified as a serious problem since 1998, and consequently, MLIT has improved various inspection procedures such as making it mandatory to have magnetic particle flaw detection for certain locations on the bogey frame. Over the years, these improvements are then reflected in approved model specifications. However, the approved model specifications at the time of the accident did not designate the location just above the spring-seat as an critical location (Figure 4-16), despite having recognized that the highest number of cracks in the past decade had originated near the spring-seat welding (the crack origin location identified in this case) (Railway Bureau, 2001, page 315). Further, the scenarios demonstrating the crack propagation rates did not examine the effect of the reduced thickness of the plate, coupled with the initial size of the crack opening. In the current accident, it was found that the reduced thickness of the plate had contributed to the rapid acceleration of the crack propagation, since the time the crack became perceivable from the inspection methods prescribed in the approved specifications, and hence could not be detected based on the pre-designated inspection frequencies.

From the facts discussed here, it can be thus concluded that the MLIT had approved inadequate specifications (*unsafe control actions)* and had not stressed enough on the risks of the crack originating from the welded joints. Over the years, the MLIT had recognized the importance of this issue and had proposed numerous countermeasures (Railway Bureau, 2001, Page 312), and the lack of cracking record

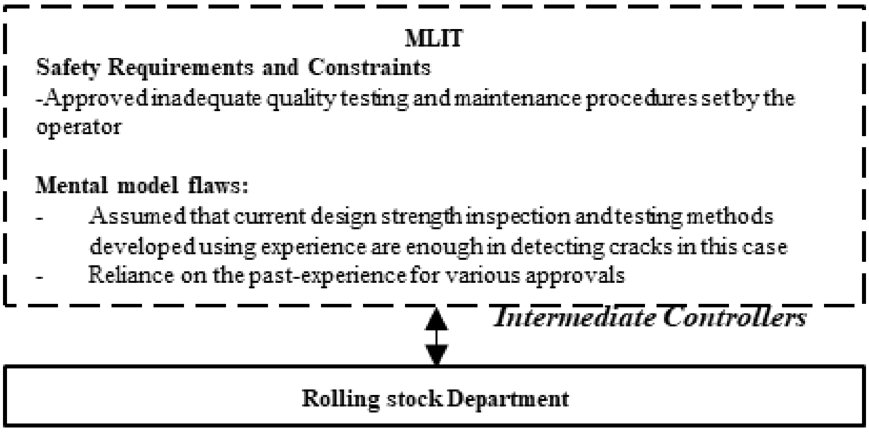


Figure 4-17 Specification approval factors for the bogey frame crack accident

thereafter was assumed to be the proof of the effectiveness of the proposed countermeasures (*wrong interpretation of the feedback*). The unsafe control actions and the process model flaws of the MLIT have been summarized in Figure 4-17.

4.5.7 Analysis of the Train Operation

Another important dimension of this accident is associated with the response of the various personnel of the railway TOC when they had first observed the signs of distress. A detailed analysis for each of the crew members is not presented here, but an overview of the interactions among various crew members is presented.

The train crew had to make a judgment for stopping the train operation, and they failed to do so for a long time. The main reasons highlighted in the report are as follows. First, there was no information available to the crew that could be objectively associated with the crack. The crew had noticed intermittent abnormal noise, vibration, and odor, but the crew members (the driver of the train) could not interpret these feedback signals appropriately (*feedback incompatible with the recipient)*. Such difficulty in interpretation could also be caused by the fact that the operational manual had not recognized these in-formal sensors as a presence of the accident causal factors, and the interpretation was left subjective to the crew members. Hence, the process model of the crew about the current state of the running train was incorrect. The accident report also analyzes the coordination issue between multiple controllers that could stop the train. For example, the train driver, the control-center operative, and the staff from the rolling stock maintenance department could all take the necessary control action of stopping the train; however, none actually took it. This can be described as a clear problem arising out of overlaps in responsibility and lack of authority among various controller controlling the same process. The accident report analyzed the patterns in the communication between these staff members and found out that it was not authoritative from either party, and there was an unspoken intent to continue the train operation and not taking the train for inspection. However, the accident report does not analyze in detail about why the staff was hesitant in taking such action. As per the organizational theory, this issue could be associated with the incentives/punishments associated with various actions and should be examined in detail. The HSR operator involved in the current accident has had a previous history of punitive actions as a means to enforce the rules, that was found to be leading contributing factor for human reactions involved in one of the most serious accidents in the history of Japanese railway, i.e., Amagasaki Railway Accident of 2005 (Ota, 2008). Even in this case, there is a long history of not taking the appropriate safety action, as reflected in the historical trend. In JR West Japan, for a period of April 1 to December 11, 2017, in only 4% of the cases of abnormal noise, vibration, and odor, the train was taken for inspection (Out of 101 reported case). In comparison, on another HSR operator JR Central with a proven safety record, in the same period, about 81% of such cases were taken train inspection (out of 156 totals reported). The historical trends thus surely suggest that there are deeper organizational factors present in the behavior demonstrated by the JR West personnel and should be carefully investigated in detail.

4.5.8 The overall analysis of SCS

Once the SCS control structures have been analyzed, an overall analysis of SCS is carried out to check the coordination between various components. As evident from SCS, the MLIT does not have any direct control over the actions of the manufacturer, and MLIT only regulates the HSR operator to ensure the procurement of quality products. Under such conditions, analysis of the control-feedback relationship between the operator and the manufacturer becomes essential. Interviews with JR officials revealed that, usually, efficient communication channels between the two bodies exist. Both parties jointly develop the specifications and share information about personnel and their capabilities in ensuring the quality of the manufactured goods. However, such communication does not usually include sharing information on the suppliers of the manufacture or detailed information on the safety management system. As already explained in the accident report by the manufacturer, the manufacturer's procurement department failed to consider the potential impact of changing suppliers and did not communicate this change within the organization. There is a possibility that such information on the new supplier was also not transmitted to the HSR operator and could have contributed to the accident.

The STAMP analysis also finds a gap in the assigned responsibilities for important safety constraints, i.e., conforming to the dimensional accuracy of the manufactured bogey. The current SCS does not explicitly assign the responsibility of checking the dimensional accuracy for each of the parts of the bogey to any of the controllers in the SCS. Instead, the SCS in-directly assigns such responsibility through defining another performance-based criterion, that the manufactured bogey has to satisfy. Clearly, in this case, the specified performance-criteria are not sufficient in assuring the dimensional accuracy of the manufactured parts.

In addition, the issue of multiple staff and their poorly defined authority in making a judgment to stop the train has been identified as a coordination issue.

4.5.9 Summary and Results from STAMP analysis

The following important lessons can be derived from the STAMP analysis conducted on the Bogey frame crack accident. First, this accident is not a component failure accident but a systemic accident, which cannot be dealt with the reliability engineering-based concepts or with the event-chain based accident models. Garnett (2018) describes a systemic failure as a situation where a failure in one part of the system propagates through the whole system such that the emergent behavior can no longer be produced. Systemic failure can happen when the nodes are lost from the system, or the relationship between the nodes is no longer interreacting. In this accident, the system design was such that it could have managed the cracks propagating at certain pre-defined values. But when the crack propagation rate was accelerated because of the interaction in one-part of the system, the interactions across the system remained meaningless, and crack could propagate close to being fatal. The system functioned exactly as designed and was still ineffective. Further, despite having collected long-term data for crack prone areas, the site-specific to this accident could not be recognized as critical because of the lack of any previous similar experience. This highlights the difficulty in assigning a failure probability to accident emanating from complex system interactions. Thus, instead of reliability-based engineering, a vulnerability-based criterion for risk-management must be developed.

The analysis also reveals the vulnerability of the HSR system due to *asynchronous evolution*. In this accident, the supplier of a one-part was changed without considering its effect on other parts of the system, which lead to a propagation of a catastrophic failure. This highlights the importance of the change-management for the HSR systems as the effect of change in one part of the system should be carefully analyzed to the other parts.

STAMP analysis reveals the gap inadequate allocation of responsibilities corresponding to an important control requirement. In this case, the responsibility to confirm the dimensional accuracy of the built bogey, exactly as designed, was not allocated to any of the controllers. Instead, indirect performance criteria were established, which were thought to be adequate in judging the quality of the manufactured bogey. In this regard, either the detailed risk assessment should be conducted on confirming the suitability of the prescribed performance criteria in assuring the dimensional accuracy of the manufactured bogey or responsibility to confirm to dimensional accuracy should be explicitly assigned to the necessary controllers.

In addition, the analysis demonstrates that several organizational factors at the TOC contributed to the accident. Lack of adoption of systemic risk-assessment and hazard analysis methods is one of the most prominent organizational factors. In this accident, it is clearly demonstrated that the excessive reliance on the past experience caused this accident. Systematic risk assessments conducted for deciding the inspection and testing processes during various life-stages of the bogey, such as during the design, during manufacturing, during hand-over, and during the inspection, could prove to be useful. The error in judgment of the crew members in deciding to stop the train clearly highlights other organizational factors such as issues in safety culture, issues with the reward and punishment system in the TOC, lack of continuous improvement in safety management, etc.

The STAMP analysis is also useful in identifying the necessity of close coordination between the TOC and the manufacturer on issues such as review of safety management of the manufacturer, thus highlighting the effect of organizational interactions with other organizations. This factor has not been explored in the official accident analysis report by JTSB, but can be obtained using the STAMP analysis, in which checking the overall coordination between the system components is considered an essential step for identifying potential issues. More organizational factors and the factors related to the relationship between the regulator and the TOC are identified in the next section.

Further, the structured analytical approach of STAMP is also useful in highlighting the information that should be further explored to collect more information about a few organizational causal factors. First, the context in which the decision making was implemented at the rolling stock manufacturer must be further explored. For example, the marketing department at the manufacturer had seemingly conducted coordination meetings in a hurry. The report should further investigate contexts such as external pressures, historical background, organizational culture, etc. (Stringfellow, 2010). Further, a similar context should also be explored for the shop-floor managers for the manufacturer. There is a high chance that the shop-floor manager may have to negotiate safety along with other production-related pressures. If such a context is not clearly identified, the accidents could resurface in some other form. A similar context should also be explored to understand the contextual factors underlying the TOC's crew members' decision making. Identifying the accident causal factors while exploring contextual factors allows developing a deeper understanding without attributing blame to any specific system component and is thus an important strategy. Accident analysis at STAMP also reveals the gap in the investigation at the regulator level, where the approval process has not received any significant scrutiny in the accident report. Accidents can not only be an important learning opportunity for the organizations but also for the regulators to further improve their regulatory process.

4.6. Modeling the dynamics of the Bogey frame crack accident

The causal relationship explored in the STAMP based accident analysis can also be utilized for developing a causal loop diagram as per the System Dynamics (SD) methodology. Using SD, the accident mechanism at the organizational and institutional level can be represented using feedback structures in a simplified manner. Moreover, additional causal relationships can be identified, connecting 2 or more feedback structures. SD Archetypes can then be used to identify common patterns, and thus their solutions can be obtained using the same archetypes. In this study, the feedback structures are revealed by combining SCS with the STAMP results to reveal these feedback structures. Examples, SD structures are discussed in the next sub-section.

4.6.1 Dynamics of the manufacturer

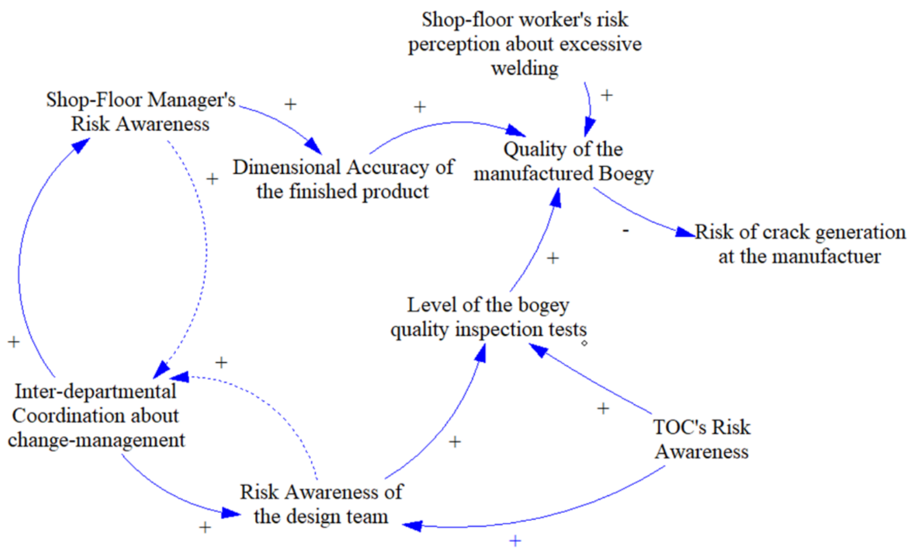


Figure 4-18 Dynamics of the manufacturer

Figure 4-18 shows the dynamics involved in this particular accident at the manufacturer level. As highlighted above, shop-floor manager's risk awareness was the main reason for the inaccuracy in the dimensions of the finished bogey frame, leading to a decrease in the quality of the manufactured bogey and thus increasing the risk of crack generation at the manufacturing unit. The quality of the manufactured bogey is also dependent upon the Level of bogey quality inspection tests, the more the level of the test, the more the quality will improve assuming the increase in the level of bogey inspection quality will be supported by an increase in resources to produce the high-quality product. The level of bogey inspection tests is, in turn, dependent on the risk awareness of the design-team and the TOC's risk awareness. In Figure 4-18, two reinforcing loops are identified as part of the inter-departmental coordination. Inter-departmental coordination at the manufacturer was found to be weak in this accident. If this, structure alone is considered, a slight increase in inter-departmental coordination such that it becomes habitual, will lead to a continuous and rapid increase in the product quality. Or if there is a slight decrease in inter-departmental coordination, the quality of the product will continuously decrease. However, in reality, such a reinforcing pattern do not exist and there could be numerous balancing feedback structures from outside the manufacturer system or even within the manufacturer system (for example, Increase in Level of bogey quality inspection tests may also lead to increase in production pressures at the shop-floor this affecting the overall quality of the produced goods).

4.6.2 Dynamics of the TOC

The risk perception of the HSR TOC is directly dependent upon the number of incidents related to the Risk. As highlighted above, Japanese TOCs focus extensively on accident investigation; hence, it can be expected that root-causes of the accidents are identified, and the risk awareness quickly changes upon the occurrence of an accident. Once the risk-awareness of the TOC increases, they take comprehensive measures to increase the adequacy of the inspection procedures, to increase the Level of bogey quality inspections, to describe the rules delineating the risk for improving the risk perception of the TOC Crew and may also take measures to improve the sensor quality to provide reliable feedback to the employees. All of the above-mentioned actions then help the TOC to reduce the system risk, thus forming a balancing feedback structure. However, TOC may also adopt measures for strict enforcement of the procedures, etc. Multiple approaches for implementing such enforcement exist. TOC may choose to provide incentives and punishments for various safe and unsafe behaviors. The relative importance of more unsafe behavior (e.g., higher incentives to service punctuality than safety) may then reinforce the unsafe behavior of the employees and forcing the system to be in a high-risk state. Since the incidents/accidents are realized only after a significant time-lag once the risk has increased, the short-term punctuality related goals may receive priority, thus jeopardizing the safety. Hence, the dynamic behavior of the TOC may depend on the relative combination of various balancing and reinforcing feedback structures. Figure 4-19 shows the dynamics of the TOC.

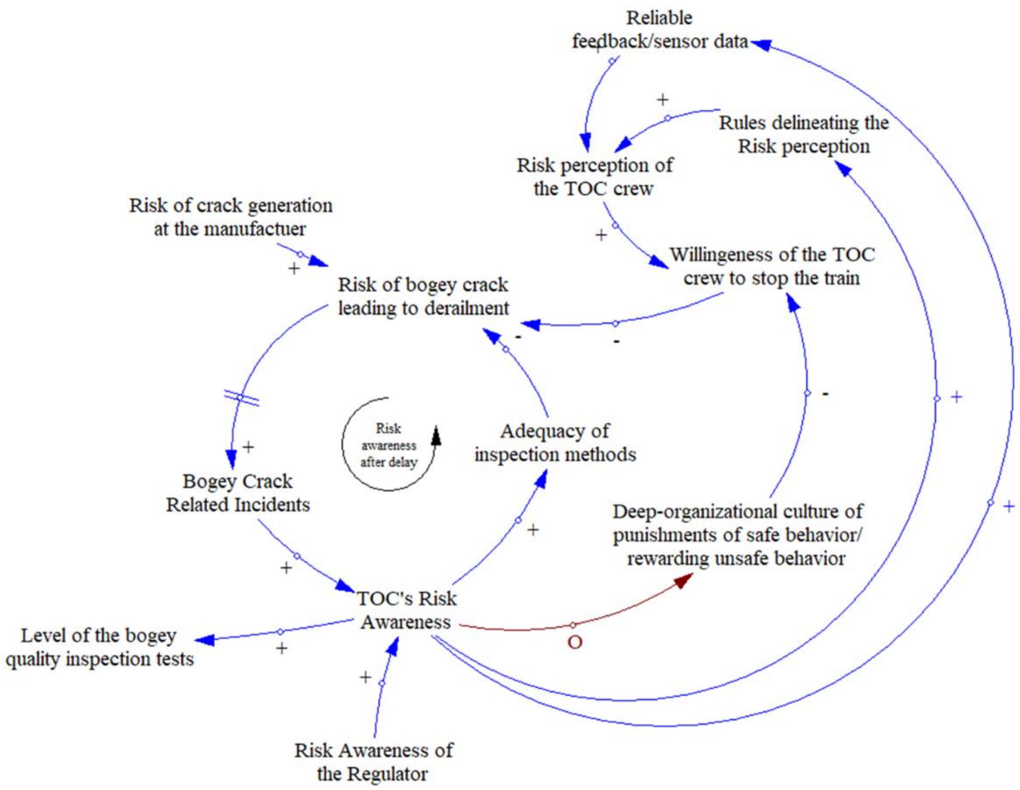


Figure 4-19 Dynamics of TOC

4.6.3 Dynamics of the Regulator

Figure 4-20 shows the dynamics at the regulator level. As highlighted above, the risk awareness of the regulator also relies on past-experience. Thus, an initial increase in Risk bogey frame crack will cause an increase in related incidents after a time-lag. When the number of related incidents increases, the regulator will take actions such as improving TOC's Risk awareness or increasing the level of bogey inspection tests, thus reducing the risk.

In addition, in the absence of formal risk management, the decisions taken by the regulator are based upon collective expert opinion. If the decisions based on these collective opinions perform as expected, confidence in their robustness is developed (after a certain time lag)(Railway Bureau, 2001). When such confidence is built, it then decreases the will of the regulator to further introduce more measures, as there is a push on the regulator to keep the regulatory burden to a minimum, thus reducing the risk awareness of the regulator. Hence, if the confidence on the regulatory measures is generated in a shorter term compared to the time-lag between the increase in incidents upon an increase in system risk, then a situation may arise that the long-term systemic risk is not reduced, even after observing some of the incidents.

The basic dynamic structures for each of the components in the SCS for Japanese HSR can then be compared with the reported archetypes to identify similarity. Similarly, an attempt here is also made at developing a new type of archetype. These archetypes are discussed in the next subsection.

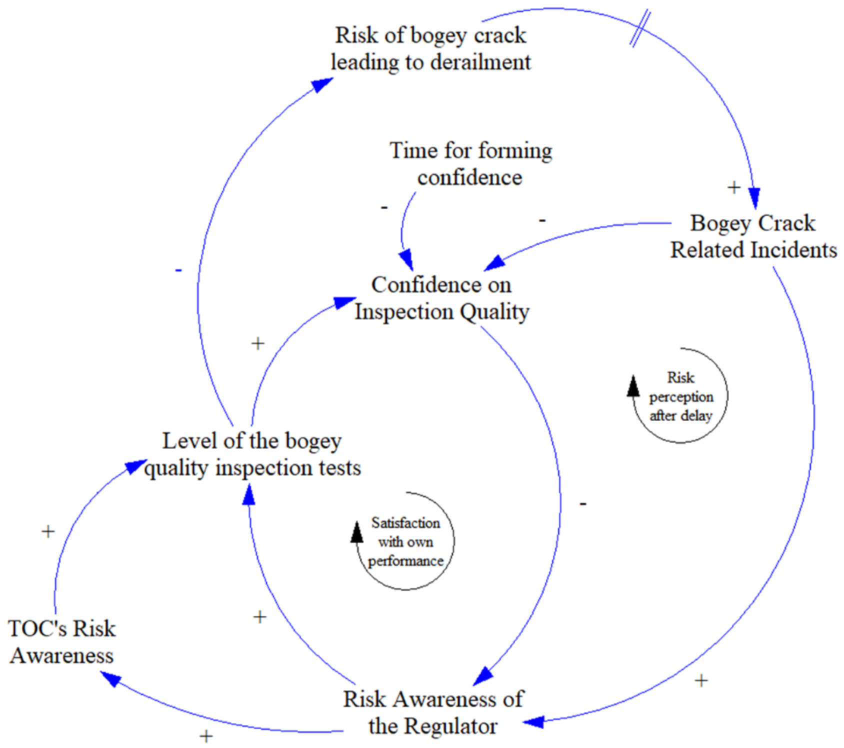


Figure 4-20 Dynamics of the Regulator

4.6.4 Proposing a new archetype: Ineffective Redundant Regulation

Based on the accidents analyzed so far, one of the commonly occurring patterns is related to the relationship between the regulator and the TOC. As described previously, each TOC is responsible for developing its own set of standards, and the role of the regulator is to approve these standards so that these standards can be used for future product development. This mechanism is also known as the self-regulation mechanism as described in (Fan *et al.*, 2015), which is in contrast to the inspectorial mechanism of regulation, where the regulations are prescriptive in nature rather than performance-based. Figure 4-20 shows the overview of the redundant-regulator archetype.

The archetype is comprised of the two-main agents, the regulator and the entity being regulated, both of which rely on the same information and similar process to develop new standards. The term redundant is used here to showcase the apparent complementarity of the safety-related functions of both the agents. In case the operator fails, the regulator can guide the operator to ensure adequate safety. However, both agents use similar information sources and the information processing method. Hence, both the agents are prone to fail in a similar manner, making their apparent redundancy ineffective. The above-mentioned archetype is shown with two feedback structures in blue color in Figure 4-21.

The mechanism is discussed with respect to the accident cases, as described in previous sections. In the bogey frame crack accident of 2017, various procedures set by the Japanese TOC to detect the cracks were all based on the incidents that had occurred in the past but did not rely on the systematic risk assessment. When these procedures are sent for approval to the regulator, the regulator also relies on the same information of the past-experiences. The regulator also verifies the new procedures against the existing methods being used by another operator. In this way, if one specific issue is considered less likely, there are high chances that the same issue will also be approved by the regulator as such. Essentially, the failure mechanism for both the regulator and the TOC is the same, and thus despite seeming redundancy, the system will actually do little to prevent errors as the failure mechanism for both the agents is the same.

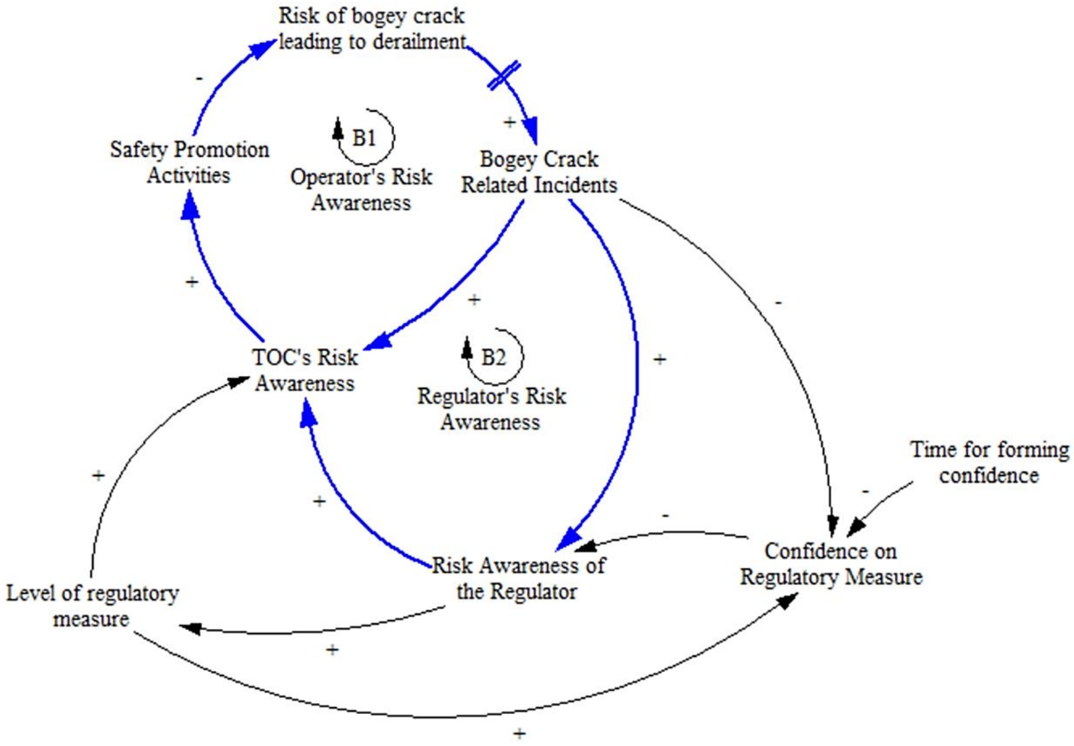


Figure 4-21 Redundant Regulator accident archetype

The mechanism described so far, is generalizable in the Japanese context. Other examples from HSR accidents in Japan relating to this are as follows. In the 2016 case of the earthquake-related derailment of JR Kyushu, there are at least two instances where such a mechanism would have likely contributed to the accident. Firstly, the design of an earthquake-early detection system that applies emergency brakes to reduce the speed of the trains significantly was found to be ineffective and poorer than the industry-wide practices (that were revised after the 2004 earthquake). The principle behind this system is very well known, and the method adopted by all the Japanese TOCs is the same. However, the specific characteristics of the system may affect its overall response time, for which there are no approved model specifications in Japanese ministerial ordinance (Railway Bureau, 2001). In the absence of such approved model specifications, the system would be tested based on the proved conformity by other HSR TOCs in Japan. And since the basic principle of the system is the same, it is likely that such a system with slower response time was approved for the JR Kyushu. A second example related to the standard adopted by JR Kyushu for implementing measures to install deviation prevention measures. To identify the critical locations for installing such measures, JR Kyushu had relied on published information on fault-lines. Since the location of the derailment was identified to be 10 KM away from the end of the fault-planes, JR Kyushu’s standard did not even consider the location to be worthy of installing such measures. The above-mentioned incident can also be explained using the *Ineffective Redundant Regulation* archetype. The plan developed by the JR Kyushu had underestimated the risk for an in-land earthquake for the location concerned, and the same risk was also approved by the regulator. Although the exact process of the approval is not known in this case, it is likely that the non-systematic approach taken by the regulator will likely cause such a risk to be approved, making the regulator ineffective.

A similar feedback structure at the institutional level was also proposed for the Amagasaki accident of 2005 (Ota, 2008), suggesting that the archetypes at the institutional level offered in this study are generalizable in the Japanese context. In the Amagasaki accident, a train entered a curve at speed considerably higher than the limit and overturned. The analysis presented in (Ota, 2008) demonstrates that the risk of overturning was not sufficiently perceived by both the railway operator and MLIT, as historically, there were very few accidents of this type, and in fact, none experienced in passenger railways. The lack of incidents from which to learn from led to inadequate attention given to this risk, resulting in a fatal accident. The same mechanism can also explain the accident of an axle crack that occurred in 1966 (Saito, 2002).

The archetype described here is also helpful in understanding other dynamics related to the relationship between the regulator and the operator and is not only limited to the Japanese Railway system. Figure 4-21 also demonstrates one possible vulnerability. As the number of incidents increases, the regulator might choose to establish a strict set of regulations. This strict set of regulations combined with the declining trend in incident/accident frequency may lead to confidence in the effectiveness of the increased regulations. Once the confidence in the current level of regulation is developed, it then limits the pursuit of the regulator to improve the regulation level even further, partly because there is always pressure from various operators to not increase the regulations significantly. In such a scenario, if the confidence in regulation is generated too fast compared to the time it takes for the risk to materialized into accidents, the necessary level of regulation may never be reached, thus contributing very little to reduce the actual level of risk in the system. Such confidence in the regulatory system can also be affected by the historical effectiveness of the regulator's performance (such as the case of FAA in the USA), or by the financial pressures facing regulators, where an increase in the level of regulations is associated with increased costs on the part of the regulator himself. The above-mentioned dynamics, coupled with the blindfolded compliance attitude by the TOCs, then can give false hope to the operators that their measures are safe when, in reality, they are not.

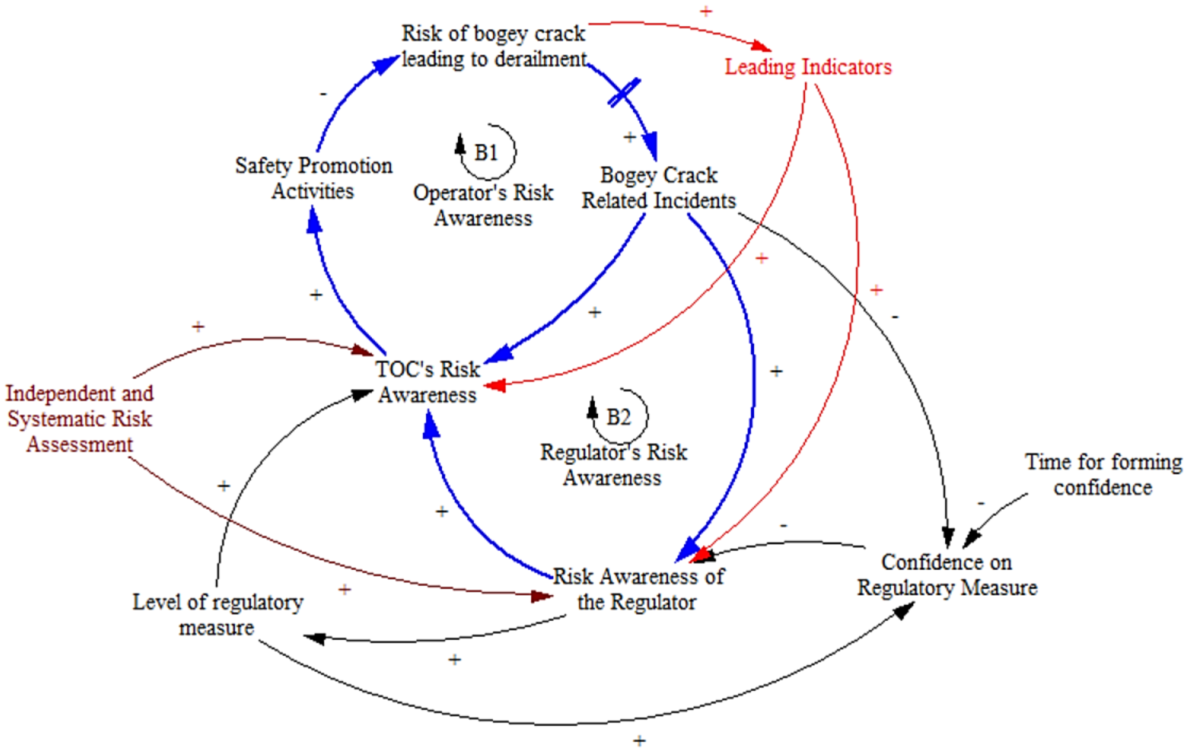


Figure 4-22 Possible solutions of Ineffective Redundant Regulation archetype

Figure 4-22 discusses the potential solutions for Ineffective Redundant Regulation Archetype. One potential solution to the challenges described by the archetype above has an independent and systematic risk assessment for the regulator and the organization being regulated. Or, both the operators and the regulators must rely on independent information sources to conduct their risk assessment. By having multiple approaches, there is a chance that some accident causal factors that ware missed in one set of assessment can be identified in another. Alternatively, the system-theory based risk assessment methods such as STAMP can be utilized for joint analysis. STAMP has been shown to provide a robust structure that can identify causal factors in a systematic manner. However, even when the comprehensive risk assessments framework is carried out, independent assessments from the regulator and the organization are necessary. The recent accidents in Boeing are also testimony to the importance of the independence of the regulator. Because of the financial pressures, the Federal Aviation Administrator (FAA) in America has long been outsourcing its regulatory activities to the aircraft manufacturers themselves, simply because the aircraft manufacturers can afford to hire quality engineers and testing pilots (Stringfellow, 2010). However, even in that, the certification process of the FAA has changed over the years, such that it jeopardized the independence of the assessments provided by the FAA and the aircraft manufacturer. (Gates and Baker, 2019) describe how the process of Aircraft certification has changed over the years. In the old system, the Designated Engineering Representatives (DERs) would work on behalf of the FAA, were appointed by the FAA, and were appraised by the FAA. They were only paid by the aircraft manufacturers. The DERs would directly report to the FAA, and the FAA would use the information obtained from the DERs to certify the aircraft. However, under the new system, DERs were replaced by the Authorized Representatives (ARs). Further, under the new system, these ARs were appointed by the aircraft manufacturer and not by the FAA. The ARs would report directly to aircraft managers, and then these managers would send reports to the FAA for its approval. Hence, under the new system, the ARs are totally guided by the principles and processes within the Aircraft manufacturers, and the report sent to the FAA is controlled by the aircraft managers. Hence, the independence of the two assessments from the operator and the regulator has been lost. Such factors have then been identified as crucial causal factors contributing to the two Boeing 737 Max accidents that occurred in recent years (Campbell, 2019). Thus, the independent risk assessments are an important step for ensuring safety for highly safe systems such as HSR that are also expected to go under transformation as the technology continues to evolve.

Another source of complexity in the archetype described above is due to the time lag in realizing the incidents after the risk level has risen. This time lag could often be very long; for example, in the bogey frame crack case, the bogey in question was manufactured in 2007, while the incident had occurred after almost 10 years. While the time lag could be very long and be unpredictable. On the other hand, time for getting confident about whether a change in regulation is effective or not, can be rather shorter and have a tendency to become smaller under the pressures described earlier. In this regard, if the time-lag between the incident realization and risk increase could be shortened, the complexity of better control could be executed. Incidents and accidents are often considered as Lagging indicators of the system, as it is often too late to stop a major accident once some incidents are observed. In this regard, certain leading indicators should be developed that, when monitored, could provide a better overview of the system risk state and thus could be considered as proactive management. The official accident report for the crack in bogey frame accident provides wonderful examples of developing leading indicators, e.g., by monitoring the pressure difference in the springs for diagonally across springs, it is possible to identify if the load transferred by each spring is equal and hence any significant difference between various pressures could serve as a leading indicators. Another leading indicator suggested by the official accident report is the temperature of the gear assembly mechanism that helps maintains the rigidity of the bogey structure. The temperature of this gear assembly rose because of the relative displacement between wheels when the rigid action from the bogey was compromised. These leading indicators have readily been adopted by various HSR TOCs across Japan. Such leading indicators should then also be identified not only for the technical subsystems but also for other subsystems such as human and organizational subsystems.

4.6.5 Lessons by comparing with existing archetypes

In this section, an attempt is made to identify similarities between the archetypes discussed in the literature and the dynamic behavior observed in this case. When similarities can be found out, important lessons can also be derived for identifying the solutions. Figure 4-23 shows the causal loop diagrams when the dynamic behavior of the TOC and the manufacturer is combined.

In Japan, TOCs have implemented numerous steps to continuously improve their safety practices. However, some of the socio-economic challenges are faced by all players in the railway supply-chain, and the performance of other components could also create issues which might affect the safety, which is primarily the responsibility of the TOC. Further, as highlighted by the STAMP analysis, the relationship between the manufacture and the TOC is also vulnerable, and the institutional structure is designed such that the TOCs have to provide the necessary control to the manufacturer so that the failures in the manufacturing company should not affect the safety. It is due to the above-mentioned reasons that the interaction between the two-organizations becomes important, and lessons for improvement should be identified. The combined dynamics of the two organizations and their brief comparison with the existing SD archetypes are shown in Figure 4-23.

The first associated archetype is Unintended consequences archetype, which can be observed for the Japanese TOC from experience presented in the bogey frame crack accident. One of the natural reactions from the TOC to improve the human-factor is to develop a more comprehensive set of rules, prescribe training, etc., in the hope that employees will follow these rules with improved training. Similarly, for the accident in the discussion, the TOC had added the situations such as abnormal noise, odor or vibration to be added as a situation where the operations of the train should be stopped and shall be resumed only after confirming the safety. Even after that, in a recent incident involving the same TOC, driver of a High-Speed Rail failed to report an abnormal noise or bump, which came from the front of a train operating at high speeds. The driver thought that an animal must have hit and did not consider it worthy of reporting. HSR tracks in Japan are grade-separated, and such obstructions on the track are instead a rare event. Nevertheless, the driver failed to communicate despite the recent addition of a rule mandating the reporting of abnormal situations. When the train arrived at the next station, the station staff noticed that the nose of the train was heavily damaged, even then, the station staff reported this incident to control center only after the train left that station (The Asahi Shimbun, 2018). The braking of the nose possibly did not pose a safety threat; however, the situation was deemed necessary for first checking the train before the operations could be resumed. The example discussed here highlights that even after careful measures to implement safety are introduced, the unintended consequence may affect the effectiveness of the safety measures. Thus, careful investigation of deeper organizational factors must be made, which could cause such unintended consequences.

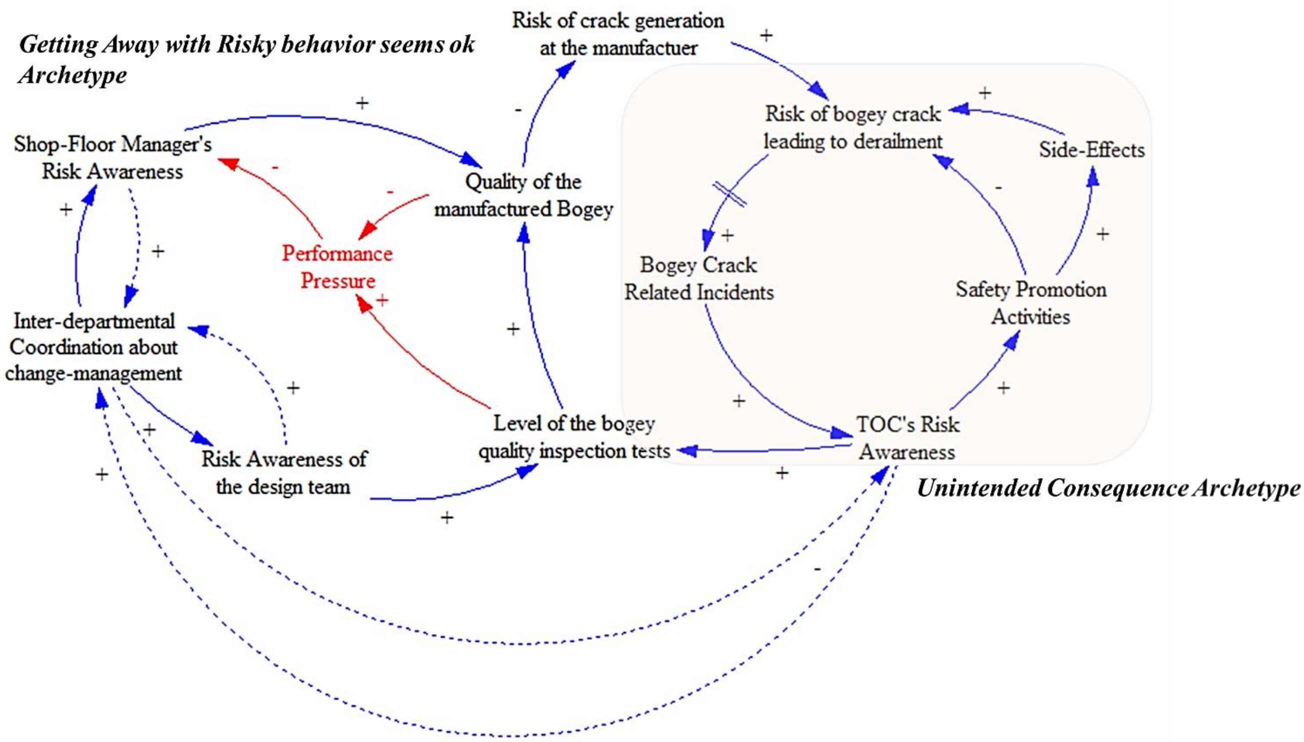


Figure 4-23 Combined dynamics of TOC and the manufacturer and comparison with S archetypes

Also, the relationship between the TOC and the manufacturer can be best understood from the archetype. Getting away with risky behavior seems ok, as proposed by (Stringfellow 2010). Although, the name of the archetype given by the author originally suggests a deliberate attempt to take risky behavior, however, that is not the intent of this archetype. Such a system is characterized by 1) long delays before negative consequences reach decision-makers combined with immediate rewards for risky decisions; 2) numerous decision-makers, and 3) an asymmetric distribution of benefits and negative consequences among related stakeholders in a system. Often, the benefits of risk-taking are experienced by a decision-maker in the short term, while the consequences to other stakeholders are experienced for years. The relationship between the TOC and the manufacturer also shares the similar characteristics such as there were long delays before the consequence of the unsafe behavior, i.e., dimensional inaccuracy were realized, the poor safety performance had a severe negative consequence in the train operator while the manufacturer could easily avail benefits of selling the unfit bogeys to the manufacturer.

As per Stringfellow (2010), one immediate solution for this type of an archetype is to provide immediate feedback about the consequence of unsafe behavior to the decision-maker making this unsafe behavior, which is reinforced by the short-term gains. Providing such feedback is likely to immediately affect the behavior of the risk-taker to moderate the consequence of their behaviors. Applying similar logic to the Japanese context, information about the importance of workers' decision (inside manufacturer) tasks in assuring the safety of HSR operations should be promoted through training campaigns or by providing social recognition of their campaign.

Another characteristic of the system is the delay between the risk undertaking and the realization of the consequences. A number of these delays are inherent to the system, and little can be done to significantly improve these delays. However, as described in the previous section, the development of leading indicators could prove to be useful for risk monitoring in the system. Although, in this context leading indicators for organizational monitoring are required to be developed. Both the interactions that could help improve the interaction between the TOC and the manufacturer is described using the blue dotted arrows in Figure 4-23.

4.7. Result and Suggested Improvement verification

4.7.1 Practitioner's understanding of the RM related results

One of the central themes and novel contribution of the thesis is related to the necessity for improving the current risk management practices at the organizational and institutional levels in Japanese HSR. The accident taxonomical analyses conducted in this study provided evidence that contrary to popular belief, a majority of accident causal factors in Japanese HSR are not related to technical failures or human errors but are linked with organizational and institutional factors affecting safety. Further, the analyses discussed the demerits of the existing RM practices, especially the prevalent accident models. In the Japanese system, the use of event-chain models is prevalent, as opposed to the state-of-the are safety theory for complex socio-technical systems. Several important limitations of the event-chain models were discussed, especially in the context of analysis at the organizational and institutional levels in Japanese railways. In particular, the event-chain models could not explain the accidents involving systemic factors, factors that can render multiple defenses ineffective simultaneously, that have been observed in the Japanese HSR. The use of system-thinking based safety theory was also helpful in identifying a novel accident archetype at the organizational and institutional level in Japanese HSR. Such an archetype was confirmed to be generalized in the context of Japanese HSR, as well as could explain some of the accident causal factors in other ultra-safe complex systems such as the aircraft. Several theoretical safety improvements can be identified using a safety archetype.

However, a question then emerges on why there is a big difference in the current RM practices in Japanese HSR and the state-of-the-art safety theory for complex systems? In a system, where the safety is clearly a priority for all stakeholders involved, why have the Japanese HSR TOCs not adopted a 20 years old prominent and widely accepted safety theory for complex systems? Do the Japanese HSR TOCs don't know about the methods utilized in this study, or the organizational and institutional factors do not warrant consideration among the stakeholders in Japan? The questions mentioned above are all associated with the practical implementation of the ideas and the recommendations generated in this study. To obtain answers to these questions, a detailed discussion with the same experienced retired JR

Central officials was organized, who had been instrumental in information gathering for several parts of the studies. The discussion focused on sharing the results and seeking answers to the questions raised above. Information from several public sources was also used to tentatively identify the answers of the questions raised above. The detailed discussions are as follows.

4.7.1.1 Result sharing with Japanese HSR experts

The experienced HSR professionals showed an acute understanding of the key ideas discussed the prevalent RM practices in HSR TOCs. Their understanding of the accident mechanism was similar to the event-chain models, and they were very intrigued by the idea of dysfunctional interactions, structured through a control-feedback loop, affecting safety. The HSR professionals had agreed to the two important limitations of the event-chain models described through the examples. A detailed discussion on the Kagoshima Mainline accident, of February 22, 2002 (see chapter 4), reaffirmed that the accident could not be effectively analyzed by the usage of the event-chain models, and indeed the concept of asynchronous evolution, essential concept in the system-thinking based safety theory, is necessary to understand the organizational factors involved in the accident. The discussion also confirmed that the use of the event-chain model masks the interactions among several factors that affect safety. The interviewees recalled that indeed, in all safety meetings at their organizations, they think about technical failure, the rule-following or human error, the human-technical interaction, whether a revision in the rule is necessary, or more training should be provided. Rarely they think about the reasons for how the rule was made, and under what circumstances the rule makes sense, or why training was not given to them before. In that, the causal factor identification process is bottom-up and rarely the causal factor identification at the level of management's decision making or whether the approvals from the regulatory authority needed to be considered.

The interview reaffirmed the second prominent limitation of the event-chain models that their bottom-up approach allows the subjectivity and biases to affect the analysis at the organizational and institutional levels. Multiple interpretations of the Amagasaki accidents were shared with the interviewees, each derived from the event-chain models. In that, the interviewees themselves did not agree to one of the interpretations in a published academic study, while they had another interpretation, which was indeed not discussed in the previous studies. Such a discussion, in-fact validated the limitation of the event-chain models, that they do not provide a systematic approach to understand the contextual factors affecting accidents, and thus looking for certain commonly occurring factors affecting safety, but rather allows the analysts to interpret the results based on the context that they are aware of. Such subjectivity can often lead to blame-attribution, thus jeopardizing the whole purpose of accident analysis.

Then, the HSR professionals acknowledged the findings from the STAMP analysis and the key message delivered through the proposed accident archetype of the study. One of the comments received was –

"*The causal -loop diagram is concise and conveys such a difficult message very clearly*."

Overall, the HSR professionals expressed great support for the findings of the study, as reflected through their comments.

"*I feel a new spark in my brain, and it is indeed a unique perspective to think about safety…. I will share the results with my other colleagues*".

The experiences from the interview suggest that the STAMP approach and the perspective of safety theory for the complex system were novel to the experts interviewed and largely to JR Central as an organization. In this particular case, clearly, the HSR professionals were not aware of the STAMP methodology. However, based on the information available in the public domain, it is not the first time for the Japanese HSR TOCs to utilize STAMP. Table 4-7 provides for some of the known applications of STAMP by Japanese HSR TOCs. Table 4-7 is by no means complete but provides a general overview of the STAMP applications.

Table 4-6 STAMP applications in Japanese HSR TOCs

No.	Title	Author	Year	Affiliation	Source
1	Application of a Systems-Theoretic Approach to Risk Analysis of High-speed Rail Project Management in the US	Soshi Kawakami	2014	JR Central	Academic thesis at MIT (Kawakami, 2014b)
2	Assuring safety in high-speed magnetically levitated (maglev) systems: the need for a system safety approach	Daniel Ota	2008	JR Central	Academic thesis at MIT (Ota, 2008)
3	Interaction of lifecycle properties in High-Speed Rail systems operation	Tatsuya Doi	2016	JR Central	Academic thesis at MIT (Doi, 2016)
4	STAMP / STPA analysis on the functional specification of Level Crossing Control in the Station Logic Control Device	Rihito Aman	2016	JR East	STAMP Workshop[9]
5	Application and extension of STAMP/STPA to Railway Signalling System	Yusuke Takano	2017	JR East	STAMP Workshop[10]
6	Safety analysis of level crossing obstruction detecting system using the STAMP/STPA method	Satoru Kitamura	2017	JR East	STAMP Workshop[11]
7	Safety requirement analysis of level crossing control system using STAMP/STPA method	Takashi Kanifuji	2017	JR East	STAMP Workshop[12]
8	JR-East's attempt to apply STAMP to safety verification of railway system	Satoru Kitamura	2018	JR East	STAMP Workshop[13]

The trends from Table 4-7 shows that the concept of STAMP is not completely unknown to HSR TOCs, and there can be seen an increasing trend in its applications. However, a majority of the STAMP applications focus at the level of physical subsystems such as the devices to be used at the level crossing, etc. Note that Japanese HSR do not have level crossings, but the HSR TOCs in Japan, also operate the regular trains. Only a few studies focus on utilizing STAMP at the organizational and institutional level for either HSR systems overseas, or the Maglev system in Japan.

The current understanding of the HSR professionals about the organizational and institutional factors contributing to accidents, the known but limited application of STAMP at the organizational level, the lack of information about management's decision making process in the official accident reports (Chapter 4), lack of academic literature focusing on such factors for safety of Japanese HSR (Chapter 1), and lack of industry-wide research on organizational and institutional factors affecting safety for Japanese HSR (Chapter 1) all support the conclusion **that while the HSR stakeholders in Japan are aware of the state-of-the-art safety theory and associated tools, rarely have they apply these tools for systematically examining the organizational and institutional factors affecting safety of the Japanese HSR**. Hence, the analysis conducted, and the results obtained in this study have important academic and practical contributions.

4.7.1.2 Context governing lack of focus on Organizational and Institutional factors in Japanese HSR

Several potential reasons for such a lack of focus on the organizational and institutional factors are then explored, based on various historical contexts. The fundamental philosophy for the HSR system in Japan has been to maximize the use of technology to minimize the necessity of the human. Since then, technology has been a key focus on improving safety. On the other hand, the HSR technology in Japan has always been operator-led, and the operators are expected to ensure safety mainly on a self-regulation basis. In this regard, the system of HSR safety management in Japan has always been concentrated on the top management of the HSR TOCs. In such a system, the management sets the detailed procedures of operation, and the individual human operators follow the rules, etc. Hence, the safety has been largely top-driven, and the accident is expected to happen through a series of events in

[9] https://www.ipa.go.jp/english/sec/complex_systems/stamp_workshop-1.html
[10] https://www.ipa.go.jp/english/sec/complex_systems/stamp_workshop-2.html
[11] ibid
[12] ibid
[13] ibid

a bottom-up fashion and not top-down fashion. Such a system of power concentration at the top management of the HSR TOCs thus can be considered to be the root of the lack of organizational and institutional factors affecting safety.

In addition, the system of safety management in Japan has also been driven by accumulated experience. Further, the concept of system integration between various technical, human, and other organizational factors affecting safety has always been accepted. Hence, the Japanese HSR TOCs were able to consider a lot of systemic interactions through their unsystematic approaches. Such a system had several common elements with the existing state-of-the-art safety theory and had been effective in ensuring safety for a long-long period, thereby generating confidence in the system.

The expert interviews also revealed another argument of why the HSR operators have not focused on the organizational and institutional factors. In HSR, the big or serious incidents have been very rare, and hence the necessity of such thorough examination using system-theory principles was possibly never thought as necessary. Further, the current system of event-chain models allows identifying the factors that are required to change, and hence, the process of safety improvement is swift and effective. In recent years, in Japan, unlike in many other parts of the world, the top management of an organization is immediately seen to take full public responsibility of safety, and rarely, the blame is attributed only to the front-end staff in official reports, etc. However, the safety reports do not examine the top-management decision making and their interaction with the regulator in detail, not to further tarnish the image of individual HSR operators. Thus, a variety of factors contribute to the system-theory based accident models not being adopted and systematic masking of various organizational and institutional level factors affecting safety in the current Japanese HSR system. These factors should be adequately considered in the future research work, in order to promote the understanding of the system-theory based safety theory and their adoption in the Japanese HSR TOCs.

4.7.2 Practical Implementation of the enhanced operator-manufacturer safety coordination

The results from the overall coordination analysis conducted in the SCS, the necessity for enhanced safety coordination between the operator and the manufacturer was deemed necessary. In Japan, the TOC is the only component governing the quality of the manufactured products, and the manufacturer is not regulated by any other entity above it. Under such conditions, the safety-coordination between the operator and the manufacturer becomes very critical. Our interview also revealed that currently, the operator does not monitor the detailed process of manufacturing, and only superficial control is executed, such as ensuring that all the people involved in the manufacturing process have adequate training. Further, the operator surely does not involve actively in managing the change-management at the manufacturer’s end. While the STAMP analysis revealed the necessity for such enhanced coordination, such a factor was not identified in the official accident report by the JTSB.

However, a review of the recent Annual report of the JR West (JR West, 2019), for the first time highlights that the JR west has started to assume greater roles in quality management of the suppliers such as throughout advance checks of documentation, including materials regarding inspection systems (including certification management), work processes, drawings, molds, the management of contractors and others, and education and training. Such an approach is at par with the desired safety-coordination as per the STAMP analysis, and hence provide support for the results obtained from the STAMP analysis and their practical applicability.

4.7.3 The necessity of an independent risk-assessment

One of the recommendations generated using the accident archetype is the necessity of conducting an independent and systematic risk assessment for the Japanese HSR. In Japan, both the regulator and the operator often rely on the same information gathered from the past-experience, using the unsystematic risk-assessment method that is unsuitable for hazard identification. However, the results from the STAMP analysis show, that when the information itself is faulty, the risks can still pass undetected through the operator and the regulator. The official accident report also suggests, that by using a systematic risk-assessment approach, the location where the crack originated, could easily be denoted as the critical point, and thus become eligible for being tested. The similar, necessity of the independent assessment at the operator and the regulator level, has also been identified to be crucial for the recent accidents involving Boeing's 737 MAX accidents, as described in (Gates and Baker, 2019). Such generalizability of an important recommendation obtained in this analysis provides support for the suitability of the proposed recommendation for the Japanese HSR system.

4.7.4 Leading Indicator Development

The seemingly proactive approach of Japanese HSR operators to analyze long-term trends using extensive system monitoring is, in fact, reactive in nature. The analysis is able to demonstrate how mental models of various stakeholders relying heavily on past events can contribute significantly to the occurrence of accidents. Such an approach is not genuinely proactive as there will always be a relatively long-time delay in the risk perception of the operator and the real risk of accidents (nearly 10 years in the case of a crack in bogey frame). In this regard, the development and effective monitoring of system-specific and assumption based leading indicators for process safety should be an effective approach for improving safety in such complex and ultra-safe systems (Dokas, Feehan, and Imran, 2013; Leveson, 2015). Monitoring leading indicators can help reduce the time-lag in updating risk perceptions and thus can contribute to improving safety. Japanese HSR operators currently do develop leading indicators, and in fact, the JTSB report on the bogey frame crack identified one such indicator (Japan Transport Safety Board, 2019). In a perfectly balanced bogey, the sum of the "Normal reactions forces" on wheels located at diagonally opposite ends of the frame should be equal. The official accident report then prescribes the monitoring of these forces through a sensor system that could issue a warning when this assumption on the sum of forces does not hold true. Such an indicator is consistent with the idea of system-specific assumption-based leading indicators necessary for complex systems (Dokas, Feehan and Imran, 2013; Leveson, 2015), and should also be expanded to human, organizational, and institutional components of the system. One of the inherent assumptions in the current Japanese system is related to the dimensional accuracy of the manufactured bogey. Current indicators to assure dimensional accuracy, such as the strength and running - tests have clearly, shown to be ineffective in preventing the propagation of cracks. It is, therefore also necessary to revise the current testing procedures, which requires initiation from the organizational and institutional levels. Several indirect leading indicators, such as adequate monitoring of the information on the change-management of manufacturers, can also be derived from the system-specific requirements described in the STAMP analysis. Nevertheless, contemporary methodologies for leading-indicators have largely focused on physical components (Leveson, 2015), and further research on developing formal methods to identify leading indicators for non-physical system components is necessary. For the Japanese HSR, leading indicators for organizational components may prove to be suitable not only for MLIT's regulation of operators but will also be useful for operators to monitor the safety management systems of their suppliers.

4.8. Discussions on methodological consideration

4.8.1 Railway Operations: Centralized vs. Decentralized Control and relevance to HRO

One of the important categorizations of the complex system exists on the basis of the centrality in their control to achieve global safety-related goals. In a centralized system, a central controller executes control over the other lower-level system components through the use of hierarchical relationships such as the one described by Safety Control Structure (SCS). On the other hand, a decentralized system is one in which the complex behavior emerges through the work of the lower-level system components based on processing the information locally to their context. Based on the information analyzed in this thesis so far and certain expected trends for the future of railway technology, the relative merits of the two types of systems are discussed in this section.

Such a discussion should also be made in the context of the prominent organizational theory, such as the HRO, and system-control safety theories. While previous sections have discussed in detail the necessary type of safety management that is consistent with the system-control safety theories. In this section, the discussions are centered on the context of HRO.

While it is generally argued and is assumed as such in the current study that process safety is enabled through the appropriate centralized control (Leveson, 2004; Hopkins, 2019), countering theories have also been discussed in the context of the Railway and other systems. Hale (2000) and (Hale and Borys, 2013b, 2013a) have described the process of the evolution of Rules and its associated challenges for safety management in railway organizations. He argues that over the years, systems have grown to become more complex, leading to the corresponding addition of more procedural rules prescribed through the centralized control based on the lessons learned from the past. While the old rules are rarely omitted. Such is the state of rule-based safety now that rules have become too complex or simply too many for the employees to remember. The faster evolution of the system has made some rules to be obsolete. Nevertheless, they are still practiced, creating a distance between an employee's understanding of the purpose of the original rule and its manifestation in practice. The main argument thus, is that the system of rule-based management is no longer sustainable in the context of railway safety, and focus should on empowering the front-end employees to take local decisions based on the information available. Numerous counter-arguments also exist essentially discussing the usefulness of the rules from the perspective of employees, as they are often perceived as protection instrument, and are known to have an easing effect on decision-making for the employees (Bourrier, 2017). The systems theory perspective on the same is that for any front-end employees to be able to make safety-critical decisions, system-level information should be available for them to be processed in time. Often the judgment, to what system-level information should be provided to the front-end employees is a judgment of the centralized control hierarchy, and hence, for any system, a certain degree of centralized control is indeed necessary.

Another trend that can be seen in the railway industry is related to a reduction in the role of the Haman operators in train operation (as discussed in Chapter 1). The Japanese HSR has always been designed to keep the role of human involvement to the minimum level.

With the upcoming, maglev technology in Japan, the human dependency for safe railway operations is going to be further minimized. In a maglev system, the onboard driver, if any, will have virtually no role to play in the train operation. The train control center on the ground will prepare the train-speed curves in advance. These train-speed curves are then fed to the power generation system, which automatically adjusts the power supply in the superconducting magnets to control the speed of a given train. The concept of system redundancy is also used here, where an onboard system, independent of the control center, will be able to apply brakes to stop the train to a safe state [14]. Regardless of the financial viability of the maglev systems, sooner or later, such advanced systems of signaling will become available to be used in the HSR technology. Under such a trend, the conventional role of train operation by the human is going to mover further up the hierarchy in the SCS, thus further emphasizing the importance of the centralized control for railway systems. In the advanced technological systems, the rules of the operation, the envelope of safe operations, etc. all will be defined by the system components at a higher level in safety control structure, and the adequateness of these rules will then determine the safety performance of the system. Such trends form the increased automation is also consistent with the original prediction by (Bainbridge 1983).

From the perspective of the HRO theory, based on the experiences reviewed in this thesis, HSR systems do not possess all the features of a typical HRO but are still shown to safety effective. From a general definition perspective, where a complex system is able to perform reliably when, in reality, there could be many accidents, HSR organizations do qualify for an HRO. However, the HSR systems have only a few characteristics in common from the HRO literature, as described in Chapter 2. Table 4-6 summarizes the comparison of the Japanese HSR system with respect to the HRO system.

Table 4-7 Comparison of the Japanese HSR TOCs with the HRO theory

HRO Concept	***Main Idea in HRO theory***	***Japanese HSR System***	***Conform to HRO***

[14] https://scmaglev.jr-central-global.com/about/system/

Preoccupation with failure	Focus on latent organizational weaknesses	Yes, however using the obsolete event-chain models, often masking several latent factors	Partially Yes
Reluctance to simplify interpretations	Consideration for Systemic interactions to understand accidents	Yes, however, using the unsystematic ways and through excessive reliance on the past.	Partially Yes
Sensitivity to operations	System monitoring to ensure that the system remains in place and operate as intended	Very acute focus on system monitoring and accordingly modify the systems to keep the system within the limits of safe operation	Yes
Commitment to resilience	Capability to detect, contain and recover from errors	Only to a limited extent, some of the common accident causal factors show their inability to detect, contain and recover from errors	Partially not
Deference to expertise	Flexibility in changing the communication hierarchy during the emergency conditions	No, the hierarchy does not change	Absolutely not

As the thesis already established previously, that RM practices of the Japanese HSR TOCs rarely focus on a systematic analysis of the latent organizational and institutional factors affecting safety. Hence, they can be the best thought as only partially conforming to the HRO characteristics. Further, the selection of the event-chain accident is also known to masking a number of interactions among latent factors. Hence, despite having an acute focus on in-sync system evolution at the level of physical subsystems, the systemic factors are rarely interpreted in Japanese HSR TOCs.

On the other hand, HSR TOCs in Japan surely are sensitive to their operation, and they rely extensively on careful monitoring of the system as much as possible (Bugalia, Maemura, and Ozawa, 2019), and do seem to follow the HSR characteristics in this aspect. However, from the accident cases reviewed in this study, it is clear that many of the common accident causes are indeed related to the poor ability of the HSR operators in detecting and containing the errors (see a summary of the ACAT analysis). Finally, HSR TOCs do not show any signs of their ability to operate flexibility in case of an emergency. Operators tend to follow the same chain-of-commands as they follow in their routine operations, and in-fact, their inability to have such flexibility was one of the prominent factors on why a decision to stop the train was not made even when the information about the odor, noise, and vibration was observed by the train crew and other railway staff. So, the current practices of the Japanese HSR TOCs can be at best described to be partially resembling an HRO.

A question then emerges, whether if all the characteristics of HRO's could be inculcated in the Japanese HSR TOCs could safety have been improved. The answer to this question is not simple, however. An improvement in Preoccupation with failure and Reluctance to simplify the interpretations is surely argued as one of the crucial contributions of the current study. However, even after using the RM tools such as the STAMP would improve the safety of the HSR TOCs is a question yet to be answered. Often multiple causes interact with each other and lead to accidents, and knowledge about these factors alone may not be sufficient for improving safety. All identified Risks should be adequately mitigated or managed, and then the RM process should also be conducted periodically. Hence, knowing about the Risks, even at the organizational and institutional level alone is not sufficient to improve safety. Similar arguments could also be made for other characteristics such as Deference to expertise or Commitment to resilience. For the case of "serious accident," an argument could be formed, that if the HSR TOC could have followed a different hierarchy, probably the crack could have been detected earlier. For example, if the person from the maintenance division would have been allowed a clear authority to take action about stopping the train when the presence of abnormal noise etc. was confirmed, the train would have been stopped sooner. However, even if such characteristics could be built in the organization, nothing would prevent the crack from originating and propagating. Further, it is hard to argue that HSR TOCs are not committed to resilience. A number of the latest technological changes are to solve the newly emerging problems of the organization. For example, focus on reducing the number of trackside cables, as their management takes a lot of effort, or innovating newer technologies, which allow faster service recovery during the disturbance, are all examples of making HSR more resilient. However, our analysis has also demonstrated, that often the same level of resilience is not shown by the HSR TOCs at the organizational level; for example, the rule revision is rather a slow process or the degradation in practice as compared to the originally approved rules, etc. is not sensed. Hence, no conclusive evidence could be provided that even if all the characteristics of the HRO were introduced into HSR TOCs, their safety would inherently improve, a finding that is consistent with other works (Stringfellow, 2010). Numerous other safety-related trade-off exists for centralized vs. decentralized systems, such as the speed of the flow of the information within the organization, etc. However, in practice, it is difficult to identify a perfectly centralized or perfectly decentralized system, as any system have some elements for both. However, this thesis adopts a view that centralized control is a necessity for managing operation safety for complex socio-technical systems such as HSR, as considered in previous studies (Saito, 2002; Leveson, 2004; Ota, 2008; Kawakami, 2014b; Hopkins, 2019).

4.9. Conclusions

In this chapter, multiple analyses were conducted to identify the challenges with the existing RM practices in Japanese HSR at the organizational and institutional levels. The analyses had primarily relied on the information about the reported accidents in Japanese HSR. Official accident reports collected by JTSB proved to be an important source of information along with expert interviews, several other reports, and literature. The analyses conducted in this chapter were useful in identifying prevalent organizational factors in Japanese HSR TOCs, some of them which could not be highlighted even in the official accident reports. Also, the analyses identified important solutions to improve the organizational factors as well as highlighted the academic gaps they should be filled for further improving the organizational factors. The conclusions are-

C4-1. **RM related issues are among the most prominent issues in past HSR accidents, while the current focus of the practitioners is on technical and human-error-related factors (Section 4.3.4, R1, O1)**

The results obtained from the simultaneous analysis of multiple accidents reveal several interesting trends for organizational factors that are not observed in an individual accident report. First, despite having achieved remarkable progress on the technical front, the technical system of Japanese HSR does experience issues. Further, the ***ACAT analysis reveals that a majority of accident causal factors for Japanese HSR are not equipment failure or the human-error type***, which is in contrast with the popular view (Saito, 2002). Further, some common accident causes include the failure to sense degradation in Information (procedures, programs, methods, or knowledge), failures in confirming the applicability of Information to the situation, and failures to establish Information based on thorough risk assessments.

However, when compared to existing accident analysis models adopted by the Japanese industry (such as m-shell model or the 4M4E model), ACAT was found to be superior in many aspects such as an explicit focus on a number of agents such as resources, environment, and information, etc. Thus, having demonstrated the advantages of the ACAT method and its potential, the section recommends that the ACAT method of accident analysis can be an important step for the Japanese TOCs to move towards the adoption of system-control based safety theory that is deemed necessary for complex systems such as HSR.

C4-2. **RM practices in Japan at the organizational and institutional levels are comprehensive and, on the principle of system-safety for complex systems. However, the underlying tools and the understanding of the accident is old and not suitable to be applied for**

complex systems, as they do not offer systematic recommendations for improvement at the organizational and institutional level. (Section 4.4.5, R2, O1)

An in-depth comparison between RM practices of the Japanese HSR and the recommendations by the state-of-the-art safety theory for complex systems reveals that the current RM practices in Japan at the organizational and institutional levels are very comprehensive and have adopted principles that are suitable for managing the safety of the complex system that an HSR is. However, in the current Japanese system, the principles adopted are not always supported by adequate tools necessary to analyze the complexity of the HSR system, especially at the organizational and institutional levels. Given the limitation of the prevalent event-chain models in systematically analyzing various organizational and institutional factors affecting safety, the next section presents the analysis of a recent accident in Japanese HSR, using the system-safety theory-based method, called STAMP.

C4-3. Due to increased complexity in Japanese HSR, the system is more prone to systemic accidents in which multiple safety-defenses can be rendered ineffective by a few systemic factors. Such accidents cannot be analyzed by the event-chain models and need accident models such as STAMP. (Section 4.5.9, R2, O1)

The bogey frame crack accident is not a component failure accident but a systemic accident, which cannot be dealt with the reliability engineering-based concepts or with the event-chain based accident models. Thus, instead of reliability-based engineering, a vulnerability-based criterion for risk-management must be developed. The analysis also reveals the vulnerability of the HSR system due to *asynchronous evolution*. This highlights the importance of the change-management for the HSR systems as the effect of change in one part of the system should be carefully analyzed to the other parts.

C4-4. The STAMP analysis also finds a gap in the assigned responsibilities to various controllers for important safety constraints, i.e., conforming to the dimensional accuracy of the manufactured bogey. (Section 4.5.8, R2, O1)

The current SCS does not explicitly assign the responsibility of checking the dimensional accuracy for each of the parts of the bogey to any of the controllers in the SCS. Instead, the SCS in-directly assigns such responsibility through defining another performance-based criterion, that the manufactured bogey has to satisfy. Clearly, in this case, the specified performance-criteria are not sufficient in assuring the dimensional accuracy of the manufactured parts.

C4-5. ***In this regard, either the detailed risk assessment should be conducted on confirming the suitability of the prescribed performance criteria in assuring the dimensional accuracy of the manufactured bogey or responsibility to confirm to dimensional accuracy should be explicitly assigned to the necessary controllers*. *(O1)***

In addition, the analysis demonstrates that several organizational factors at the TOC contributed to the accident. Lack of adoption of systemic risk-assessment and hazard analysis methods is one of the most prominent organizational factors. The error in judgment of the crew members in deciding to stop the train clearly highlights other organizational factors such as issues in safety culture, issues with the reward and punishment system in the TOC, lack of continuous improvement in safety management, etc.

C4-6. The STAMP analysis is also useful in identifying the necessity of close coordination between the TOC and the manufacturer on issues such as review of safety management of the manufacturer. This factor has not been explored in the official accident analysis report by JTSB, but can be obtained using the STAMP analysis. **(Section 4.5.8, R2, O1)**

Further, the structured analytical approach of STAMP is also useful in highlighting the information that should be further explored to collect more information about a few contextual organizational causal factors such as external pressures, historical background, organizational culture, etc. (Stringfellow, 2010). Accident analysis using STAMP also reveals the gap in the investigation at the regulator level, where the approval process has not received any significant scrutiny in the accident report.

The causal relationship explored in the STAMP based accident analysis can also be utilized for developing a causal loop diagram as per the System Dynamics (SD) methodology. Using SD, the accident mechanism at the organizational and institutional level can be represented using feedback structures in a simplified manner. Moreover, additional causal relationships can be identified.

C4-7. **The study identified a safety archetype describing the vulnerability of the operator-regulator relationship in providing adequate safety control. (Section 4.6.4, R2, O1)** Based on the accidents analyzed so far, one of the commonly occurring patterns (archetype) is identified based on the relationship between the regulator and the TOC. This new archetype, called *Ineffective Redundant Regulation*, comprises of the two-main agents; one of the agents is the regulator, and another agent is being regulated, both of whom rely on the same information and similar process to develop new standards. This method is shown to be generally applicable for the Japanese HSR as well as for the railway industry in addition to its applicability to recent Boeing's Max accidents. The archetype is helpful in highlighting the potential solutions for Ineffective Redundant Regulation Archetype.

C4-8*. One potential solution to overcome the vulnerability in the operator-regulator relationship is to have an independent risk assessment for the regulator and the organization being regulated. Another source of complexity in the archetype described above is due to the time lag in realizing the incidents after the risk level has risen. In this regard, certain leading indicators at the technical and organizational level should be developed, which, when monitored, could provide a better idea of risk level in the system*. (Section 4.6.4, O1)

Also, the relationship between the TOC and the manufacturer can be best understood from the archetype. Getting away with risky behavior seems ok, as proposed by (Stringfellow 2010). Such a system is characterized by 1) long delays before negative consequences reach decision-makers combined with immediate rewards for risky decisions; 2) numerous decision-makers, and 3) an asymmetric distribution of benefits and negative consequences among related stakeholders in a system. Often, the benefits of risk-taking are experienced by a decision-maker in the short term, while the consequences to other stakeholders are experienced for years. A number of these delays are inherent to the system, and little can be done to significantly improve these delays. However, the development of leading indicators at the organizational level could prove to be useful for risk monitoring in the system.

The key findings of the research were then also shared with HSR professionals in Japan. The key differences in the theoretical RM practices and the current Japanese practices identified through the study were well supported by the professionals. Further, limitations of the event-chain models for their applicability at the organizational and institutional levels were well understood and supported by the professionals. The interview revealed several possible factors that could explain the key differences between theory and practice and can provide important guidance for future research.

Further, STAMP results identify a greater number of accident factors at the organizational and institutional level, which the official accident report does not mention. The novel safety archetype can also help in explaining several other accidents in Japanese HSR as well as regular trains. Further, the archetype is also helpful in explaining Boeing's recent accident involving 737 MAX airplanes, thus confirming the generality of the archetype. The interview with the experts confirmed the adequateness of the safety archetype in explaining a complex set of causal relationships using simple SD representation.

In summary, the majority of the organizational issues in Japanese HSR TOCs are related to efficient risk communication within the organization. In this regard, the development of leading indicators and their effective implementation in the organization is considered as an important strategy. As highlighted in chapter 2, at present, no methods exist for organizational leading indicator development, and hence the next sections in this thesis will focus on development and effective implementation of leading indicators in an organization, such as Japanese TOCs.

Chapter 5. Generalized Leading Indicator Approach

"Learning from the past" is an important strategy for organizations managing safety for man-made complex socio-technical systems. As shown in Chapters 3 and 4, such a strategy is considered to be one of the most significant factors in the continuous system improvement for the Japanese HSR TOCs. Organizations implement several safety assurance activities to understand the gaps in the planned safety promotion and realized safety promotion within the organization. In this regard, the conventional approach of closely monitoring "near misses," an event which must be followed by some other failure to result in major failure, offers valuable learning opportunities and paves the path for future development (Leveson, 2011). However, as much as it may be justified as being a "proactive" safety management approach, in reality, it will always be a "reactive" approach (Dokas, Feehan and Imran, 2013). Thus, the need of the hour is to introduce approaches that will support proactive risk management strategies in organizations.

In this context, it is generally argued that early detection of potential failure causes of a system is an essential task in a proactive risk management strategy (Dokas, Feehan and Imran, 2013). Early Warning Signs (EWS), indicating the presence of accident causal factors, do exist and precede accidents(Leveson, 2011), and hence, systematic collection of these warning signs is essential for proactive risk management (Dokas, Feehan and Imran, 2013; Leveson, 2015).

In the previous chapter, it was identified that the identification and operationalization of leading indicators for organizational factors and organizational components are an important step towards proactive safety management in Japanese HSR. Operationalization here refers to the practice of integrating leading indicators with safety management systems of a complex socio-technical system. However, as demonstrated in Figure 2-15, the current work on EWS operationalization has been implemented primarily for technical components (or the *Physical* subsystems) and for the operation stage (Leveson, 2015). However, since the socio-technical system comprises of various non-technical subsystems (such as human, organizational, institutional subsystems), the methods for EWS operationalization must also be developed non-technical subsystems. Further, going by the argument that the "safety must be built into the system"(Leveson, 2004), there is a further necessity that the EWS must also be developed for the System Design stage.

Thus the objective of this chapter is to develop a new EWS operationalization program that is generalized for not only technical subsystems but also on social, organizational subsystems and is applicable not only for the System Operation stage but also for the System Design stage. Only such a generalized framework can then be universally applied to all the life stages of a system to proactively detect the EWS and ensure that the system remains in a safe state.

The study first presents a review of the theory of complex socio-technical systems, the safety-theory for complex systems, and the existing approaches for leading indicator identification and operationalization. The detailed review of these concepts is already presented in Chapter 2; however, here, key concepts are revisited. The review helps in identifying the requirements from a generalized indicator operationalization approach, as well as highlighting the limitations of the current approaches in achieving the requirements of a generalized leading indicator operationalization scheme. The study then attempts to develop a generalized approach, considering the requirements and limitations of the current approaches. The current study proposes two new suitability criteria to identify the appropriate receiver of the warning in a signal. These criteria are then compared for their relevance in explaining some of the accidents in the complex systems. The generalized leading indicator approach, thus developed for the study, can then be implemented for non-physical system components in a complex system. The proposed implementation steps are similar to those originally proposed in EWaSAP, except that the appropriate warning receivers can be identified using the suitability criterion described above. Further, SHOW is used instead of STPA for the analysis of the organizational and human components. The approach was then applied for a complex system in Japan, i.e., for the inspection agency monitoring the performance of decentralized wastewater treatment units

5.1. Overview of the Key Concepts

5.1.1 Concepts of Complex Socio-Technical Systems

The system comprises of a group of parts and is defined by their interactions and interdependence. In man-made systems, these parts could correspond to individual parts of a machine, which working together are responsible for its functional behavior. For example, none of the individual components of an aircraft engine has the ability to propel itself, but when combined together, they acquire the ability to propel the whole aircraft. In addition, human interactions with the machine could also affect the behavior of the man-made system; for example, commands from the airplane pilot could also affect the output of the aircraft engines. Interesting to note here is that the same aircraft engine can be classified as a technical system as well as a socio-technical system, depending upon the choice of setting up the system boundary. The system boundary is an important concept that separates a system with that of its surrounding *environment* (Sussman *et al.*, 2007). The boundary can be a *closed* boundary, not allowing the exchange of material, information, energy, etc. with its environment or alternatively, could be an *open* boundary. The behavior of the system is thus both influenced by the interactions within the system and by the interactions of the system with its environment through system boundary.

For a generalized socio-technical system, the components or the sub-systems could be broadly classified as the *Physical* sub-system, *Human* sub-system, *Organizational* sub-system, and *Institutional* sub-system. Where, *Physical* or the technical sub-system corresponds to inanimate objects such as equipment, materials, etc. *The human* sub-system controls physical sub-system (Suokas, 1985; Rasmussen and Suedung, 2000).The *Organizational* sub-system sets up goals and objectives for its functional components, allocates authority and responsibility, and generally guides activities. The *Institutional* subsystem relates to governments and regulators which provide regulate the organizational subsystem.

One of the most crucial characteristics of socio-technical systems is their goal-seeking behavior (Meadows, 2008; Arnold and Wade, 2015). Although, not all systems necessarily have a goal, however, most socio-technical systems do. For example, the railway system exists for providing safe and efficient passenger services at an affordable price. In that, systems could have multiple goals, for example, safety, energy efficiency, cost-effectiveness, etc. Often the priority assigned to these goals determines the behavior of the system (Leveson, 2004). In some cases, system goals can also be influenced by the environment. The characteristics of the general socio-technical systems are such that they can adapt (do things differently) or re-organize (corrections) themselves according to “pressures” that they feel when one or some of their goals are not fulfilled. For example, a train driver can speed up to gain some of the time caused by the delay at the origin station. For a railway infrastructure, vertical segregation of functions such as train operation and asset maintenance could occur to gain efficiency.

Based on the review presented above, the generalized socio-technical system consists of subsystems such as technical subsystems, e.g., *Physical* subsystems, and non-technical subsystems such as *Human, Organizational, and Institutional* subsystems, and interaction between these subsystems. These socio-technical systems are usually goal-oriented systems, that can adapt or re-organize themselves to avoid pressures arising from not fulfilling their system goals. Any proposed framework of operationalizing EWS for complex socio-technical systems should be consistent with these general characteristics of the socio-technical systems.

5.1.2 Overview of the Safety-theory for complex systems

The system-control theory-based accident models are proven to be effective in explaining the accidents for the complex socio-technical systems. The accident models reviewed in this study then form the basis of systematic hazard analysis in identifying potential accident scenarios for various components of the system, which in turn forms the basis of early detection of warning signs (Dokas, Feehan, and Imran, 2013). Over the years, the system-control accident models that were originally developed for physical components have been improved to be applicable for human or organizational components. Hence, a combination of these frameworks can thus be utilized when developing practical frameworks for operationalizing EWS in an organization.

5.1.3 Overview of the leading indicator approaches

A detailed review of the current leading indicator approaches is presented in section 2.5 of the thesis. Here the EWaSAP approach is re-summarized.

Dokas et al.(2013) have created EWaSAP, a process to design leading indicator programs. The important steps in EWaSAP correspond to (i) defining the data indicating the violation of safety constraints and design assumptions and (ii) specifying the characteristic of the sensors in order to perceive these data. For identifying the data corresponding to step (i), EWaSAP relies on STAMP based systemic hazard analysis process. In addition to the conventional generalized feedback-control structure, the study defines an additional type of control action, known as awareness action. An awareness action allows the controller to provide a signal to other controllers, within or outside the system boundary, when the data indicating the violation of safety constraints are perceived by the controller. EWaSAP had conceptualized a total of 4 types of signals. “All Clear” signal states the presence of the system being in a safe state. “Warning” refers to a signal that makes other controllers aware of the perception of flaws in the process that a controller control. “Alerts” represent a state that a hazard has occurred. Finally, “Algedonic Signals” refer to special warning or alerts about a perceived serious condition directly to the controllers at the highest level of the control structure. The generic control structure is shown in Figure 5-1. Additionally, guide words for accident taxonomy are then proposed, such as accidents can happen when warning signals are not transmitted, are wrong, or are not perceived.

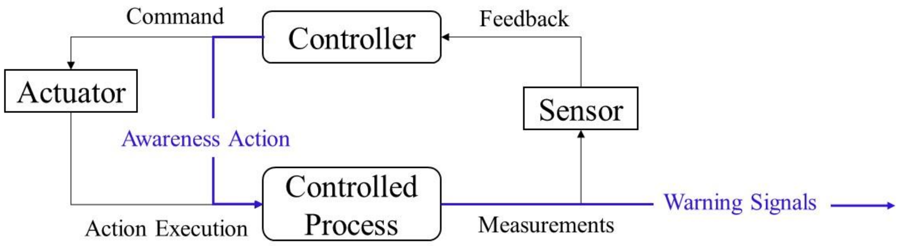


Figure 5-1 Generalized feedback-control structure for EWaSAP

Adapted from Dokas et al.(2013)

5.2. Requirements of a generalized EWS program for an organization

Based on the review of basic concepts of safety theory, the accident models, and the current approaches for EWS, presented in Chapter 2, requirements of a generalized EWS program can be identified as follows –

a.) *Lifecycle requirement* – the original STAMP model, has been developed for both System Design and System Operation phase, whereas, the current EWS programs is limited only for System Operation stage. The generalized EWS program should be extendable to all the life stages of a system.

b.) *Controller-level requirement* - The STAMP accident model was developed primarily for physical subsystems or physical controllers. On the other hand, the current approaches for the EWS program, such as EWaSAP, have been developed for physical subsystems operations. In order to develop a generalized EWS program, approaches (new or like EWaSAP) must be extended to components other than the physical subsystems. A similar need to extend EWaSAP for organizational controllers has also been voiced by (Leveson 2015).

c.) *System-level requirements*- Considering the general characteristics of the complex socio-technical systems, the generalized EWS program should appropriately consider the goal-seeking behavior of the systems, i.e., the process of goal setting, progress monitoring, and corresponding adaptations or structural-changes should be considered. Since the systems can have multiple goals, and hence, the generalized EWS program should consider interactions between various components interacting for fulfilling safety and other goals.

Based on the requirements described above, first, a consistent framework for consideration of the underlying mechanism on system-evolution is necessary. While, for physical components, a clear distinction between system design, system operation, and corresponding system evolution stages can be made, the same is not necessarily possible for a human, organizational, and institutional components. Non-physical components are often in a stage of continuous evolution. Thus, a generalized operationalization scheme should consider the mechanism of system evolution in detail in order to satisfy the lifecycle and controller level requirements described above. Second, the generalized framework also has to give adequate attention to the possibility of local adaptation by the human, organizational, and institutional system components upon sensing the presence of accident causal factors.

In the next section, specific limitations of the current accident models and EWS approaches for satisfying the above-mentioned requirements have been highlighted. The proposed generalized EWS program could then be developed by improving upon the limitations of the existing approaches.

5.3. Limitations of the current model and EWS approaches

5.3.1 Limitation in satisfying lifecycle requirements

A review of the accident models for different types of controller reveals that consideration of system life-stages is different in each of these models. For physical subsystems, it is indeed easy to demarcate clearly, end of a system design phase and beginning of the system operation phase, for example, new rolling stock for the railway system, is in the development stage and once approved by certain agents, can then be put into operation. System evolution is thus described as a process, where feedback from system operation leads to improvement in the physical subsystems (Leveson, 2004). However, the System Design stage is impossible to describe for components other than physical. For example, for an employee (human component), hired at any point in time of her/his professional life, the behavior will largely be governed by her/his previous experiences (Stringfellow, 2010), since birth, and it is difficult to characterize her/his initial stage at the beginning of their active participation in the system. Similarly, it is difficult to describe a system design phase for organizational or institutional subsystems (Kazaras, Kontogiannis, and Kirytopoulos, 2014). The only generalizable fact about these subsystems is that they are in a stage of continuous evolution based on the feedback received from various stakeholders having influence over these subsystems (Stringfellow, 2010; Kazaras, Kontogiannis and Kirytopoulos, 2014). Adequate address of this difference between the notation of system evolution for various components will be an important step towards a generalized framework of EWS in an organization. To adequately represent this difference, a solid line has been used to denote the boundary between System Design and Operation Stages for physical subsystems, whereas only a partial boundary is used for other components in Figure 2-12.

5.3.2 Limitation in satisfying controller level requirement

Two types of controller-level requirements can arise from two distinct steps in the EWS process. The first step in the EWS program is to identify the warning signs. The identification of these warning signs is dependent on the process of hazard analysis adopted. As discussed before, the system-control theory-based accident hazard analysis methods were originally developed for physical subsystems. However, over the years, the STAMP based systematic approaches of hazard analysis has been improved to capture the processes for the Human and organizational controllers better. Thus, accident models such as SHOW or STAMP-VSM could be applied for a generalized EWS framework. Although current processes for institutional controllers such as regulators, etc. have not been addressed explicitly (Figure 4) and should be explored further. In doing so, either new accident models for institutional controllers should be developed, or the applicability of the existing accident models for institutional level should be confirmed.

The second step in the EWS program (with reference to the EWaSAP scheme) is to issue a warning signal when a specific controller senses the presence of potential accident causal factors. In such a framework, awareness actions are effectively issued only when the information about the potential causal factors as well as sensor characteristics that indicate the presence of such causal factors are both defined without ambiguity (Dokas, Feehan and Imran, 2013). However, there is a greater likelihood that both of this information are not defined in a non-subjective manner. For physical subsystems, such ambiguity could result in warning signals not being issued. However, for controllers other than physical (not considered by the current EWaSAP approach), other reactions, as opposed to the intended awareness action, could occur. Several such examples from reported accidents are reviewed here to identify potential reactions from non-technical controllers upon sensing the warning signs.

In 1974, for a High-Speed Train in Japan using the Automatic Train Control (ATC) system, showed a speed-limit of 30 km/hr while the point (the location where rails intersect) was closed (not suitable for the current train to move ahead) (Saito, 2002). In this case, the driver chose to apply the brakes rather than blindly following the speed limit shown by the cab signal. This example demonstrates that human controllers can adapt to providing their control actions upon perceiving the warning signs. Although, the adaptation by the driver, in this case, was helpful in avoiding the accident. Another incident related to High-Speed Train involving the ATC system occurred in 1973. For a train approaching a main-line, the ATC system showed a speed-limit of "zero." Both the driver and the ATC system had applied brakes; however, the train failed to stop and entered the mainline (a clear sign of the presence of hazardous condition). The confused train driver and the traffic controller thus adapted and tried to reverse the train (an unusual control action possible because of the lack of understanding of the risk of reversing the train), leading to a derailment of the train (Saito, 2002). This example also demonstrates that adaptations can occur for the Human and Organizational controllers upon receiving the warning signs. The adaptations, in this case, led to the system being in a hazardous state.

For controllers at the human and organizational level, it is possible that they do not issue a warning sign even after clearly knowing that the information obtained through sensors indicates the presence of the hazardous state. This tendency of the human/organizational controller could generally be linked with the reporting culture of the organization.

The above-mentioned examples clearly highlight that upon receiving the warning signals, adaptation may occur for non-technical components. Although, as part of safety research, the mechanisms of the adaptation must also be studied carefully, however, for the purpose of the current study, it should be sufficient to be aware that any generalized EWS program should also consider the effect of such adaptation for a different type of controllers.

5.3.3 Limitation in satisfying System-level requirements

In the previous section, the effect of sensing the presence of potential accident causal factors on the individual controller was described. In this section, the limitation of the current studies in considering the impact of warning signals upon the receiver is considered. Such consideration is important from the perspective of interactions among various components, as per the theory of complex socio-technical systems described in section 5.2.1.

Warning signals are an important type of feedback that indicates the increase in safety pressure arising due to the non-fulfillment of the safety goals. Accidents can occur in the absence of a mechanism to allow for the adaptation to happen based on feedback (Kazaras, Kontogiannis, and Kirytopoulos, 2014). Thus, it is the expectation from a pro-active safety management approach of developing general

EWS program, that it will help facilitate the communication of the warning signs to appropriate controllers, so that resulting adaptation could be adequate.

The EWaSAP method does not describe any suitability criterion for selecting the appropriate receiver of the transmitted signal, except for the "Algedonic Signals." In part, this could be because the EWaSAP method is applied for a physical system in operation, where the identification of the suitable controller could easily be possible by asking simple questions about the reporting channels of an existing structure. However, any attempt to develop a generalized EWS program should clearly define the suitability criterion to seek suitable controllers among the numerous components that are linked with each other as part of complex organizational processes.

On the other hand, for any given complex socio-technical system, safety is among one of the multiple goals. Hence, it may happen that a few of the system components, do not have a direct role to play in safety, but they may affect the safety, through their interactions and adaptations related to other goals. One important limitation of the system-control feedback structure is that it is the functional representation of safety-related responsibilities for various components. However, in complex socio-technical system, the process may involve a diverse set of relationship among components, such as resource allocation, performance appraisal, appointment, procurement, etc. (Dulac, 2007), and often these relationships could also, directly or indirectly, affect the safety responsibilities of the components (Stringfellow, 2010).

Hence, a set of general requirements for a general EWS program is that it should adequately consider the effects of a variety of processes in a socio-technical system and present the effects in an easily communicable manner. A few of the above-reviewed studies have attempted to present the effect of such organizational processes etc. through use of executable causal loop diagrams (CLD) using the concepts of a methodology called System Dynamics (SD) (Sterman, 2000), in addition to the STAMP based hazard analysis (Dulac, 2007; Stringfellow, 2010). Such methods, which are crucial for demonstrating the boundaries of safe performance to the stakeholder, serve an important objective of the proactive risk management, as described by Rasmussen and Suedung (2000), and efforts must be made to improve the communication further.

5.3.4 Summary of the review

The literature review also suggests that the accident models based on system-safety theory are now well-developed to be applied for all types of system components, across all system life-stages. Hence, system-safety theory-based hazard analysis tools such as the System-Theoretic Accident Model and Process (STAMP) (Leveson, 2004) and STAMP extension for Humans and Organizations using guide words (SHOW) (Stringfellow, 2010) can be applied to leading indicator identification for various kinds of system components.

However, several modifications are necessary to generalize the existing indicator operationalization schemes, such as EWaSAP (Dokas, Feehan, and Imran, 2013). EWaSAP is a powerful approach. However, it has several limitations to satisfy the requirements for the generalized operationalization approach described above. EWaSAP focuses only on physical indicators during the system-operation stage. However, the possibility for its extension to other system component types has also been emphasized (Leveson, 2015). Furthermore, the EWaSAP approach does not consider the possibility of local adaption by the Human or Organizational components, which first sense the presence of accident causal factors. In addition, the EWaSAP approach does not define a clear criterion to identify suitable receivers for all warning signals generated upon the enactment of the awareness actions, and thus does not fully consider the integration of indicator operationalization into the existing SMS.

In the next section, an attempt is made to develop a generalized approach, considering the requirements and limitations of the current approaches.

5.4. Proposed new Generalized EWS approach – the GEWaSAP

In this study, the excellent framework for operationalizing the EWS program, called EWaSAP (Dokas, Feehan and Imran, 2013), is utilized to develop it further for a generalized system. This new generalized framework is termed as GEWaSAP. The following section describes the salient features of the GEWaSAP approach.

5.4.1 Generalization across the system lifecycle

As demonstrated in section 5.3.1, the continuum paradigm of system evolution is generally applicable for all subsystems other than the physical subsystems, which have a clear distinction of system design and system operation stage. Thus, to maintain the uniformity across different types of a subsystem, this section explores the applicability of the continuum paradigm of system evolution for physical subsystems.

There is no denying to the fact that technical systems have a clear point in time, which can mark that the fabrication process of the technical system has been completed, and the system can be put into operation, e.g., a newly manufactured rolling stock is finally put into passenger service. However, in almost all system development protocols, for physical systems, there is a continuous evolution even during the system design stage. For example, it is almost rare that a physical system is conceptualized from zero. The construction of the system inarguably relies on accumulated knowledge from similar or other system experiences. Further, in almost all system development protocols, there is a component of running test (e.g., for new aircraft development, or new rolling stock development) as an essential process in determining whether the system qualifies for going into real operations (example in Figure 5-2, for aircraft certification). These running tests are necessarily a representation of the potential operational conditions that may occur when the system is in operation (e.g., carrying passengers or cargo). Based on the results obtained from running tests, the system can be further modified (or evolved). Thus, the system evolution can be considered as a continuous process characterized by cycles

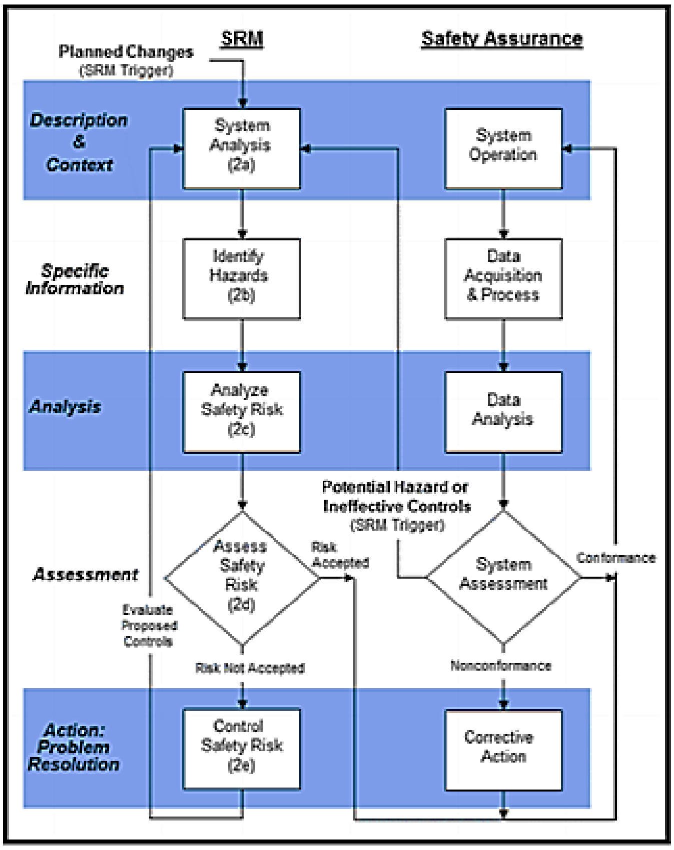


Figure 5-2 Safety Confirmation Process, Order 8040.4B, Federal Aviation Administration

of system development and system operation. Inclusion of such a view on system evolution can then allow the control-feedback based accident models and related process to be directly applicable for micro-cycles of system change even during the system development stage for physical systems.

The process of receiving feedback from operation stage, is also similar to the continuous inputs from stakeholders for improving the system (generally applicable for organizational and human subsystems), whose inputs are dependent on the state of the system, and whose input then change the current state of the system (Stringfellow, 2010; Kazaras, Kontogiannis and Kirytopoulos, 2014). Hence, with the continuum ideology of system evolution, the STAMP, and the STAMP based EWaSAP, becomes generally applicable for all type of subsystems, even for whom the system design stage is not clearly defined.

Hence, the study hypothesizes that the paradigm for continuous system evolution is generalizable not only for the non-physical subsystems but also for the physical systems. The hypothesis is grounded in a review of the practices of system-development prevalent in several industries. In general, the system development stage is also accompanied by system testing (equivalent to system operation)[15], and multiple modifications are made before the system is put into commercial operation. Such practices thus confirm that system evolution is a continuous process even for physical subsystems.

In the next section, a generalized mechanism of the system evolution is identified by reviewing the current leading indicator approaches and their treatment to system evolution.

5.4.2 Mechanism of System Evolution

As discussed in section 5.3.3., for appropriate adaptation to occur in a system, the warning signs should reach an appropriate system component, and hence, an EWS program should also be able to identify the suitable receiver of the warning sign. In order to be able to develop a suitability criterion, we must first understand what happens when the warning signs reach to a specific system component.

Firstly, as described in (Dokas, Feehan and Imran, 2013), for a receiver a warning sign could be an opportunity to update process models for their own controlled processes, or it could also serve as important means to update the organizational process model (Stringfellow, 2010), meaning that there is a possibility that, that the warning receiver may adapt upon receiving the warning signs. It is also possible that the receiver does not comprehend the warning sign, and no adaptation occurs.

To further understand the possible outcomes of one system component receiving the warning signs, the role of a special system component presented in the dual control-structure of STAMP, i.e., the role of Maintenance and Evolution (M&E) component should be examined. A simplistic representation of the same is shown in Figure 5-3.

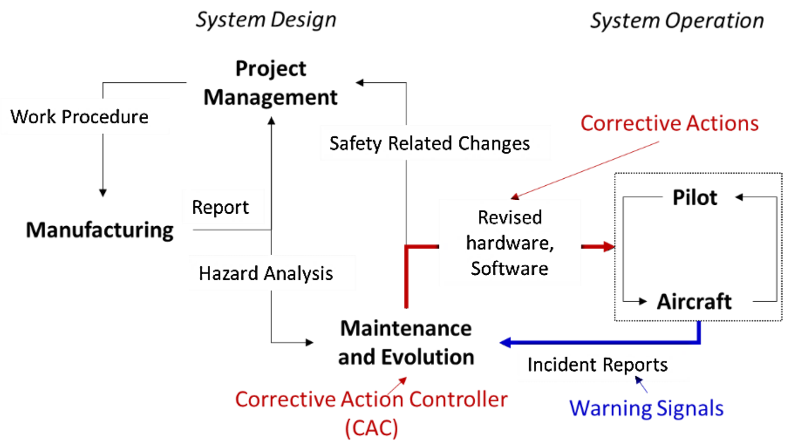


Figure 5-3 Role of M&E component in the generalized SCS of STAMP

[15] For example, the safety confirmation process of Federal Aviation Administration, Order 8040.4B

A closer look at the functionality of the M&E reveals that the actions provided by it cannot be classified as the typical control actions. As per the Handbook of STAMP [16], a control action must be given with a goal to achieve a certain state, and ideally, it should involve supervision. Hence, despite having the ability to affect the Physical subsystem, the actions from M&E are not *Control Actions*, as they are likely triggered only after the feedback is received from the system operation and not otherwise. In a strict sense, the actions provided by a component responsible for system maintenance will still be a control-action, as the maintenance could be pre-planned. In the original example used by (Leveson 2004) of the aircraft manufacturer and the airline operator, the manufacturer is defined as a component responsible for system evolution. In that case, the manufacturer is not constantly monitoring the operating performance, but only responding to the feedback provided by the airline operators. Thus, the functionality of M&E tells us, that there is a possibility that a component might issue further actions (different from control-actions) upon receiving the warning signs.

Taking cues from the original STAMP for physical subsystems, the process of system evolution can then be generalized for all other types of subsystems. In STAMP, a "*Maintenance and Evolution*" component plays an important functionality. Essentially, it provides, what this study term as "*Corrective Actions"* (CA) upon receiving the problems in operating performance (i.e., warning signs).

CA could be of the form of revised operating procedures that are aimed to change the control algorithm of the controllers at the physical subsystem and thus can change the control actions that these affected controllers provide. The study uses the term *Control Algorithm Corrective Action (CACA)* for such actions. Alternatively, corrective actions are of the form of software revisions or the hardware replacements, that essentially affect the functioning of the structure of the feedback control loop. For example, providing a new software update could shift the relative control to the machine controller than the human-controller, effectively altering the structure of the original feedback-control loop. The term *Control Structure Corrective Action (CSCA)* is used to describe such actions. CSCAs can permanently alter the feedback-control structure and thus can affect the ability of the SCS to enforce safety constraints. Important to note here is that the "*Maintenance and Evolution"* controller is embedded into the System Development SCS, and thus the corrective actions provided by the "*Maintenance and Evolution"* controller are approved by the system development SCS.

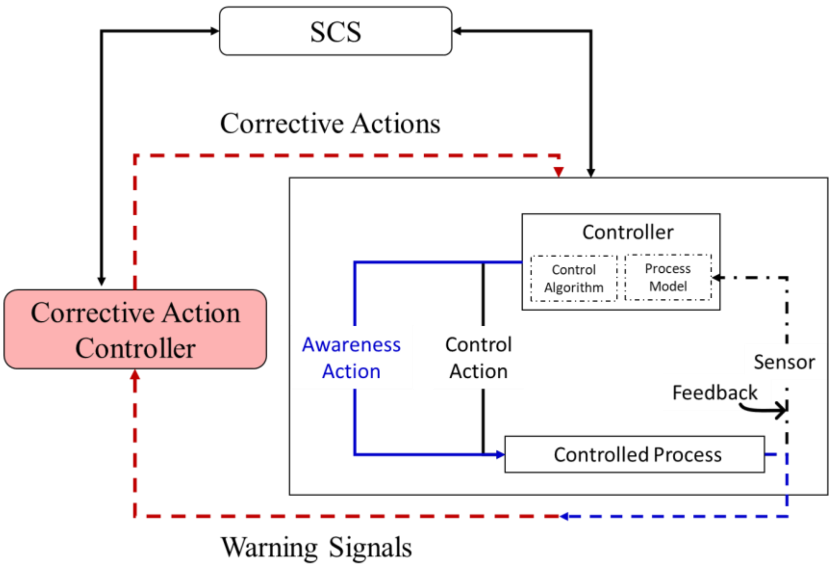


Figure 5-4 Overview of the Corrective Action Controller

Now, by identifying at least one "Maintenance and Evolution" as a controller, termed as *Corrective Action Controller (CAC)* for each type of subsystem in the SCS, the process of system

[16] https://psas.scripts.mit.edu/home/get_file.php?name=STPA_handbook.pdf

evolution can be generalized for all types of subsystems and is shown in Figure 5-4. Upon receiving the warning signals, a corrective action controller can issue a CA. Thus, CA is a special type of control action, which is contingent upon receiving the warning sign. The objective of the corrective action is either to change the structure of the feedback-control structure from where the warning was originated or to provide updated control algorithm for the controller issuing the warning sign. In a correctly designed system, the corrective action controller should be part of the overall SCS, and its action must be based on the safety constraints imposed by the SCS.

Although the above-mentioned corrective-action control structure, is derived for safety responsibilities, however, the same structure can be used to represent the interaction of safety functions and the normal organizational process. In that, the corrective action controller does not have necessarily have to be part of the SCS and, the warning signal does not necessarily have to be in the context of a potential safety issue. The warning signals could also represent pressures for other organizational goals such as financial goals etc. CA thus provided should be paid special attention to as they might affect safety SCS without the direct intention to do so. In this way, the corrective action controller feedback structure shown in Figure 5-4 can be utilized to understand the interactions among functional safety components and the organizational process components.

5.4.3 Developing Suitability Criteria for warning signal receiver

The corrective action control structure shown in Figure 5-4, is also helpful in identifying additional causal factors (Guide Words (GW)) in which accidents can occur.

For example, an accident can occur when,

GW (1) **-** Corrective Actions are not given

GW (2) **-** Corrective Actions given are wrong

GW (3) **-** Corrective Actions given are delayed

The situation related to GW (1), can thus arise out of numerous causes. Warning signs perceiving ability is one such cause identified in (Dokas, Feehan, and Imran, 2013). However, it might also be possible that warning signs are not received by the controller who can provide adequate CA. The general principle, that warning signs should reach at least one corrective action controller, who can provide CAs for the part where the warnings were first observed, could then serve as a *First suitability criterion* for warning signal receiver. Hence, a mapping of organizational components that could issue CAs to a given part of SCS should be prepared in advance, and the EWS program should be made consistent using the first suitability criteria identified above.

The situation related to GW(1), GW(2), and GW(3) could also arise when, for example, a metaphorical Corrective Action Algorithm(CAA) of the corrective action controller is nonexistent, faulty or not updated. The corrective CAA is deemed metaphorical because there is a high likelihood that such an algorithm is not predefined because the situation leading to warning signals is likely infrequent or unknown. In this regard, it is generally expected that the CAs should be determined such that they do not weaken the SCS and push the system towards the boundary of safe behavior. A suggested appropriate way for the correct determination of CA could thus be that CAs should be based on thorough risk assessment and be determined through stakeholder consultations and not based on local adaptations that may occur upon receiving warning signs. Thus the *second suitability criterion* for identifying the appropriate receiver of the warning sign should be that the warning Signs should reach at least one controller who can check for local safety-related adaptations for each of the system components, which either originally sensed the presence of hazardous causal factors, or received warning signs from other controllers.

5.4.4 Steps for GEWaSAP approach

In this section, detailed steps to implement the proposed generalized approach are shown. The generalized leading indicator approach, thus developed for the study, can then be implemented for non-physical system components in a complex system. The proposed implementation steps are similar to those originally proposed in EWaSAP, except that the appropriate warning receivers can be identified using the suitability criterion described above. Further, SHOW is used instead of STPA for the analysis of the organizational and human components. The necessary steps are marked as GEW and have been shown in the fourth column of Table 5-1.

As highlighted in the original EWaSAP, for step EW (1), coordination with the external stakeholder should be established. This external stakeholder should be informed about the perceived progress of the hazard occurrence. An additional step is proposed here for the current GEWaSAP. Such an external stakeholder should be identified by applying the proposed suitability criteria described in section 5.4.3. Similarly, the voluntary early warning signs from the surrounding should also reach to the receiver selected by the proposed suitability criteria.

Table 5-1 Proposed steps for GEWaSAP analysis

Sequence	***EWaSAP Steps***	***EWaSAP Description***	***Proposed Modifications in GEWaSAP***
1		Identification of Hazards and system-level constraints	
2	*EW (1)*	Coordination with external stakeholders who needs to be informed about the perceived progress of the hazard occurrence	
2'	*GEW(1)*		In addition to the EW(1), identify the Appropriate Corrective Action Controllers for various levels of SCS and apply the "Suitability Criterion" for selecting appropriate warning signal receiver
3		Create the SCS and identify the inadequate control actions that can lead to hazards	
4	*EW (2a)*	For each top-level safety constraint, identify those signs which indicate its violation	
	EW (2b)	Find those systems in the surrounding environment with sensors capable of perceiving signs defined in EW(2a) and request to establish Synergy. The surrounding system should be able to transmit voluntary early warnings to appropriate recipients	The voluntary early warnings from the surrounding system should reach to the receiver selected upon the *Suitability Criteria.*
5		Determine how the potential Hazardous control actions could occur	Depending upon the type of controller, the guidewords should be taken from the appropriate accident model. For example, for analyzing the organizational controller, SHOW, or the STAMP-VSM based framework, must be used.
6	*EW (3a)*	Describe the items for monitoring and the characteristics of the sensors such that controllers can perceive - (a) The sign indicating the occurrence of a flaw	

		(b) The violation of assumption made during the design of the system	
	EW (3b)	Describe the pattern of perceived data that indicate the occurrence of the flaw or violation of its designing assumption	
	EW(3c)	Update the process models of the controllers with appropriate awareness actions and control actions which should be enforced based on the perceived warning signs	
	EW(3d)	For each perceived warning sign, define the meta-data for the sign so as to ensure that it will be perceived and ultimately understood by the appropriate controllers.	
7	*GEW (2)*		Update the process models of the Corrective Action Controllers with appropriate corrective actions which should be enforced based on the perceived warning signs
8		Restate the flaws identified in the previous steps and repeat the steps (3-7). If necessary, revise the control structure diagram to depict new components or more detailed information on each identified component.	

In addition, in the original EWaSAP study, hazard analysis was proposed to be conducted using STPA as an approach, due to its proven ability to identify the potential hazards in a systematic manner for complex socio-technical systems. However, STAMP has received some criticism for relying acutely on the physical systems (Kazaras, Kontogiannis and Kirytopoulos, 2014). Hence, an accident model and hazard analysis method suitable to be applicable for non-physical components are often necessary.

In our review of the safety theory in Chapter 2, two such methods for hazard analysis at the human and organizational level components have been discussed. These are SHOW by (Stringfellow, 2010) and a joint STAMP-VSM approach by (Kazaras, Kontogiannis, and Kirytopoulos, 2014). A comparative analysis of the two models presented in Chapter 2, also demonstrates that the SHOW includes more failure patterns and utilize a process similar to the STPA. Since the original EWaSAP study had developed steps by combining the steps of the STPA analysis, SHOW seems to be a natural choice for conducting a similar analysis for non-physical components. However, in the proposed methods, there is no restriction of utilizing SHOW alone, and any method suitable for such analysis for complex socio-technical systems should serve the purpose.

5.5. The theoretical underpinning of the proposed approach

The original EWaSAP was developed for the system operation stage of the physical subsystems. In the proposed GEWaSAP approach in this study, the focus has been on generalizing the EWaSAP for across life stages (continuum notion of System Evolution) and for all types of controllers. The additional guidewords were identified as potential contributing factors to accidents, and based on that, the suitability criterion was proposed. In this section, the ability of the proposed suitability criterion in explaining the real-world situations is examined. The examination is conducted using multiple aspects as follows

a.) Comparison with real-world accidents in complex systems b.) Comparison with other theoretical frameworks

5.5.1 Comparison with real-world accidents in complex systems

5.5.1.1 2017, Crack in Bogey Frame case for High-Speed Train in Japan

The Japanese high-speed train or *Shinkansen* were known for their commendable safety record of zero passenger fatalities since the beginning of its operation more than 50 years ago. However, in December 2017, on a Shinkansen traveling from Hakata to Tokyo, a crack in the bogey frame was detected in an operating train. The accident was termed as the first "serious accident" in the history of the Shinkansen and triggered a detailed inquiry (Japan Transport Safety Board, 2019). Although the train operating company was heavily criticized for the continued operation of the train even after discovering the unusual noise/odor/vibrations, the focus of this analysis is on the manufacturing of the concerned bogey frame, almost a decade ago, where the roots of the accidents were laid.

As per the official report of the bogey manufacture (Kawasaki Heavy Industries Co. Ltd., 2018), the crack propagated because the thickness of the bogey frame near to the connected springs was less than the nominal accepted value. The thickness of the frame was inadequate because of the excessive grinding of the bottom surface of the frame. Further, the thermal cracks resulting from the inadequate heat-treatment of the part quickly propagated to dangerous levels for a frame with smaller thickness. The causal links for excessive grinding were traced back to change in the supplier of the side-bogey frame. The new supplier had used a different method for part fabrication, which affected the overall fitting of the new bogey frame.

Such, problem in the fitting of the part was discovered by the workers at the shop-floor assembling the bogey, and they indeed reported it to the Shop-floor manager (Warning Signs). However, the manager, unaware of the fact that the supplier and thus the fabrication method of the part concerned had changed (inadequate process model), told the workers that it was all right for them to grind (Wrong CA due to incorrect local adaptation), without checking the actual thickness of the concerned frame.

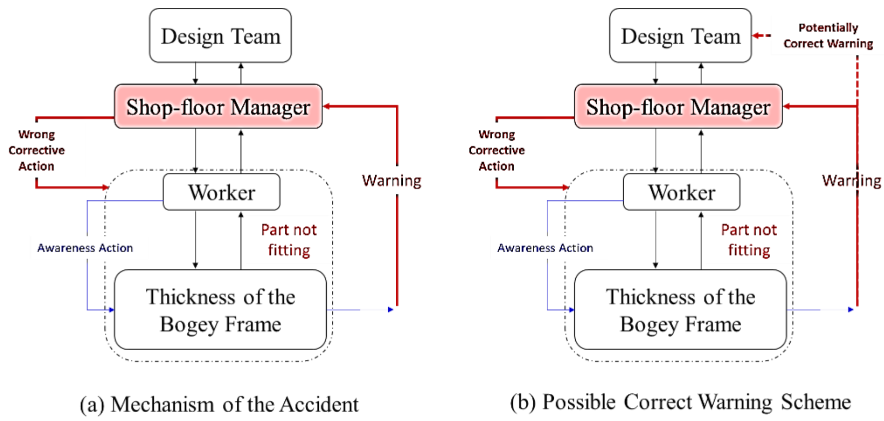


Figure 5-5 The accident mechanism for Shinkansen through GEWaSAP

Considering the nomenclature presented for GEWaSAP, the worker at the shop floor is a controller to enact an awareness action upon sensing the potential accident causal factors (that the parts do not fit). In this case, the shop-floor manager was one of the CAC as it can issue CACA for the worker, as well as CSCA, by rejecting to use the specific part supplied. So, in that case, the first suitability criterion was fulfilled as the warning signal reached to at-least one CAC. However, in this case, the CACA issued by the shop-floor manager was not based on adequate consultation, and there was a local adaptation by the shop-floor manager, resulting in an unsafe control action for the worker. Here, the second suitability criterion was not satisfied as the warning sign did not reach to the controller who could sense the local adaptation of the shop-floor manager. In fact, the official accident report suggests that the shop-floor manager's over-reliance on the past judgment and lack of coordination in issuing the updated action (for example, consultation with the original design team) was instrumental in this accident (Japan Transport Safety Board, 2019). Although the purpose here is not to blame the accident on the manager, as the manager's decision was also influenced by the fact that the change in supplier was not adequately discussed in the organization and in fact, the shop-floor manager was not aware of such change at that time. However, this incident supports the necessity of the second suitability criterion. The GEWaSAP allows us to present the scenario graphically and is shown in Figure 5-5(a). Figure 5-5(b) shows one possible scenario to avoid this incident using a direct warning channel between the workers at the shop-floor and the design team. Alternatively, if the Shop-floor manager had clear facilitating conditions for him to communicate with higher authority readily, the issued CACA or CSCA could have been with thorough risk assessment.

5.5.1.2 British Petroleum's Gulf of Mexico Blowout

In 2010, the blowout accident at British Petroleum (BP)'s Macondo exploratory well in the Gulf of Mexico, led to the killing of 11 people and was termed as one of the biggest environmental damage in North America. Blowout refers to the situation where the oil and gas from the reservoir, enter the drilled well and leak to the surface of the rig or the seawater. Numerous causes have been identified for this accident, focusing on the initial design of the well, the drilling operations, and the post-disaster response, a very comprehensive analysis is presented in (Tafur Muñoz, 2017). However, the focal point of analysis in this study is about the design of a cement seal that is created post-drilling operations to prevent the hydrocarbons from the reservoir enter the well. The SCS and GEWaSAP related factors are shown in Figure 8.

The drilling engineers were responsible for designing wells and ensuring that these wells complied with various safety guidelines and regulations. They also have to request the design specifications, models, etc. from the specialist contractors (in this case, contractors for cementing process) and have to present such results for BP's management. The engineering managers, in this case, were responsible for the management of changes while ensuring compliance with various safety requirements. Hence, the engineering managers were one of the Corrective Action Controllers who could issue both CACA and CSCA.

As per the analysis presented in (Tafur Muñoz, 2017), the drilling engineers had sensed that the proposed cementing action would not act as a barrier and had communicated their concerns to the engineering managers, who are indeed appropriate receiver of the warning sign as per the suitability criteria. However, the engineering managers did not issue any corrective actions in this regard, and hence, the inadequate cementing process got approved, which was one of the main factors involved in the blowout. One of the prominent arguments, exploring why the engineering managers had approved such a process, relates to the organizational structure and the incentives provided to the engineering managers. The engineering managers were also incentivized for the time and cost-efficiency of the good construction. Further, these managers reported to the senior executive of the Gulf of Mexico, who were primarily focused on managing the efficiency of the line, and not the safety. Moreover, these executives rarely would have understood the technical issues. In this regard, even the prominent safety researcher have argued that, if such warning signs could have been communicated to high-level decision-makers early in the process, the catastrophe could have been avoided (Hopkins, 2019), thereby confirming that indeed, the second suitability criterion is essential for determining the appropriate receiver of the warning.

5.5.1.3 Accidents in other fields

While a detailed comparative study for accidents in various other fields is not possible, a discussion with regards to general categories of fields is presented here. In this regard, a novel approach to classify the systems as proposed by Pariès *et al.*(2019) is utilized. The classification proposed by (Pariès *et al.*, 2019) is as follows.

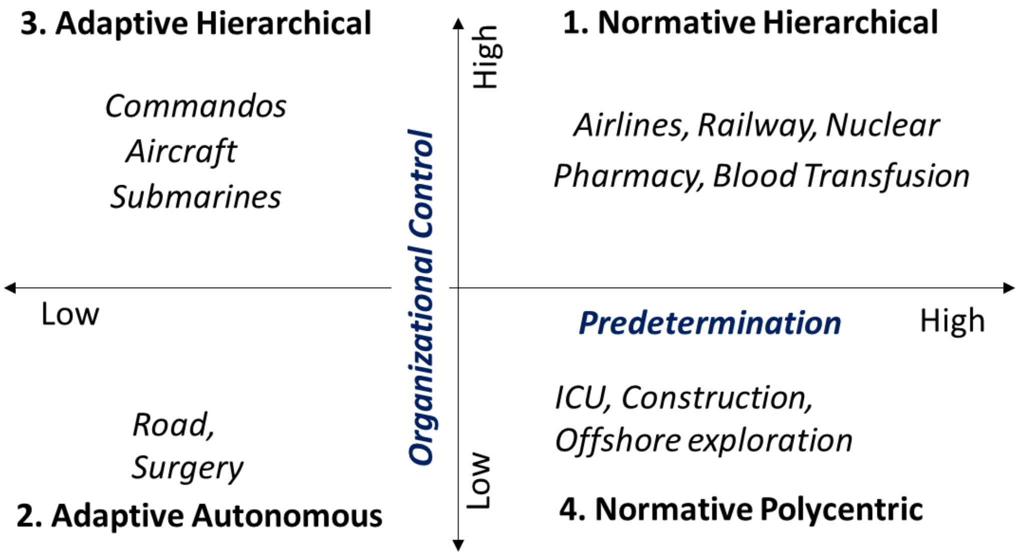


Figure 5-6 Classification of SMS systems

Adapted from (Pariès et al., 2019)

Pariès *et al.* (2019) have defined 4 types of systems based on their variation in two dimensions, i.e., Degree of Centralized control and Degree of pre-determination. The 4 types of systems thus formed, namely 1, 2, 3, and 4, are shown in Figure 5-6. The characteristics of these systems are summarized in Table 5-2. After a brief description of each of the systems, the common accident causes are identified in each of them. Once such common causes are understood, the suitability criterion proposed in this study is discussed for their applicability in each of the situations.

Table 5-2 Characteristics of various systems

Factor	***1 - Normative Hierarchical***	***2 - Adaptive Autonomous***	***3 - Adaptive Hierarchical***	***4 - Normative Polycentric***
Operating Environment	Reduced dimensions of variability	Navigate high level of unpredictability	High level of unpredictability	Variability in operational situations
Expectations of the Front-line Staff	Compliance to norms and hierarchical control	Manage trade-off between risk and performance, Self-regulation among flexible teams	Trained and disciplined front-line staff acting in a tightly coordinated and standardized way	Highly trained, specialized and cooperative teams
Learning	Learning for expanding the repertoire of the unknown	Learning for determining the adaptive response	Learning for determining an adaptive response	Learning for improving coordination among teams
Flow of Information	Bottom-up	Remain at the bottom	Bottom-up	Bottom-Up
Information Processing / Prime responsibility of Safety	Top-Management	Local Agents	Top-Management	Local operative teams
Importance of Standardization	High	Low	High	High

The 1st type of system is Normative Hierarchical systems. These systems are characterized by a high degree of centralized control, where the response of the front-end staff is determined based upon the pre-agreed standards, procedures, and responses. The objective of the system is to operate in a pre-determined zone of safety. Such organizations engage in learning to improve their responses against the known potential hazard, but not to prepare for any eventuality that may unfold. Hence, the responsibility of the safety lies at the top management for planning and executing adequate responses against all known eventualities. The role of the front-end staff is largely to execute the procedures. In such type of a system, the presence of the warning signs is sensed by the front-end staff, and the information should then reach as high in hierarchy as possible as quickly. For such a system, the applicability of the proposed suitability criteria can be readily shown. The example of manufacturing in the HSR accident discussed above also falls in the same category.

The 2nd type of system is Adaptive Autonomous systems. In such systems, the responsibility of information collection, information processing, and corresponding execution all lie on the local agents. Pariès *et al.* (2019) suggest that for safety, the adaptive response of the local agents is essential, and accidents can happen when the local agents are overwhelmed with the information load.

However, in such a case, the proposed suitability criteria to identify the appropriate receiver of the warning hold little meaning, as the corrective actions should also be determined by the local operator/ or the local agent themselves. Nevertheless, even in such cases, the information about the potential warning signs should be shared with certain controllers at a higher level in the SCS, who could provide CAs such that the system design should be improved. For example, in the road-safety system, most safety-related decisions must be taken by the driver during the vehicle operation. While driver (human) may have to take great efforts to observe its environment as much as possible and act accordingly. The driver should also receive certain warning signs about the system's current state to make a calculative adaptation. For example, humans may have difficulty in judging their exact speed, purely observing based on their surroundings, and an accurate signal about the speed of the car, and the speed limit is necessary for safety in many situations. Hence, in this situation, certain system-level information should always reach an appropriate CAs for enabling safe operations, thus supporting the basis of 1st suitability criterion. Further, even in such cases, information about the reliability of the brakes, the reports from the crash-tests, issues about the car designs, etc. should all be communicated to the automobile manufacturers so that the design of the cars could be improved (using 2nd Criterion) . Hence, for an Adaptive Autonomous system, the suitability criteria proposed in this study may not be meaningful in avoiding a specific accident from happening in a short time reference but may contribute to the overall safety in the long term.

Similarly, the applicability of the proposed suitability criteria can also be demonstrated fo the other two types of systems, i.e., Type 3 Adaptive Hierarchical System and Type 4 Normative Polycentric System. For type 3 systems, the warning signs generated locally, should again quickly reach to the agencies executing centralized coordination. Both the suitability criterion proposed in this study, are then adequate, as they seek to establish such information coordination so that the safety objectives are not jeopardized by local adaptations of the front-end agents. Type 4 systems are more similar to the type 2 systems in terms of their requirement for information collection, processing, and acting upon, and similar discussions thus can also be made, once again supporting the applicability of the proposed suitability criterion in explaining the process of information coordination. The example of the Macondo well demonstrates that the aspects of the process safety, such as the design of the well-seal, should be controlled as centrally as possible, and hence 2nd suitability criterion is necessary to improve safety on a longer timeframe.

5.5.1.4 Summary of Comparisons with Accidents

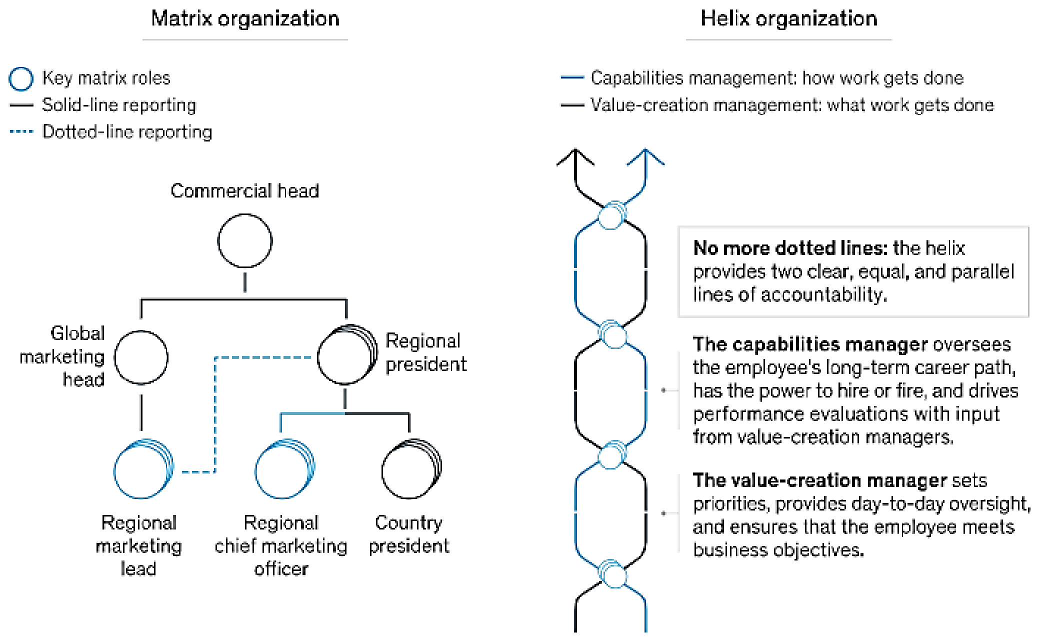
Based on the discussions presented in the current section, the proposed two criteria seem to be generalizable in the context of all complex systems. However, an important consideration for utilizing these for designing the information flow within the SCS is to consider the urgency of the situation and the timeframe in which the CAs need to be implemented. In general, the proposed criteria are suitable to manage safety issues arising due to systemic factors in all types of systems. Systemic factors need to manage through centralized planning, coordination, and execution, and hence, the information should reach the controllers at the top as soon as possible (Leveson, 2015; Hopkins, 2019). The proposed suitability criterion can enable such information circulation. On the other hand, even for systems operating in a highly unpredictable environment, information about the environment as well as system-level information is necessary for enabling safe actions. While the proposed suitability criterion may not be suitable in determining the flow of information about the environment, the system-level information should again be managed through centralized planning and control. Once again, the proposed suitability criteria are deemed useful in circulating system-level information.

5.5.2 Comparison with other theoretical frameworks

In this section, the proposed suitability criteria are discussed with respect to other theoretical frameworks focusing on decision coordination and organizational processes. Two such frameworks are discussed here. The first is the concept of *Helix organization*, recently promoted by McKinsey, a global consulting management-consulting firm. The second framework is related to the *inclusion criteria* for a component to be included in the safety control structure, as discussed in (Dulac, 2007; Stringfellow, 2010).

5.5.2.1 Helix Organization

The concept of helix organizations is proposed by the experienced management consultant from McKinsey, as an alternative to the conventional matrix form of organizational structure (De Smet, Kleinman, and Weerda, 2019). Organizations often need a mix of both centralized and decentralized control, and often they tend to switch between the two. There are numerous challenges associated with the purely Centralized and Purely Decentralized organizational structures, which are evident from the discussions presented in the previous section (refer to Table 5-2). As an alternative, a matrix structure is often selected, essentially creating two reporting lines for employees. In typical organizational structure charts, these are shown using the Solid lines and Dotted line. The solid line corresponds to the "Primary Boss" who holds control over the resource, budgets, hiring, firing, promotions, and evaluations. On the other hand, the "Secondary Boss" is often responsible for the direction, supervision, and prioritization of daily work. The concept of the matrix organization is shown in Figure 5-7.



McKinsey & Company

Figure 5-7 Matrix and Helix organizations (De Smet, Kleinman and Weerda, 2019)

Despite the distinction between the “Primary” and the “Secondary” bosses, often, the boundary between the two becomes invisible over time, leading to several coordination issues. Both primary and secondary bosses found themselves having significant overlap in their responsibilities and thus leading to several tensions and affecting the decision-making within the organization. Employees are often confused about who to report and whom to prioritize in case of conflicts. In extreme cases, such a structure can then lead to suppression of important safety-related decision coordination, leading to accidents, as happened with several accidents involving British Petroleum (Hopkins, 2019).

As an alternative, McKinsey proposed an idea of two parallel hierarchies, equally important but serving two distinct purposes (Figure 5-7). In such an arrangement, the people-leadership tasks are managed by two different managers, but neither of them is “primary.” One of the managers has to make decisions about ***How work has to be done***; thus, it is responsible for hiring, promotions, training, and capability building of the employees. The other manager has to make a decision about prioritization of goals, task execution supervision, and quality assurance or, in other words, decides on ***What work gets done***.

Although the helix organization theory is proposed from the perspective of the people management, it has important implications for the system safety aspects. Through the decoupling of the matrix structure, people responsible for functional aspects such as process safety, such as engineers, designers, and other functional experts, can be saved from the burden of supervising and monitoring daily work. Such a structure is shown to be effective from the safety perspective (Hopkins, 2019), which allows quick dissemination of safety-critical information to reach to as close to top as possible and hence is suitable for effective safety management. Important to note here is that such a helix structure necessitates closer coordination between the two types of managers with equal priority. Such a structure can then also enable efficient decision making related to safety, allowing it to less affected by the pressures arising from lack of achievement of other goals, such as the production pressures, etc.

The issue of coordination between the various organizational components has also been discussed in the safety-theory. Dulac (2007), in his study of NASA, has proposed several criteria to be satisfied for ensuring a coherent functional SCS. In particular, Dulac (2007) discussed the *Multiple-Loyalties or Reporting Appraisal Criterion,* according to which, if a component A reports directly to multiple other components let’s say B and C, then each of B and C should have a say in the appraisal process of A. Otherwise, the loyalties of A could shift towards one controller, which may or may not be suitable for controlling safety. The proposed helix theory is consistent with the criterion proposed by Dulac (2007), as it allows better coordination between the two managers about the performance appraisal of the employees. As per the helix theory, the appraisal responsibility lies in the hands of capability managers (or the functional managers), who can serve as the better guardian of the safety function and can influence the controllers reporting to it, for prioritizing safety.

The two suitability criteria proposed in this study are also essentially creating a helix-like structure for safety-related functions. The first suitability criterion assures that the warning signals should reach a functional manager who has a certain ability to influence the quality of the function itself. By ensuring the first suitability criteria, the warning signals do not reach to a controller who has no control or the capability to take the necessary corrective action. For example, in the Macondo well accident, the warning related to sealing design had reached the production manager, who was neither technically capable of managing such complicated engineering design-related aspects nor had safety as a priority. The second suitability criterion also holds true in this context, as the warning should reach to at least one controller who could sense the safety-related adaptations of the controllers below. Following this criterion, in a helix organizational structure, the warning signal will reach to a safety functional manager, who is both capable of sensing the safety-related adaptations as well as have incentives to take adequate actions. Thus, the current study finds that the proposed suitability criteria in this study are coherent with the state-of-the-art management theories derived using the accumulated experiences across several domains and thus seem generalizable.

5.5.2.2 Inclusion Criteria for a component to be included in the SCS

When developing the SCS for real complex socio-technical systems, a common problem faced by the analyst is to identify which system component to be included in the SCS, which is a functional representation of the actual organization dedicated to safety. In a socio-technical system, a single component could influence the overall system in a variety of ways, and the objective of the development of such inclusion criteria is to determine whether a certain component should be included, considering the various types of influences a component can bring to the overall system. In particular, the known organizational contexts affecting safety have been included. The complete list of the inclusion criteria is shown in Table 5-3.

Table 5-3 Criteria for Component Inclusion in SCS

System Development	System Operation
Discussed in (Dulac 2007). The component responsible for:	
Defining high-level system requirements, mission objectives, and development schedules	Defining criteria and metrics for system performance, production requirements, and mission objectives
Funding decisions	Funding decisions
Enforcing schedule, budget, and/or system requirements	Enforcing schedule, budget, and/or system requirements
Defining development standards and processes	Defining operations standards and processes
Initial system certification	System certification, renewal or review
Halting or slowdown of the system development	Halting or slowdown of the production
Employing a significant number of people working on safety-related activities	Employing a significant number of people working on safety-related activities
Important contracting work in the main development	Important contracting work in the main operation
System evolution and upgrades	
Discussed in (Stringfellow 2010). The component responsible for:	
Influencing the outcomes of those responsible for system requirements and system design	Influencing the outcomes of those responsible for system requirements and system design
Will be affected in the event of an accident	Hiring/Firing controllers
Allocation for resources	Will be affected in the event of an accident
	Allocation for resources

The inclusion criteria shown in table 5-3, are, in principle, have created a distinction in the system development and system operation stage. However, the criteria above-mentioned keep in mind the system evolution, explicitly and implicitly. For physical systems, the components responsible for system evolution are explicitly mentioned to be involved in SCS. Further, various controllers that could provide CAs are also necessitated to be included in the SCS; for example, components that could change the system requirements or (CACA) and system design (CSCA) have to be included in the SCS. In this regard, the proposed generalized indicator operationalization scheme proposed in this study can be seen as the extension or complementary to the existing component inclusion criteria defined in previous research. The proposed method here identifies additional criteria to identify the suitable receiver of the warning signals, which enables a double loop learning mechanism to be integrated within the existing SCS structure. The conventional SCS is based on single-loop learning, while the necessity of the double loop learning has been considered quintessential for ensuring safety for complex socio-technical systems (Kazaras, Kontogiannis and Kirytopoulos, 2014).

The schematic of double-loop learning is shown in Figure 5-8 (Kazaras, Kontogiannis, and Kirytopoulos, 2014). With respect to the current discussions, warning signals trigger the process of rethinking the decision-making rules of the original system, as the warning signal challenges the current mental model of the whole system. The CA are, thus, essentially a change in the decision-making rule through CACAs and CSCAs.

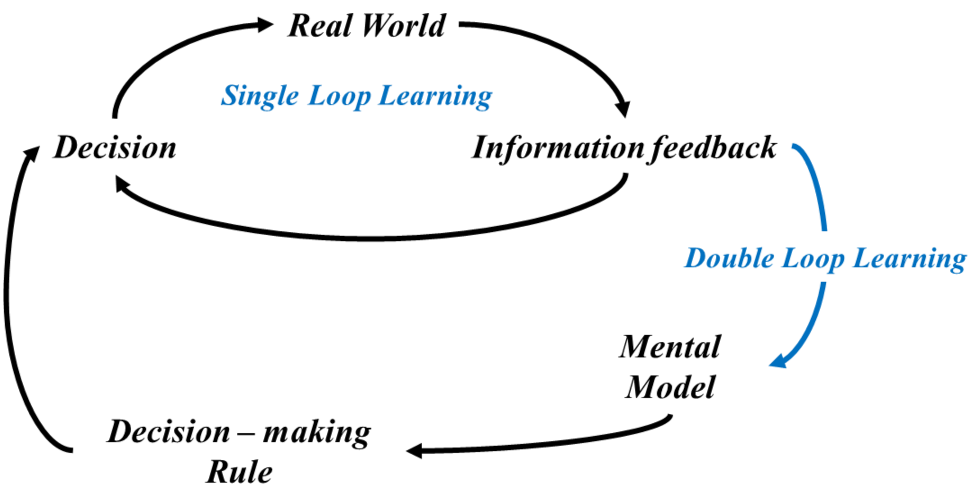


Figure 5-8 Double-loop learning

5.5.3 Summary

In the previous section, the applicability of the proposed suitability criteria developed in this study was examined. The proposed suitability criteria were developed considering a generalizable mechanism of system evolution. The criteria proved to be useful in explaining the accident mechanisms across systems categorized based on their degree of centralized control and degree of pre-determination for managing safety. In general, the criteria are useful to be applicable systems with a high degree of central control. For systems requiring decentralized control for managing safety, the proposed criteria are deemed useful for transmitting the system-level information necessary for system evolution and safety improvement in the long-term.

The proposed mechanism was also discussed with contemporary management theories proposed by practitioners as well as existing theories on organizational factors affecting safety. In this regard, the proposed suitability criteria in this study, are confirmed to be synergetic to the idea of a helix organization, that is deemed useful for enabling efficient safety-related coordination in several complex systems. Further, the proposed criteria also complement the existing STAMP methods by providing an approach to assimilate the idea of double-loop learning in the existing SCS. The importance of double-loop learning has been very well emphasized in the organizational safety theory.

While the proposed suitability criteria are shown to be applicable for a variety of situations, by no means, they are exhaustive. In this study, only one mechanism of the system evolution was considered, but in reality, many other mechanisms of system evolution could exist, especially for non-physical system components. For example, the local adaptation by the system components, when going unnoticed, can become normalized, thus leading to the formation of a new system state (probably undesirable). Such mechanisms should also be considered in detail, and new suitability criteria should be developed to keep the system within the safety boundaries. In this regard, more studies should focus on the decision-making process within the organization and its safety-related implications. Once again, accidents could serve as an excellent starting point for understanding such processes, and the same should be the focus of future studies.

5.6. Case study selection and method application: Case of Johkasou in Japan

In the previous section, the accident model proposed in this study was compared with its applicability in various systems by analyzing the mechanism of how accidents occur in several types of systems. Further, the framework developed in this study is also found to be consistent with the newly emerging management theories and existing theoretical frameworks. In this section, the GEWaSAP approach is implemented for a case, and its effectiveness is confirmed for the real world. Ideally, for this thesis, such an exercise should have been conducted for HSR system; however, HSR system is too complex and requires extensive inputs from the practitioners to carry out such an activity, which is difficult partly because of the language-barrier and availability of the information in the English language. Hence, as an alternative, a simpler complex socio-technical system was selected, i.e., the decentralized packaged wastewater treatment plant or *Johkasou* in Japan. The decentralized here refers to the geographical decentralization of the wastewater management, as opposed to large scale sewerage transport network and treatment units. However, in terms of safety functional management, the system in Japan is based on a high degree of centralized control (assured through a robust law and institutional framework, as discussed in later sections). Further, the safety management of the Johkaosu system is ensured through a high-degree of predetermination, where the designated law governs specifies as many risks as possible and stipulates detailed procedures to keep the system within the boundaries of safe operation. In this regard, the system can be classified as a Normative-Hierarchical system, as per the classification proposed by (Pariès *et al.*, 2019), and is comparable to HSR (which is also a Normative-Hierarchical System). Hence, once the effectiveness of the method can be confirmed for the Johkasou system, the general lessons can be extended to the HSR system in Japan.

5.6.1 Overview of the Johkasou System

Treatment of domestic wastewater is a public health issue that many countries across the globe face challenges with (Seetharam, Hashimoto, and Bugalia, 2018). Household wastewater is divided into two categories, namely *Black Water* containing fecal matter (wastewater coming out of the toilet), and *Grey Water* containing a high content of fats, etc. (wastewater coming out of kitchens, bathroom, etc.). Although in different concentrations. Both the type of waters contains solids, biodegradable solids, nutrients, and the harmful E. coli bacteria. The presence of these materials creates numerous environmental and public-health related issues, e.g., excessive nutrients dumped to rivers will lead to eutrophication damaging the local ecosystem in the rivers, etc. or the E. coli bacteria can create issues to public health in some cases even fatal damage. There are numerous other ways in which the wastewater can affect life negatively, and hence all the constituents of the domestic wastewater, i.e., solids, liquids, nutrients, and the bacteria, must be treated before this water is put into the environment or is utilized for other usages.

The value chain of the wastewater involves access to a toilet, containing the waste, transporting the contained waste to treatment plants, and then re-use or recycle the treated water. Conventionally, the sewerage system, a network of underground pipes, is laid out to carry out the wastewater from households directly to the wastewater treatment plants. However, in many countries, construction and operation of such large-scale underground facilities are no longer possible, and hence decentralized value-chain of sanitation should be utilized. In such a value chain, each household is connected with a wastewater containment facility, e.g., septic tanks. The septic tanks provide primary treatment by separating the solids and the liquids and facilitating anaerobic digestion of the biodegradable materials. The digested solids accumulate at the bottom of the tank, while primarily treated wastewater goes away (this water is considerably less harmful than the gray or the black water). However, to maintain the

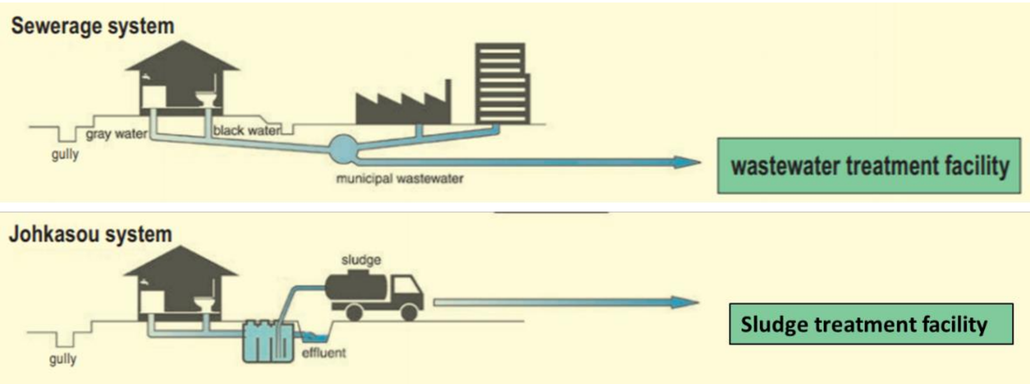


Figure 5-9 Overview of the Sewerage and Johkasou value chain

Image adapted from (Ministry of Environment, 2015) quality of the treatment of the septic-tanks, the septic tanks need to be cleaned periodically, and the collected sludge should also be treated efficiently. An overview of both systems is provided in Figure 5-9 (Ministry of Environment, 2015).

Johkasou is a treatment facility such as the septic tank, but is more sophisticated than the septic tank and provides better treatment performance. The treatment process in the Johkasou involves the use of a number of aerobic and non-aerobic steps requiring some energy to turn the motors fixed inside the Johkasou system. The Johkasou system is designed such that effluent coming out of the Johkasou should be directly discharged to the water-streams; hence, the effluent quality must match with a strict criterion for removal of solids, nutrients and the pathogens (E. coli). To facilitate this, the effluent of the Johkasou system requires steps for chlorination. Like any other decentralized wastewater containing facility, the Johkasou also needs to be emptied periodically (called as desludging). Whereas because of the technical sophistication of the system, the system also requires periodic maintenance (Seetharam, Hashimoto, and Bugalia, 2018).

5.6.2 Johkasou market in Japan

As per the national level plan, the Johkasou system is deemed suitable only for low-population density areas in Japan, where the conventional sewer system is not economical. So the Johkasou system is installed in households designated by the local governments. With such a policy, Japan had witnessed a steady growth in the number of Johkasou system installed along with a consistent rise in the total population having access to the safely managed sanitation services.

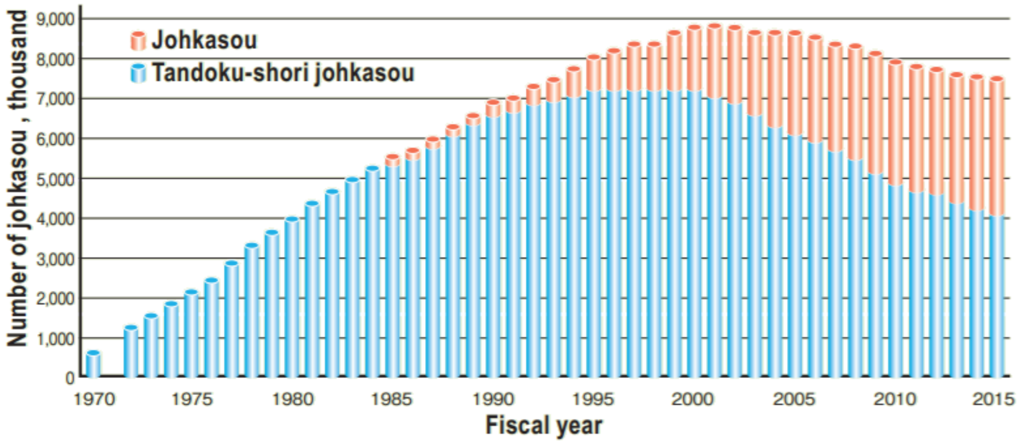


Figure 5-10 Overview of the Johkasou Market in Japan

Image source : (Ministry of Environment, 2015)

Recently, Japan is undergoing demographic changes in the declining and aging population. Simultaneously, many of the low-density areas of Japan are getting depopulated where the younger generation migrates to big cities in search of better jobs, etc. Because of such a shift, a decline in the Total number of Johkasou installed can be seen beginning in the early 2000s. While the total Johkasou market is declining, the market for the new Johkasou system (called as Johkasou in this thesis and is capable of treating both the black and the gray water) is increasing compared to the old Johkasou system (known as Tandoku-Shori Johkasou system capable of treating only black water), partly because of the recent Johkasou law, which prohibits the new installation of the Tanodoku system. An overview of the Johkasou market is shown in Figure 5-10.

Nevertheless, the Japanese Johkasou stakeholders have now long been eyeing on international markets, and their business is increasing several South-Asia and South-East Asian countries, because of the renewed momentum on the decentralized wastewater treatment (Seetharam, Hashimoto, and Bugalia, 2018).

5.6.3 *Stakeholders and their legal responsibilities*

The Johkasou act enacted in 1983 (Ministry of Environment, 1983) and the corresponding ministerial ordinance form the ministry of environment (Ministry of Environment, 2012), delineates the legal responsibilities of various stakeholders involved in the proper functioning of the Johkasou system. An overview of such responsibility is shown in Figure 5-11. Figure 5-11 is prepared by the author by modifying the figure from another work by the author (Seetharam, Hashimoto, and Bugalia, 2018).

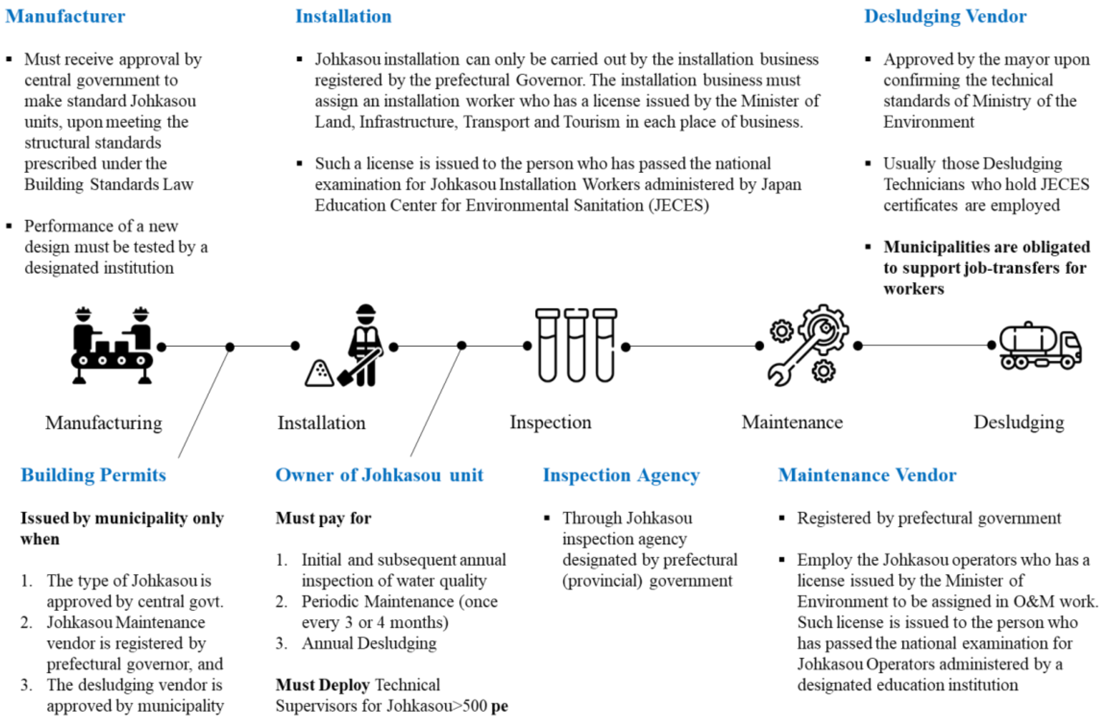


Figure 5-11 Responsibilities of various stakeholders in Johkasou management

Adapted from another study co-authored by the author (Seetharam, Hashimoto and Bugalia, 2018)

Japan has adopted a comprehensive institutional structure (defined in the Johkasou act) to define clear roles and responsibilities of various stakeholder at various life-stages of the Johkasou system such as its manufacturing, installation, legal inspection after installation, mandatory maintenance and desludging, as well as mandatory legal water quality inspection. Based on Figure 5-6, the control structure of the Johkasou Operation stage is presented in Figure 5-12.

For every Johkasou installed, the law designates a manager, known as *Johkasou manager (JM)*, who has the legal responsibility to ensure quality operation of the installed Johkasou. In this regard, the JM has to adhere to certain usage characteristics such as use the Johkasou only as per the capacity designated, not disposing of toxic material or the rainwater in the Johkasou tank, etc. Further, the JM has to contract with and pay for an O&M agency, Desludging Agency, and an Inspection agency (pre-defined periodicity in the law). The cost of O&M, equipment renewal, etc. have to be borne by the JM. In-turn, the O&M businesses, the desludging agency, and the inspection agency provide a certificate to the JM, and the JM has to produce these certificates as proof to the corresponding municipality office or the governor's office. The Governor's office has the right to issue commands deemed necessary for ensuring the effective operation of the Johkasou, and the JM and other stakeholders have to be abided by the same (Ministry of Environment, 2012).

Also, to ensure the quality for each of the O&M, Desludging, and Inspection activities, only pre-designated businesses can be contracted out. Only the agencies that are designated or registered under a governor's office can carry out such activities. The process of O&M business and the Desludging business is very similar; hence, they are shown as one functional group; however, in reality,

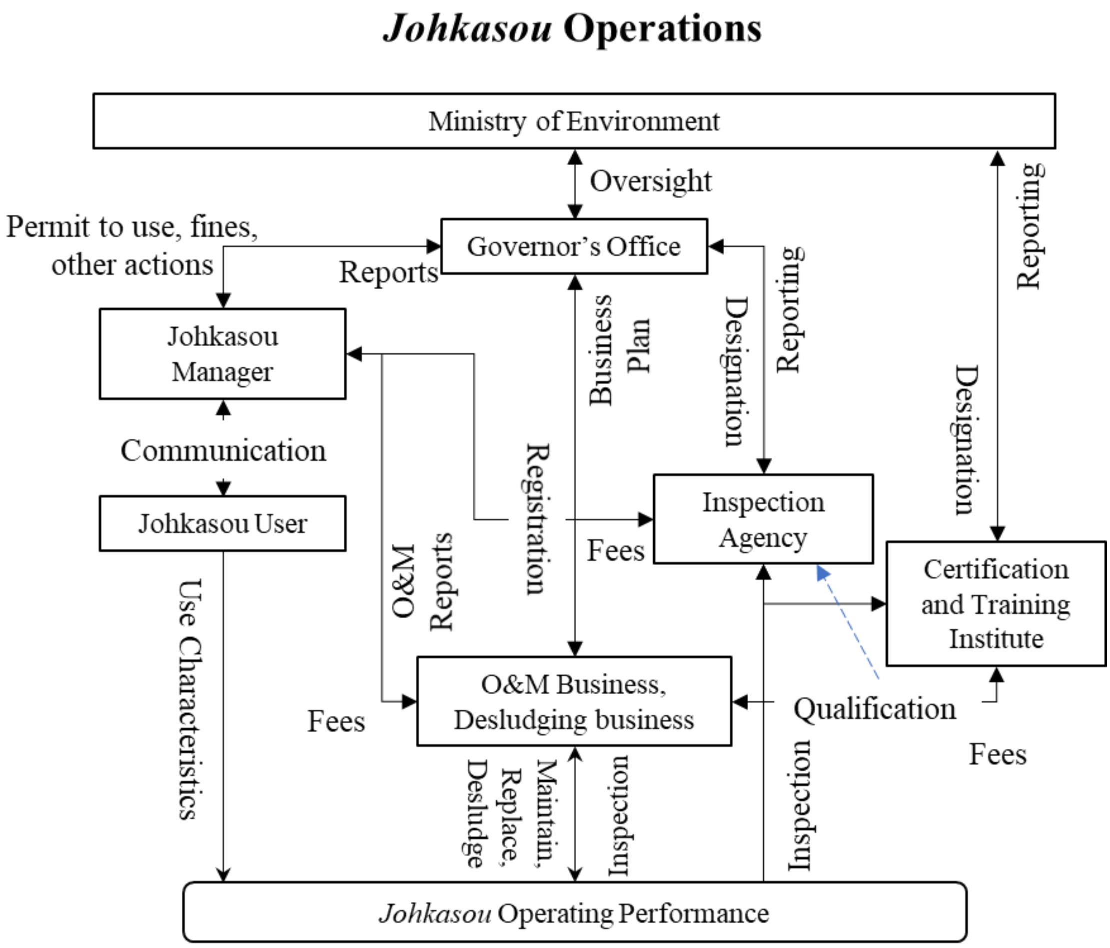


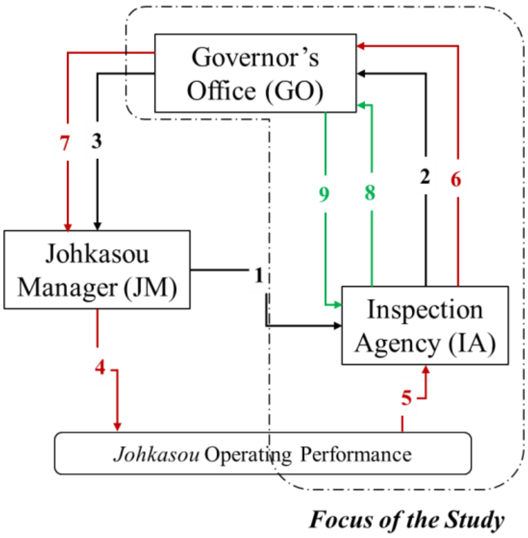
Figure 5-12 Control Structure for Johkasou Operation

these entities are different. One of the important legal requirements for the designated businesses (such as O&M, Desludging, and the Inspection Agency) is that they can only hire qualified professionals to implement the jobs. The qualification and certification are administered by an independent institute that is designated by the ministry of the environment. Such qualification standards are strictly administered in Japan.

5.6.4 Focus on Inspection Agency

The characteristics of the Johkasou system in Japan are such that it shows a high degree of control by the top-order components of the control structure. The governor's office is primarily involved in executing the central control to various stakeholders in the system. In that, the feedback about the overall functioning of the Johkasou and the effectiveness of the other stakeholders in fulfilling their responsibilities becomes crucial for the governor's office to execute effective control. In this regard, it is the inspection agency that serves as an important sensor for the governor's office. If the information from the inspection agency does not reach the governor's office adequately, the governor's office may lose control, as was seen in the Walkerton town of Canada (N. Leveson *et al.*, 2003). Like in any other control-feedback structure, the poor performance of the sensor can jeopardize the safety of the whole system; hence, careful monitoring is necessary in order to make sure that the feedback received from the inspection agency is reliable. Figure 5-13 shows a simplified control structure with a focus on the roles and responsibilities with respect to the inspection agency. Various control-feedback loops can be visualized in Figure 5-13.

A brief description of various interactions highlighted in Figure 5-13 is discussed here. These interactions are designated in the Johkasou Act and the corresponding ministerial ordinance by the ministry of environment (Ministry of Environment, 1983, 2012).



Loop No	Interaction
Loop 1	1. JM hires the IA to inspect
	2. IA reports about completion of the inspection to the GO
	3. GO sets the rules for inspection, gives direction for hiring inspection
Loop 2	4. User characteristics affect the Johkasou operating performance, including use patterns, O&M and desludging
	5. Johkasou operating status is tested by the IA
	6. IA gives report of potential problems and risks in Johkasou assessment (Warning Sign)
	7. GO can direct the JM to take appropriate actions
Loop 3	8. Agency gives business reports to IA (Article 55 of the ministerial ordinance)
	9. GO designates the inspection agency

Figure 5-13 Role of the inspection agency for efficient monitoring of the Johkasou performance

In Japan, an inspection agency is designated by the governor's office for that prefecture (province), and only this designated inspection agency can carry out the activities of the legal inspection of Johkasou. While designating the agency, the governor's office assesses the status of the equipment, testing facilities, qualifications of the personnel, and financial sustainability of the business model. Inspection Agency can hire only the qualified Johkasou Inspectors for conducting such work, and these qualifications are defined in the Johkasou Act. The fees for inspection are fixed and subsequently revised by the governor's office. Considering the limited market for Johkasou, and the governor's obligation to keep the inspection fees within an acceptable level, the usual practice in Japan is to have one designated inspection agency for each prefecture. Governor's office can revise the status of the inspection agency through careful monitoring of the functioning of the agency (through its business report, etc.). Table 5-4 shows the indicators listed in the Johkasou act that should be monitored by the Governor's office to ensure its effective performance.

Table 5-4 Designation standards for the inspection agency (Ministry of Environment, 2012)

Business Plan: Employees, Facilities, methods for inspections, and related matters
Accounting and Technical Documents
Business Sustainability: Market size, no. of competitors, reasonable inspection fees
Qualification of the Personnel involved: Appointment, Deployment, and dismissal for "Inspectors."

Legally, the Johkasou manager is obligated to contract out the designated inspection agency and pay for the inspection. Upon receiving the request, the inspection agency carries out the inspection activity within a few weeks. Some agencies, who have established long-term contracts with the Johkasou managers, can then optimize their routes for inspection and carry out an inspection on a scheduled basis. The contents of the inspection include visual inspection, water quality tests, and document-check tests. The parameters for monitoring water quality are defined by the Ministry of Environment. The inspection agency has to submit the results of the inspection activities within a pre-designated time (Reports for all inspections carried out in a month should be reported by the end of the next month) once the inspection activity is carried out. In addition to the report on the water quality parameter, the inspection agency should also conduct a risk assessment (such as actions of Johkasou Managers, the O&M business, or the desludging business) and should communicate the risk to the governor's office. Based on the reports received from the inspection agency, the governor's office can issue necessary action items for the Johkasou Manager, the O&M business, or the Desludging Business.

The control structure described in Figures 5-12 and 5-13 can be proven to be ineffective in many scenarios, for example, incorrect use pattern by the Johkasou manager, or the poor work quality of the O&M and desludging business operator. In all cases, the Inspection Agency serves an important role of being the eyes and the ears of the governor's office, who can execute better control to improve the performance of the Johkasou system. Under this scheme, if the issues arise ineffective functioning of the inspection agency itself, the whole system of control can fail. Hence, leading indicators must be developed and implemented for sensing the presence of potential accident causal factors at the inspection agency. From here onwards, we delve into detailed analysis to implement the GEWaSAP approach for the inspection agency for the Johkasou in Japan.

5.6.5 Analysis

5.6.5.1 Hazards and System-level Constraints

System-level hazards for the system in question (i.e., focus on inspection agency) is that "The inspection process must not miss communicating the current status and problems with the operating condition of Johkasou." Therefore, the system-level safety constraint is "The inspection agency should always communicate the current status and the problems with the operating conditions of the Johkasou to the governor's office."

5.6.5.2 Coordination with external agents (Step GEW(1) of GEWaSAP)

In case of the occurrence of the system level hazard, awareness action should be enforced by a suitable controller to transmit the signal to an appropriate receiver. The suitable controller, in this case, is Johkasou Manager, who can sense some aspects of whether the inspection agency is performing efficiently or not. For the purpose of this analysis, the Johkasou Manager is considered as an external controller. Another suitable controller is the Inspector him or herself, as they can also sense the presence of hazardous causal factor about the effective functioning of the inspection agency. Inspection Agency itself is another suitable controller who can enforce the awareness actions. Inspection agency is better suited for analyzing certain systemic factors analyzing the issues in the functioning of the Johkasou system affecting a region etc.

The appropriate receiver, in this case, should be identified based on the suitability criterion described in section 5.3.3. In this case, the Governor's office matches both the suitability criterion because it can issue CAs to the inspection agency, as well as they have the authority (or the means) to sense the local adaptation for both the suitable controllers identified for enforcing awareness actions.

5.6.5.3 Basic Control Structure (Step 3 from Table 5-1)

The basic control structure governing the functions inspection agency and the inspection process is shown in Figure 5-14. The structure is designed using the approach proposed by (Stringfellow 2010) in which the control elements such as the actuators and the sensors are also humans. The black arrows designate the control-feedback structure where activities related to process control is carried out, whereas, the red arrows represent the communication channel that exists between various human control-elements and the controller. The Inspection Agency is designated by the governor's office based on the review of various indicators mentioned in Table 5-4. During the system operation, the governor's office continuously monitors the inspection agencies' business and confirms its adequate performance. The governor's office is, in turn, governed by the central ministry of the environment, which establishes the desired water quality parameters to be monitored for each Johkasou.

The Inspection agency employs certified Johkasou inspectors to carry out the inspection work. Johkasou inspectors carry out various visual inspection tests, document check tests, and other water quality tests. While the Johkasou inspectors receive certificate training from an independent agency, all the Inspection Agencies also have their in-house training process where they provide various "on-the-job training" to fresh recruits and others requiring them. Inspection agencies also develop detailed procedures that are necessary to carry out the inspection work effectively. In addition, inspection

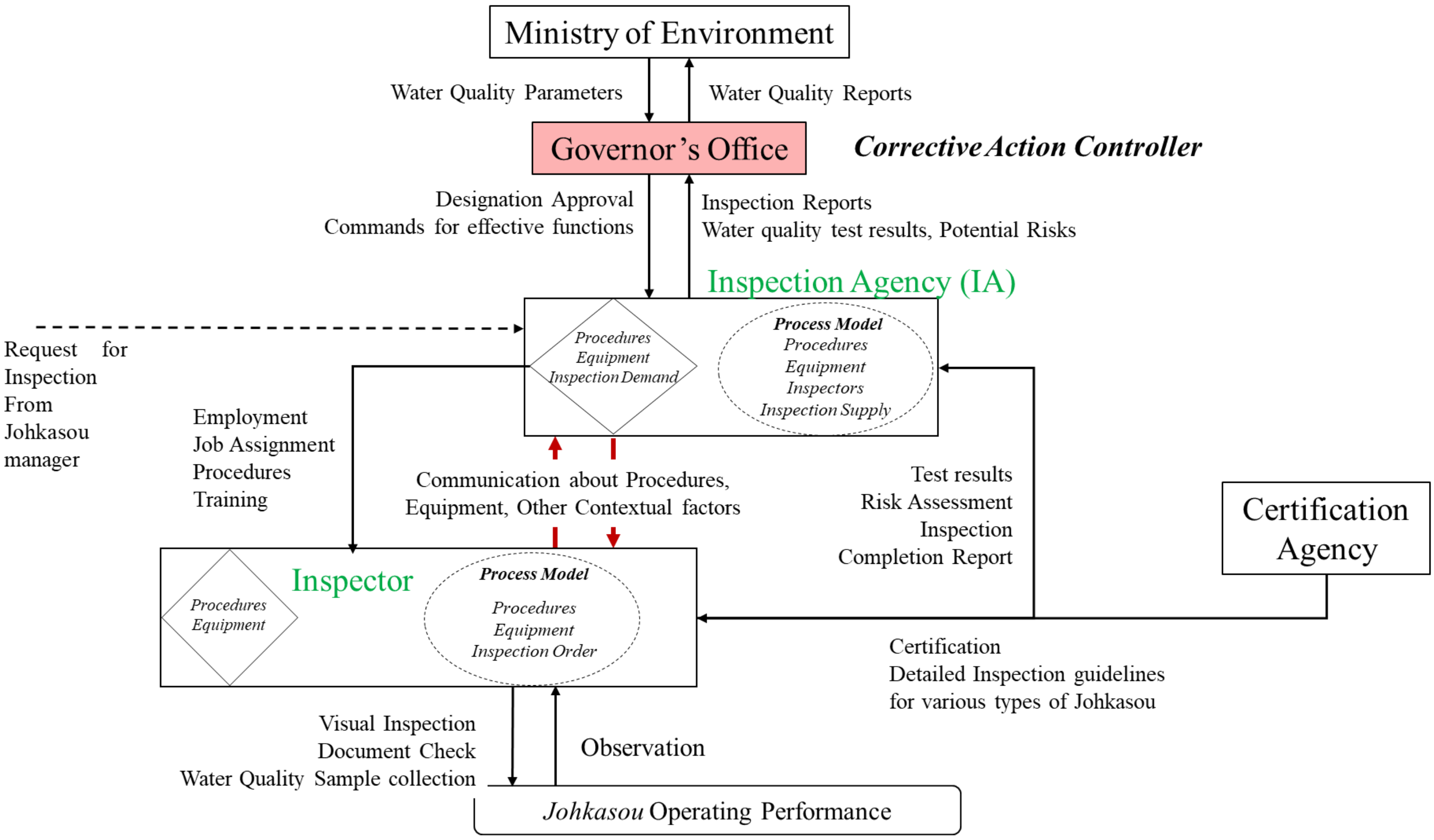


Figure 5-14 Control Structure of Inspection agency

agencies are also responsible for providing the necessary equipment to carry out all the inspection tests and their analysis, etc.

For measuring the quality of the water, some of the tests can be conducted on-site while others require careful sample collection, storage, transfer, and finally, testing at the lab. Hence, all the Inspection Agencies have their in-house laboratories. Based on the combined reports of test results, inspection reports, and risk assessments provided by both the laboratory and the inspectors, the Inspection Agency provides a detailed report to the governor's office, including the information on potential risks.

The certification agency also issues detailed guidelines about various inspection procedures depending upon the type of Johkasou. However, depending upon the equipment, and other situations, the inspection agency also develops detailed procedures for onsite and offsite testing and trains the inspectors and other personnel accordingly.

5.6.5.4 Inadequate Control Actions and Safety Constraints

The safety constraints for this case is that the entire inspection process should be implemented as per the approved standards, using quality equipment while being adequately carried out by qualified personnel in a time-bound manner. The corresponding inadequate control actions are summarized in Table 5-3. The specified control actions are with respect to the Inspection Agency, who is responsible for executing commands 5 and 6, as shown in Figure 5-13.

Table 5-5 Inadequate control actions for Johkasou inspection agency

Category	**Inadequate Control Actions**
SC 1: Adequate sampling, inspection, testing and analysis procedures	1. Standard procedures are not applied (SC1-1) 2. Procedures applied are not adequate (SC1-2) 3. Correct procedures are implemented incorrectly (SC1-3)

	4. Procedures are not performed in a timely manner (SC1-4) 5. Procedures are not implemented in the correct sequence (For example, test "X" needs to be done before test "Y") (SC1-5)
SC 2: Use good quality sampling, testing and analysis equipment	1. Sub-standard equipment is used (SC2-1) 2. Standardized equipment is inadequate (SC2-2)
SC 3: Deploy qualified Inspectors and other Human Resources	1. Qualified HR are not deployed (SC3-1) 2. Qualified HR does not work effectively (SC3-2)
SC 4: Risk assessment and Risk identification	1. Risks are not identified (SC4-1) 2. Are identified incorrectly (SC4-2) 3. Are not identified in a timely manner (SC4-3)
SC 5: Risk Communication to Governor	1. Are not communicated (SC5-1) 2. Are communicated wrongly (SC5-2) 3. Are not notified in time (SC5-3)

5.6.5.5 Signs indicating the violation of system-level safety constraints and their potential perceivers

In this stage, a synergy between controllers inside and outside the system is established. It is impossible to develop a sign for each of the safety constraints mentioned in Table 5-5; however, as a general principle, people living in the neighborhood areas where Johkasou is installed may experience a nuisance when a specific Johkasou is not functioning as designed. All the people living in the vicinity are then provided access to contact the governor's office to look into the matter and initiate necessary action from him. Further, the Johkasou manager may observe if the inspection services are irregular and can inform the governor's office. When inspection activity is carried out, the Johkasou manager also receives a certificate detailing the list of inspection related activities carried out. The Johkasou managers are informed about such a checklist in advance and can confirm if all the tests have been carried out even when they may or may not fully understand the detailed process. In all the above cases, the warning signs are to be communicated to the Governor's office, which is also a Corrective Action controller.

5.6.5.6 Process models

Process models for both the inspection agency and the inspectors are described here. The process model of the inspection agency contains two types of information. First information is related to the current status of the inspection process, such as how many Johkasou have received the required inspections in the designated time limits. Based on the inspection demand and the current status of the activities carried out, the Inspection agency can re-allocate its inspectors across the geographical boundaries of its business.

The second type of information present in the process model of the inspection agency is related to the status of various elements in the control structure. This information includes the status of quality of the procedures, quantity and the quality of the equipment, and the quantity and quality of the personnel involved.

A process model of the Johkasou Inspectors also has information on the remaining no. of inspection orders to be carried out in a given timeframe as well. It potentially contains information about the quality of the procedures and the quality of the equipment available for inspection.

5.6.5.7 Process control loop-flaws

In a normal technical component, at this stage, a hazard analysis could be carried using the STAMP process. However, in the current case, all the components are human or organizational components; hence, instead of STAMP, the SHOW method is used to conduct analysis. In SHOW analysis, each of the controllers is first analyzed, assuming its functioning as the Human controller. Each of the controllers is then analyzed, assuming it as an organizational controller. In both cases, the analysis is supported by the context-based guidewords, as discussed in Chapter 2 of this thesis. In this study, the focus is provided on all safety constraints except one related to risk assessment and risk identification. Since Johkasou is now a proven technology, numerous cases of risks have already been identified, e.g., the supply of chlorine tablets for disinfectant and various leading indicators at the technical level has been established in various documents available. Hence, for a study on organizational factors, these factors have been kept away from the study.

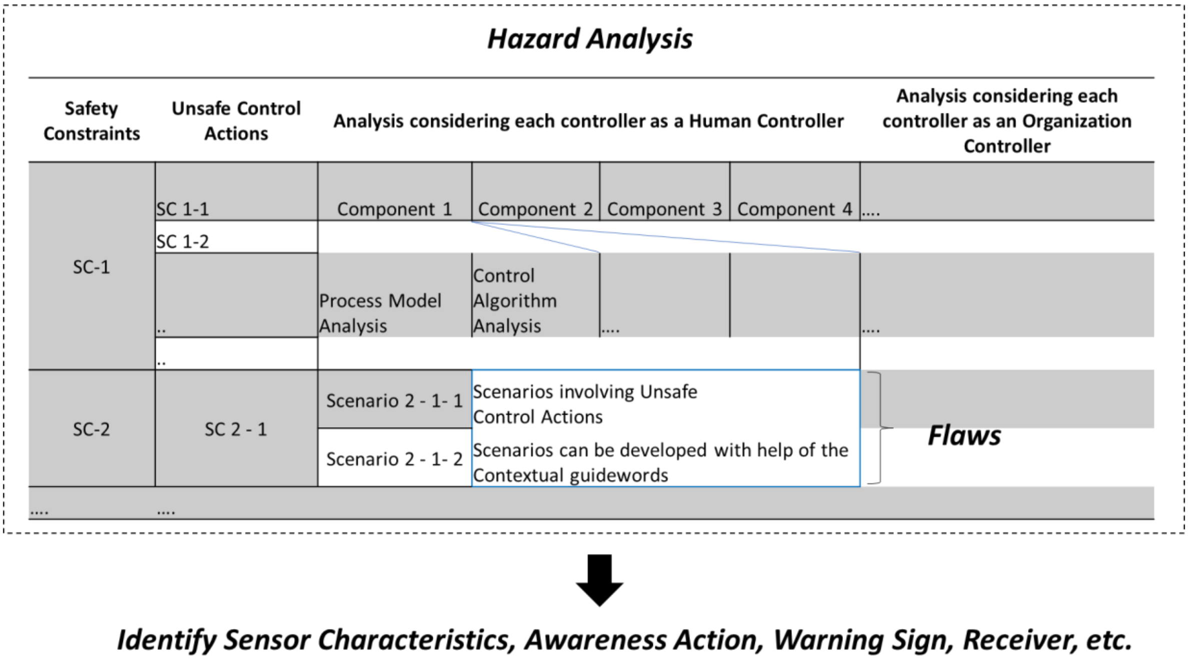


Figure 5-15 Analysis process

Figure 5-15 shows the summary of the SHOW process and its integration with the GEWaSAP process. Based on the system level safety constraints, firstly, a number of unsafe control actions are identified. These unsafe control actions will lead to a violation of the safety constraints. SHOW analysis is then used to identify how each of these unsafe control actions could happen. In that SHOW analysis helps in developing scenarios under which the Unsafe Control Action could be provided. Such scenarios, or Flaws, are then identified by adopting multiple perspectives. First, each and every controller is examined as a Human controller, and then each and every controller is examined as an organizational controller.

Table 5-6, 7, and 8 summarizes various flaws, identified through the SHOW analysis. Further, these tables also summarize the signs indicating the presence of the occurrence of a flaw, as well as summarize the necessary features of the sensor. Table 5-6 summarizes the flaws for analysis on Inspectors as Human-Controllers, Table 5-7, summarizes the flaws for analysis on Inspection agency as Human-Controller, and Table 5-8, summarizes the flaws for analysis on Inspection Agency as an Organizational Controller. In total, 85 signs were identified through SHOW analysis, out of which 46 unique EWS are summarized in Table 5-9.

Table 5-6 Inspectors as Human-Controllers

Safety Constraints	Flaw	Features of the Sensor	Signs
Controller Goal Analysis			
All	Priority to quality of inspection is compromised due to pressures such as time, schedule, etc.	**Inspector** should self-assess the situation regularly	1. The inspectors are feeling overworked

Control Algorithm Analysis			
SC1-1, SC1-2, SC1-4, SC3-2	Inspector's lack of awareness about the scope of parameters to be measured during the inspection	**Inspector** should self-assess the situation regularly	2. There are conflicts in the information provided from different sources (e.g., MOE, Certification agency and the detailed work manuals)
SC1-1, SC1-2, SC1-3, SC1-4, SC1-5	Procedures are impossible to be implemented in the field manually	**Inspector** should self-assess the situation regularly	3. That he/she is not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours
SC1-1, SC1-2, SC1-3, SC1-4, SC1-5	Inspectors are unable to understand the correct inspection process	**Inspector** should self-assess the situation regularly	4. He/she does not understand the procedures
SC1-1, SC1-2, SC1-4, SC3-2	The procedures have gradually deviated from the standards ***Guidewords:*** *(deviation begins because of various pressures and in the absence of retraining, becomes a historical trend*)	**Inspector** should self-assess the situation regularly	5. Any of the procedures are different from the real conditions as experienced in the field 6. Any of the procedures need modification as per the real condition 7. There are conflicts in the information provided from different sources (e.g., MOE, Certification agency and the detailed work manuals)
SC1-1, SC1-4, SC1-5, SC2-1, SC3-2	The equipment given to the Inspectors are not enough in implementing all the procedures correctly	**Inspector** should self-assess the situation regularly	8. That he/she is not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours) 9. Assess that the correct usage of given equipment is not understood by him/her
SC2-1, SC2-2	Inspectors do not understand the usage of equipment	**Inspector** should self-assess the situation regularly	10. He/she does not understand the adequate usage of the equipment
SC2-1	The inspectors do not detect errors in the equipment when using them in the field	**Inspector** should self-assess the situation regularly	11. He/she does not understand the process of detecting errors in the equipment while using them in the field 12. He/she are never informed about detecting such errors or provide any training
Process Model Analysis			
SC1-1, SC1-3, SC1-5, SC3-2	Inspector does not conduct a specific procedure because it is deemed unnecessary from visual inspection tests, from previous experience or under the pressures to perform many tests in a day	**Inspector** should self-assess the situation regularly **Johkasou Manager** should be able to check the checklists at the time for each inspection.	13. Checklist based implementation of procedures is not conducted 14. Any of the procedures are different from the real conditions as experienced in the field 15. Any of the procedures need modification as per the real condition
Model of the Organizational Structure			
SC1-1, SC1-2, SC1-4, SC1-5	Inspectors do not know whom to contact in a conflicting situation	**Inspector** should self-assess the situation regularly	16. He/she is not aware of the available communication channels to him/her for seeking help
Inadequate Control Loop execution			
SC3-1	The skill-level of the inspectors have degraded over time	**Inspector** should self-assess the situation regularly	17. An inspector is not able to carry out the work as per his/her own expectation
SC3-2	Inspectors commit human errors because of overwork or time-pressures	**Inspector** should self-assess the situation regularly	18. The inspectors are feeling overworked

Table 5-7 Inspection Agency as a Human Controller

Safety Constraints	Flaw	Features of the Sensor	Signs

Controller Goal Analysis			
All	Business sustainability, the time-bound inspection and the quality of the inspection can conflict with each other	**Inspection Agency** should assess the situation regularly	19. Operating profits are decreasing continuously 20. Difficulty in hiring new inspectors
Control Algorithm Analysis			
SC1-1	Lack of awareness about the scope of parameters to be measured during the inspection	**Inspection Agency** should assess the situations using survey regularly	21. The survey results show that the there are conflicts in the information provided from different sources (e.g., MOE, Certification agency and the detailed work manuals) 22. When the response rate for the survey is not high enough to be considered a good sample 23. When the methods of conducting a survey are not able to prevent the known type of biases
SC1-1	Inspection Agency does not provide the detailed procedures needed for adequately implementing inspection	**Inspection Agency** should assess the situations using survey regularly	24. The survey results show that procedures are not close to the reality as often experienced in the field 25. The survey results the procedures have to be changed to account for real conditions. 26. When the response rate for the survey is not high enough to be considered a good sample 27. When the methods of conducting a survey are not able to prevent the known type of biases
SC1-2	The testing procedure does not determine the desired water quality parameter adequately	**Inspection Agency or the Governor's office** should assess the situations using survey regularly	28. The survey results show that the there are conflicts in the information provided from different sources (e.g., MOE, Certification agency and the detailed work manuals
SC1-1, SC1-3	Inspectors are unable to understand the correct inspection process	**Inspection Agency** should assess the situations using survey regularly	29. The survey results show that many inspectors do not understand the procedures 30. When the response rate for the survey is not high enough to be considered a good sample 31. When the methods of conducting a survey are not able to prevent the known type of biases
SC1-1, SC1-5, SC1-4, SC2-1	The equipment given to the Inspectors are not enough in implementing all the procedures correctly	**Inspection Agency** should assess the situations using survey regularly	32. The survey result shows that many of the inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours) 33. The survey results show that the correct usage of given equipment is not understood by inspectors 34. When the response rate for the survey is not high enough to be considered a good sample 35. When the methods of conducting a survey are not able to prevent the known type of biases
SC2-1	The inspectors do not use the prescribed equipment as using the equipment affects their productivity	**Inspection Agency** should assess the situations using survey regularly	36. A survey conducted shows that the inspectors feel uncomfortable in using some equipment 37. When the response rate for the survey is not high enough to be considered a good sample 38. When the methods of conducting a survey are not able to prevent the known type of biases

SC2-2	The equipment used does not capture the quantity they intend to measure	**Inspection Agency** should assess the situations using survey regularly	39. A survey conducted shows that some of the equipment does not conform to the standards 40. When the response rate for the survey is not high enough to be considered a good sample 41. When the methods of conducting a survey are not able to prevent the known type of biases
SC3-1	Inspection agency cannot hire the inspectors as desired	**Inspection Agency** should assess the situations using survey regularly	42. The business plan should be suitable for the number of inspectors 43. When such statistics are not measured periodically
SC3-1	Inspection agency does not identify the training needs of the employees	**Inspection Agency** should assess the situations using survey regularly	
Process Model Analysis			
SC1-1, SC1-3, SC1-5, SC3-2	The inspection agency wrongly assumes that the inspectors always carry out their work adequately	**Inspection Agency** should assess the situations using survey regularly	44. A survey result highlighting that the inspector is not able to carry out the work as per his/her own expectation 45. Complaint received from external stakeholders about the effectiveness of the inspectors 46. The survey result shows that many of the inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours) 47. The survey results show that procedures are not close to the reality as often experienced in the field 48. When the response rate for the survey is not high enough to be considered a good sample 49. When the methods of conducting a survey are not able to prevent the known type of biases
SC1-2	The inspection agency wrongly assume that the inspectors will detect issues with the procedures	**Inspection Agency** should assess the situations using survey regularly	50. A survey conducted shows that many inspectors are not able to detect errors in the equipment 51.The survey result shows that many of the inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours) 52. When the response rate for the survey is not high enough to be considered a good sample 53. When the methods of conducting a survey are not able to prevent the known type of biases
SC1-2	Missing feedback about the effectiveness of the procedure in the field	**Inspection Agency** should assess the situations using survey regularly	54. The survey results show that procedures are not close to the reality as often experienced in the field 55. When the response rate for the survey is not high enough to be considered a good sample 56. When the methods of conducting a survey are not able to prevent the known type of biases
SC1-4	The inadequate assumption about the average time taken to fulfill an inspection request and the number of on-time completion leading to accumulation of backlog	**Inspection Agency** should assess the situations using survey regularly	57. The trend of on-time inspection completion is declining 58. Average time for inspection request fulfillment is increasing 59. When such data is not available

SC2-1	Missing feedback from the equipment maintenance division	**Inspection Agency** should assess the situations using survey regularly	60. The equipment downtime for maintenance is more than anticipated 61. When such data is not available
SC2-1, SC2-2	Missing feedback about the inspectors' ability to detect errors in the equipment	**Inspection Agency** should assess the situations using survey regularly	62. A survey conducted shows that many inspectors are not able to detect errors in the equipment 63. When the response rate for the survey is not high enough to be considered a good sample 64. When the methods of conducting a survey are not able to prevent the known type of biases
SC2-2	Missing feedback about the erroneous state of various equipment	**Inspection Agency** should assess the situations using survey regularly	65. A survey conducted shows that many inspectors are not able to detect errors in the equipment 66. A survey shows that many inspectors do not report errors in the equipment to the inspection agency 67. When the response rate for the survey is not high enough to be considered a good sample 68. When the methods of conducting a survey are not able to prevent the known type of biases
SC3-1	Inadequate feedback about the current skill level of the inspectors	**Inspection Agency** should assess the situations using survey regularly	69. A survey result highlighting that an inspector is not able to carry out the work as per his/her own expectation 70. A survey highlighting that the inspector had not received training when there was a change in equipment and procedures etc. 71. When the response rate for the survey is not high enough to be considered a good sample 72 When the methods of conducting a survey are not able to prevent the known type of biases
Model of the organizational structure			
All	Inspection agency does not know whom to contact in case of conflicting information	**Inspection Agency** should assess the situations using survey regularly	73. When the analysis shows that communication channel for conflict resolution is not effective
Inadequate Control Loop execution			
SC1-1, SC1-2, SC1-3, SC1-4, SC1-5	The department responsible for procedure development does develop the processes	**Inspection Agency** should assess the situations using survey regularly	74. Employees report missing procedure against the real conditions 75. Employees report potential conflicts between procedures from multiple sources
SC2-1	The equipment is not maintained in good condition	**Inspection Agency** should assess the situations using survey regularly	76. A survey conducted shows that the equipment used by the inspectors was not maintained properly
SC2-1	Quality equipment is not purchased	**Inspection Agency** should assess the situations using survey regularly	77. A survey to conduct if the equipment department is receiving enough budget
SC3-1	Inspection agency does not identify the training needs of the employees	**Inspection Agency** should assess the situations using survey regularly	78. A survey results highlighting that employee feels the need for retraining.
SC3-1	Inspection agency does not hire the qualified Inspectors due to lack of resources	**Inspection Agency** should assess the situations using survey regularly	79. A survey to conduct if the personnel department is receiving enough budget

Table 5-8 Inspection Agency as an Organizational controller

Safety Constraints	Flaw	Features of the Sensor	Signs

All	1. Presence of policy and its effective communication 2. Context-specific conflict arising in multiple goals 3. Adequate Dynamic Safety Management: Having a continual process of assessment 4.Proper assignment of roles and responsibilities to enforce system-level safety constraints 5. Gaps and Overlaps in responsibility 6. The role is not suitable for Human Control 7. Inadequate organizational change for reassignment of roles and goals 8. Inadequate allocation of resources 9. Communication channels do not exist 10. Communication channels do not have sufficient circumstances 11. Communication channels are not modified in response to changing the environment 12. Inadequate communication of safety goals, requirements, throughout the system 13. Organization level decisions must match the stated priorities 14. Inadequate Learning Process 15. Inadequate channels to communicate information in response to, or in anticipation of, disturbances impacting safety constraints 16. Organizational controllers must not undermine the Safety Control Authority	**Inspection Agency** should assess the situations using survey regularly	80. Safety Culture assessment 81. Measure whether the roles and responsibilities are suitable in a.) Achieving safety and performance goals b.) Are enough, and the employees are not overworked c.) Ensuring that an employee is engaged in performing these activities without losing concentration d.) Enable you to sufficiently manage all related tasks of it 82. Are you getting sufficient access to resources necessary for executing your performance and safety goals? 83. Can you get sufficient information about safety-related issues in your organization? 84. When needed, can you access a safety-related information source in your organization in a timely manner 85. Can all safety responsibilities assigned to you be adequately executed without the interference from other organizational components

5.6.6 Leading indicators for Johkasou Inspection agency

Table 5-9 summarizes various early warning signs identified through the analysis so far.

Table 5-9 Unique Leading indicators for Johkasou inspection agency

For Inspector to observe 1. Feeling overworked 2. Conflicts in the information provided from different sources (e.g., MOE, Certification agency and the detailed work manuals) 3. Inspector is not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours) 4. Inspector does not understand the procedures 5. Procedures are different from the real conditions as experienced in the field 6. Procedures need modification as per the real condition 7. Inspector does not understand the adequate usage of the equipment 8. Inspector does not understand the process of detecting errors in the equipment while using them in the field 9. Checklist based implementation of procedures is not conducted 10. Inspectors are not aware of the available communication channels to him/her for seeking help 11. Inspectors are not able to carry out the work as per their own abilities
For Inspection agencies to observe through surveys 1. Conflicts in the information provided from different sources (e.g., MOE, Certification agency and the detailed work manuals) 2. Many of the inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours) 3. Many inspectors do not understand the procedures 4. Procedures are not close to the reality as often experienced in the field 5. Procedures have to be changed to account for real conditions 6. The correct usage of given equipment is not understood by inspectors

7. Inspectors are not able to detect errors in the equipment 8. Inspectors feel uncomfortable in using some equipment 9. The equipment does not conform to the standards 10. The business plan should be suitable for the number of inspectors 11. The inspector is not able to carry out the work as per his/her own expectation 12. Complaint received from external stakeholders about the effectiveness of the inspectors 13. The trend of on-time inspection completion is declining 14. The equipment downtime for maintenance is more than anticipated 15. Many inspectors do not report errors in the equipment to the inspection agency 16. The communication channel for conflict resolution is not effective 17. Employees do not report missing procedure against the real conditions 18. The equipment used by the inspectors was not maintained properly 19. Equipment department is receiving enough budget 20. The employee feels the need for retraining. 21. Operating profits are decreasing continuously 22. Difficulty in hiring new inspectors 23. The personnel department is receiving enough budget 24. The response rate for the survey (for all of the above-mentioned points) is not high enough to be considered a good sample 25. Method of conducting a survey (for all of the above-mentioned points) are not able to prevent the known type of biases
For Inspection agencies to observe through surveys 1. Safety Culture assessment 2. Assigned roles and responsibilities are suitable for Achieving safety and performance goals 3. Assigned roles and responsibilities are enough, and the employees are not overworked 4. Assigned roles and responsibilities ensure that an employee is engaged in performing these activities without losing concentration 5. Assigned roles and responsibilities enable you to sufficiently manage all related tasks of it 6. Are all the departments getting sufficient access to resources necessary for executing your performance and safety goals? 7. Can all the departments access information about safety-related issues in your organization? 8. When needed, can you access a safety-related information source in your organization in a timely manner 9. Can all safety responsibilities assigned to you be adequately executed without the interference from other organizational components

5.6.7 Validation test : Comparison with real-world

5.6.7.1 Methodology and Data collection

To highlight the advantages of the method adopted in this study, a further comparative analysis is necessary. For comparison, the information about the leading indicators already being used is obtained by the official documentation related to Johkasou law (Ministry of Environment, 1983, 2012). Additional information was also obtained through an interview with an experienced professional in the Johkasou System, i.e., a senior officer in the Certification Agency. The interview lasted for about one hour and was done using a semi-structured approach. Questions were sent in advance to the professional; however, a strict sequence of the questions was not followed, and indeed questions were asked as they seemed to emerge naturally based on the communication happening during the interview.

The interview had been conducted at the stage where the SHOW analysis was still not complete, and only a tentative flaw identification had been made. Based on these tentative flaws, questions were summarized and developed such that they could focus the general issues around the inadequate control actions listed in Table 5-5, but not on specific flaws. This step was necessary to avoid the information overload for the interviewee. The interviewee was also not introduced with the detailed analysis steps undertaken in this study, and nor was he briefed about the system-thinking approaches to safety in general. Even without the formal introduction of the system-thinking based framework, the interviewee supported the several potential risks listed in Table 5-5. Such independent support from the interviewee is encouraging about the general applicability of the SHOW in the current context. Many pieces of information obtained during the interview were also used to revise the SHOW analysis itself. For example, through interviews, it was confirmed that in Japan, each inspection agency deploys only one inspector at a site. Hence, the information about the inspection, reported by a single inspector, has to be trusted. The same information is then shown in the SCS in Figure 5-14.

5.6.7.2 Results from the validation test

Table 5-10 and 5-11 summarize the results of the leading indicators identified in this study with respect to the leading indicators already being measured in the current system. Table 5-10 shows the status of the early warning signs that should be reported by the Inspectors to the Governor's office. Table 5-10 shows that the currently there are no warning signals go directly reported to the governor's office form the inspectors. If the information shown in Table 5-10 will paint a very negative picture of the lack of voice from the inspectors; however, the picture shown in Table 5-10 is to be analyzed carefully.

Table 5-10 Validation for early warning signs reported by the Inspector to Governor's office

No.	***Potential Early warning signs***	***Currently being used?***
1	Inspectors are overworked	*NO**
2	Conflicting Procedures	*NO*
3	Inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours)	*NO**
4	Inspectors do not understand the procedures	*NO*
5	Procedures are different from the real conditions	*NO*
6	Adaptation to procedures is needed in the field	*NO*
7	Inspectors do not understand the correct usage of the equipment	*NO*
8	Inspectors do not understand how to detect errors in the equipment	*NO*
9	Checklist based implementation of inspection procedure is not implemented	*NO*
10	Inspectors are not aware of communication channels available to them	*NO*
11	Inspectors noticed a degradation in their own working abilities	*NO*

Our interview confirmed information for several aspects listed in Table 5-10. For example, in Japan, the license to the inspectors is awarded for a lifetime, and the periodic renewal of such a license is not necessary for an inspector. However, the law does not permit a free-lancing inspection. All inspectors must be employed by a registered inspection agency. Such practice suggests that any warning signal sensed by the inspector about degradation in their own working ability is likely to go to the inspection agency (the employer) and not to the Governor's office (No. 11).

During the interview, a detailed discussion on issues regarding conflicting procedures, necessity to adapt the procedures in the face of reality, etc. was made. While the certification agencies provide training programs that equip the potential inspectors about key concepts and related knowledge necessary for the inspectors. Each of the inspection agencies has their own on-the-job training procedures, which prepare their employees to manage the complexities of the field. Complexities could be related to variation in the type of Johkasou installed in a region, each requiring a different inspection method, etc. While, the agency involved in the certification, also prepares detailed inspection procedural manuals for different types of Johkasou, these manuals serve as an important guideline for the agencies to prepare their own manuals. These agency stipulated manuals are then used in the day to day function, and hence, any conflicts in the procedures, etc. are likely to be reported only to the inspection agency but not to the governor's office (No. 2,4,5,6,7,8).

On the other hand, the Johkasou law mandates, the feasibility evaluation of the Johkasou business. The monitoring includes an assessment of whether the resources possessed by a certain inspection agency are sufficient to fulfill the inspection demand of the region. Through this assessment, the governor's office does take a cognizance of the potential workload and financial pressure facing a specific inspection agency, but to the best of the author's knowledge, this step does not involve questioning individual workers about the pressures and the workload that they face (No. 1 and No. 3). On the other hand, it is likely that such concerns of the workers are heard upon, through informal channels such as through labor unions, for which Japan has a strong culture.

Table 5-11 Validation for early warning signs reported by the Inspection Agency to the Governor's office

No.	***Potential Early warning signs***	***Already measured?***
1	Inspectors are overworked	*NO**
2	Conflicting Procedures	NO
3	Inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours)	Yes*
4	Inspectors do not understand the procedures	NO
5	Procedures are different from the real conditions	NO
6	Adaptation to procedures is needed in the field	NO
7	Inspectors do not understand the correct usage of the equipment	NO
8	Inspectors do not understand how to detect errors in the equipment	NO
9	Inspectors feel uncomfortable in using some equipment	NO
10	The equipment does not conform to the standard	Yes
11	Complaint received from external stakeholders about the effectiveness of the inspectors	Yes
12	The business plan should be suitable for the number of inspectors	Yes
13	The inspector is not able to carry out the work as per his/her own expectation	NO
14	The trend of on-time inspection completion is declining	Yes
15	The equipment downtime for maintenance is more than anticipated	Yes*
16	Many inspectors do not report errors in the equipment to the inspection agency	NO
17	The communication channel for conflict resolution is not effective	NO
18	Employees do not report missing procedure against the real conditions	NO
19	Equipment department is receiving enough budget	Yes
20	The employee feels the need for retraining.	NO
21	Operating profits are decreasing continuously	Yes
22	Difficulty in hiring new inspectors	Yes
23	The personnel department is receiving enough budget	NO
24	Safety Culture assessment	NO

Table 5-11 summarizes the early warning signs that should be monitored at the inspection agency level and whose report should reach to the governor's office, as per the analysis presented in this study. The table also provides information, whether such warning signs are already being measured as per the current practices.

We first discuss the warning signs that are identified in our analysis and also being monitored as per the current practices. Ministerial ordinance for Johkasou has a provision for license approval and renewal for the inspection agency. During such approval and renewal, the prospective inspection agency ought to prove its capabilities to manage the anticipated inspection services for its operating reasons. Capabilities are assessed on parameters including the availability of the necessary equipment to conduct the inspection process and necessary tests (No. 10, 15 and 19 in Table 5-11), adequateness of the number of inspectors to serve (No. 12), and the operating profitability (No. 21). Further, the governor's office has provided sufficient channels to the Johkasou Managers to lodge complaints and dissatisfactions against the quality of the inspection services provided by the agency, and the governor's office will take appropriate actions accordingly (No. 11). Each inspection agency also is required to produce the evidence that a requested inspection service was indeed completed in a pre-stipulated time and asks the inspection agency to take actions accordingly (No. 14).

In addition, the interviews were able to provide conclusive support for a number of factors not being monitored in the current Japanese system but are deemed important from the analysis. For example, worker overload is not explicitly reported to the governor's office (No. 1). The governor's office makes a rough estimate for a number of inspectors required to fulfill the desired number of inspections; however, an explicit assessment of the working conditions of the worker is not included in the assessment. In Japan, there are 65 registered inspection agencies for a total of 47 prefectures (states) (Ministry of Environment, 2015). In that, for many of the prefectures, there is only one registered inspection agency, and only in some prefectures, multiple agencies exist. However, even in such prefectures, excessive competition is avoided, and many inspection agencies hold virtual monopolies in geographically divided areas. Hence, the worker overload in each of the agency could be different, depending upon the number of houses, the local geographical features, characteristics of the transportation infrastructure, and type of Johkasou, etc. However, such a detailed review is not conducted by the governor. The interview also revealed why the governor's office might not necessarily emphasize on such level of monitoring. In most cases, these inspection agencies have been long established and have been able to renew their licenses without some serious problems on performance. In the context of the declining domestic market for the Johkasou, it is also difficult for the governor's office to find new agencies willing to work. Such a lack of willingness for the private sector to participate in the sector necessitates avoiding seemingly unnecessary monitoring. Hence, the fact that some of the indicators identified from the analysis are not currently being utilized does not necessarily mean that the stakeholders are not aware of the risks, but that the current practices are also influenced by certain external pressures and the overall concept of risk acceptance, etc.

Similar explanations were also obtained for certain other aspects. For example, aspects like No. 2, and No. 4-9, No. 16, 18, 20, 23, 24 which are related to possibility of conflicting procedures, as well as reality of the fields being different from that described in the manuals, etc. are also not necessarily monitored currently by the governor's office. The interview helped identify the context in which such monitoring was not deemed suitable. As mentioned earlier, the current system of the inspection process, etc. have been effective in sufficiently alleviating the public health concerns and have significantly improved the environmental conditions since its launch (Ministry of Environment, 2015). On the other hand, the new type of Johkasou systems are mainly targeted to suit foreign markets and not for domestic markets; hence, within Japan, the system does not evolve so much, leading to a stabilization in the current procedures, etc. Such confidence in the efficient functioning of the current system combined with the market characteristics as described above leads to the governor's office not emphasizing on the regular monitoring of the conflicting procedures, or on the need to review the procedures for their applicability in the real field situation. The "on-the-job" training procedures developed by each of the inspection agencies are expected to sufficiently capture such conflicts and improve themselves accordingly. However, the governor's office takes cognizance of the matter when they receive complaints from several Johkasou managers, etc.

On the other hand, a large number of NOs in tables 5 -11 can also be seen as a question mark on the suitability of the methodology used in this study to reflect the reality of the situations at all. If there are so many NOs, it is possible that the current methodology is not able to perform the context-based analysis that it wishes to perform. However, the interview helped us identify supporting arguments to judge the ability of the proposed methodology in bringing out the realistic risks associated even in the Japanese Johkasou inspection agencies. Our analysis clearly identified the inspector's lack of reporting about their own ability to implement the procedures correctly, or inspector's adaptation in implementing the adequate procedures in the field under the various financial, and other performance-related pressures that they may face, as important leading indicators. However, the absence of these leading indicators from the current practices in Japan does not necessarily negate their importance and hence, the suitability of the methodology itself. For example, the interviewee acknowledged the importance of the above-mentioned factors, especially in the context of implementing the Johkasou system in other developing countries. In his own words,

"*Yes, many foreigners highlight the issue that the Japanese Johkasou system relies only on single inspectors to adequately perform and report the results, whereas in other countries, such a system may not work, as the one single inspector may not be doing the work properly*."

He further added the importance of the Japanese cultural context in assuring the efficiency of such a system. In general, in Japan, people are diligent and take their work sincerely, no matter how important or unimportant it may seem to outsiders. Correspondingly, even the Japanese society also values contribution for each worker, and the issues such as stigma attached to being in the sanitation business, etc. are not a very big problem in Japan. Such social context might be different in other countries and will shape the patterns of human behavior affecting the overall effectiveness of the system of control. In Japan, the social context results in high-quality work by the involved humans in the whole process, and once again, their proven track record in the past does not invoke the necessity of further monitoring.

In this regard, the study acknowledges the necessity for bringing the rich contextual information into the analysis and revise the analysis accordingly. The results of this study are based on only one interview, which, although crucial, will always have limitations in highlighting the full context. Hence, the limitations of the study are in gathering more information on contextual factors, but not on the utilization of the proposed methodology itself.

5.6.7.3 Summary and conclusions from the results of the validation test

Based on the validation test conducted above, the following conclusions can be derived.

1. The proposed leading indicator operationalization approach was thought as comprehensive in identifying several possible risk factors for the complex socio-technical system at the organizational and institutional levels.

2. However, the recommended level of system monitoring based on the theory obtained a mixed response from a practitioner's perspective. The test results highlighted several trade-offs for establishing a leading indicator program recommended from the analysis. These trade-offs include the capacity constraints for the regulator in enforcing such level of monitoring, market characteristics affecting the relative power of the operator and the regulator, as well as the trade-off between autonomy to business vs. the high-level of control. The current method of leading indicator operationalization thus does not consider such practical trade-offs explicitly and should be improved further.

5.6.8 Enforcing Awareness actions

As per the original study on EWS (Dokas, Feehan, and Imran, 2013), awareness action is enforced when the warning signs clearly indicate the presence of potential accident causal factors. For a physical subsystem, defining the relationship indicating the presence of potential accident causal factor can often be characterized by signs which can objectively be compared with a safe system state. For example, any Johkasou can be confirmed to be working in a safe state if its effluent quality is BOD<10mg/l. However, for leading indicators developed for organizational factors, such a relationship may be difficult to define objectively. For example, the decision whether 1% of the employees reporting conflict in information coming from multiple sources is an acceptable safe state or whether it is 10%, depends on several other risk-management related factors. Hence, the clear thresholds for each of the leading indicators should be set by the organization themselves. It is thus difficult to provide a comprehensive list of awareness actions in this study. A few indicative examples of awareness action enforcement are shown in Table 5-12.

Table 5-12 Indicative awareness actions

Indicative updates on process models and awareness actions		***From***	***To***
If	Inspector(s) notice difference in the information obtained from different sources such as (information from certification agency, in-house training procedures, etc.)	Inspector Inspection Agency	Inspection Agency Governor's office
Then	Then erroneous procedures being applied, delays in inspection and human errors IS POSSIBLE		
	AND enforce awareness action "Warning – conflicting procedures."		

5.6.9 *Enforcing corrective actions*

As discussed before, once the awareness actions have reached a suitable controller, in this case, the governor's office, suitable corrective actions should be enforced. There could be multiple corrective actions corresponding to each warning sign; similarly, one single type of corrective action can be used for multiple early warning signs. Because of the multiple matching, the corrective actions must also be pre-agreed upon various stakeholders in the system. A consistent list of corrective actions is especially relevant in a case where one of the Corrective action controllers is a regulatory agency, as regulatory actions have to be uniform and consistent across multiple organizations being regulated as well as for multiple occasions. Further, such a list should be revised periodically. An indicative list of corrective actions is summarized in Table 5-13.

Table 5-13 Indicative corrective actions

Early warning signs	***Corrective Actions***
Inspectors are overworked	Efforts for demand optimization, incentives for attracting new recruits, or come up with new business models for inspection agencies
Conflicting Procedures	Review the procedures and modify accordingly
Inspectors are not able to adequately implement the procedures with the resource constraints (time, equipment, money or working hours)	Identify the factors hampering Inspectors' performance and take corrective actions to improve them
Inspectors do not understand the procedures	Procedural Training, manuals, etc.
Procedures are different from the real conditions	Review the procedures and modify accordingly
Adaptation to procedures is needed in the field	Review the procedures and modify accordingly
Inspectors do not understand the correct usage of the equipment	Equipment related training, or standardization of equipment
Inspectors do not understand how to detect errors in the equipment	Equipment related training
Inspectors feel uncomfortable in using some equipment	Equipment related training, or standardization of equipment
The equipment does not conform to the standard	Standardization of equipment
Complaint received from external stakeholders about the effectiveness of the inspectors	Identify the factors hampering Inspectors' performance and take corrective actions to improve them
The business plan should be suitable for the number of inspectors	Efforts for demand optimization, incentives for attracting new recruits, or come up with new business models for inspection agencies
The inspector is not able to carry out the work as per his/her own expectation	Periodic retraining for the inspectors
The trend of on-time inspection completion is declining	Identify the factors hampering Inspectors' performance and take corrective actions to improve them
The equipment downtime for maintenance is more than anticipated	Standardization of equipment
Many inspectors do not report errors in the equipment to the inspection agency	Equipment related training, Provision of the acceptable channel of reporting, make such reporting as part of the normal work
The communication channel for conflict resolution is not effective	Develop such channels and show their effectiveness
Employees do not report missing procedure against the real conditions	Procedure-related training, Provision of the acceptable channel of reporting, make such reporting as part of the normal work
Equipment department is receiving enough budget	Review the business plan
The employee feels the need for retraining.	Periodic retraining for the inspectors
Operating profits are decreasing continuously	Review the business plan
Difficulty in hiring new inspectors	Incentives for attracting new recruits, or come up with new business models for inspection agencies
The personnel department is receiving enough budget	Review the business plan
Safety Culture assessment	Review and act

5.7.Implications of GEWaSAP for Japanese HSR

In the previous chapter need for a proactive risk-management approach for Japanese HSR operators was identified. Two potential cases were identified, first being leading indicator monitoring by the industry regulator, i.e., MLIT for the HSR TOCs, and the second case was leading indicator monitoring for the rolling stock manufacturers by the HSR TOCs. In both cases, the components being monitored are organizations. In this chapter, a methodology, called GEWaSAP, has been developed and applied to for developing leading indicators for organizational components.

One of the strengths of the GEWaSAP approach is its ability to develop system-specific leading indicators. Hence, for identifying lessons specific to the HSR, the GEWaSAP has to be applied to the above-mentioned organizations in the HSR system. However, due to the high complexity of the HSR system, a collaborative approach from multiple stakeholders was deemed necessary, where inputs will be required from a large number of industry professionals. Given the barriers such as low understanding of the system-thinking framework among industry experts and the language barrier, such a study was not feasible to be completed under the scope of this thesis. Due to these limitations, lessons can only be derived by adopting a macroscopic perspective on HSR TOCs and by making simplified assumptions about various safety constraints of the HSR system.

5.7.1 Existing leading indicators for Japanese HSR TOCs

There are significant differences between the role played by the Johkasou inspection agency to fulfill its responsibility and the Japanese HSR TOCs. Unlike, inspection agency, the HSR TOCs are responsible for developing all-important railway-related technology, manage the operations, maintain the equipment, etc. However, there exists similarity in work only at the macro level, for example, HSR TOCs also have to manage procedures, equipment quantity, and quality as well as a sufficient number of human resources capable of executing various functions. In this regard, a few of the organizational level leading indicators from the Johkasou case study can be applied to the Japanese HSR TOCs. Further, a quick comparison with existing indicators mandated by MLIT as part of the review of the safety management system could give an idea of whether the application of a method like GEWaSAP will make sense for HSR context. Table 5-14 shows the indicators measured by the MLIT as part of a review of the safety management system of HSR TOCs.

Table 5-14 Parameters reviewed by MLIT as part of a review of Safety Management Systems

Responsibility of Top management; Safety Policy; Safety Focus; Responsibility of Safety Supervisor; Personnel Responsibility and authority; Information transmission and communication; Collect and utilize incident and hazard information; Response to serious accident; Compliance with relevant laws; Education and Training; Internal Audit; Management Review and Improvement; Document creation and Management; Record maintenance

5.7.2 Leading indicators from Johkasou applicable for Japanese HSR TOCs compared with existing indicators in Japan

In this section, the relevance of the leading indicators identified in the Johkasou inspection agency for HSR TOCs is discussed. A brief explanation of a few of the indicators is as follows

Working conditions of Personnel involved is a critical parameter with the potential to affect many aspects of the organizational functions. Whereas, personnel working condition has not received any mention in the parameters reviewed by MLIT (Table 5-14).

Conflict in procedures is one of the crucial aspects that are not explicitly measured in the safety management review conducted by MLIT. The difference of procedures from as developed vs. as practiced is one of the common contributing factors across multiple HSR accidents. However, the detection of such conflicts is likely to be more challenging for HSR than it is for the Johkasou system. In Johkasou, the inspectors receive initial training from an external agency, and hence they may have an ability to detect the conflicts, whereas, in Japanese HSR TOCs, the procedures are developed in-house and are taught through in-house training efforts. Hence, a comprehensive periodic assessment is necessary to identify such conflicting procedures. The issue of local adaptation, understanding of the procedures, etc. can all be considered an extension of the same issue.

Personnel's inability to adequately implement the procedures with the resource constraints (time, equipment, money, or working hours) is another important leading indicator that has not been considered in the safety management review prescribed by MLIT. The deviation from procedures must be detected, and the underlying causal factor should be addressed. In this regard, the organizational incentive structure plays an important role. This factor is also important from the perspective that it is also thought of as one of the common accident causal factors where the personnel are not able to perform their activity despite removing the ambiguity related to tasks involved.

The availability of the communication channel for resolving conflict is another important leading indicator. Top-down and bottom-up, both types of communications are essential for the HSR TOCs to function effectively; however, the focus of the safety management review is on top-down communication such as information transmission, etc. Employees' perception about whether they are aware of the communication channels that they can use when facing conflicting or an unprecedented situation is thus an important leading indicator of whether there is a possibility of local adaptation on behalf of the employees.

Also, there are many indicators from the Johkasou system, which are already monitored for Japanese HSR TOCs for example, status for safety training, status of equipment maintenance, business sustainability of the HSR TOCs, responsibility and authority of various departments, budget approvals to different departments, etc. suggesting that the safety management review of Japanese HSR TOCs also considers factors identified from the rigorous hazard analysis.

5.7.3 Comparison with the indicators from literature

Academic studies aiming to the development of leading indicators for the organizational components in the railway context are not new. Many of such studies can be found in the literature related to safety culture or safety climate for railways context. A detailed review of such studies has been presented elsewhere (Kyriakidis, Hirsch and Majumdar, 2012; Kyriakidis, Majumdar, and Ochieng, 2018; Bugalia, Maemura and Ozawa, 2019; Cheng, 2019). In particular, Cheng (2019) has summarized a comprehensive list of such leading indicators for the railway organization, and the same has been summarized in Figure 5-17.

A quick comparison of the indicators leading indicators relevant for HSR identified in this study (see section 5.7.2) with that of the supported by the recent academic work, reveals that the rigor adopted in this study has been successful in identifying a few new and unique indicators that are not included even in the current academic work.

For example, the working condition of the railway personnel such as quality of their work-life, their work-load, etc. does not merit consideration as an important leading safety indicator in the academic literature while the same has been identified to be important from the analysis in this study. Similarly, the issue of resource constraints hampering the personnel’s ability to execute the responsibilities appropriately, as well as the presence of the conflicting procedures, has not received any explicit mention in the leading indicators considered in the current academic literature. While communication within the organization has received explicit mention as leading indicators, the current literature emphasizes on communication from management to the front-end workers but not enough on whether or not adequate communication channel within the organization exist where employees can seek a quick resolution of conflicting situations that they face while executing their duties.

On the other hand, the study also reveals a few indicators which are generally seen as important as per the academic community. For example, the issue of equipment provision, training provision as per the needs of the employee, etc. have been identified to be important indicators by both the method developed in the current study as well as the recent academic literature, thus validating the consistency of the current approach in identifying system-specific leading indicators for railway organizations.

Dimension	Measurement Variable
Safety Communication	The organization communicates with employees when changes in working procedures and their effects on safety are effective
	An effective documentation management system ensured the availability of safety procedures
	Safety problems are openly discussed by employees and managers
	Employees are encouraged to discuss important safety issues
	The organization always informs employees of current safety concerns and issues
	Good communication exists between organization and contractor staff
	Good communication occurs during shift changes
	Employees are consulted before safety practices are changed
Safety Training	Potential risks and consequences are identified in the safety training program
	A training program is provided for work-related skills
	Training is conducted by people with plenty of relevant experience
	Safety training programs are useful
	The organization provides adequate safety education programs
	The organization provides sufficient safety training programs for new employees
	The organization provides safety training when employees change work tasks
Safety Management	The safety deputy's suggestions are taken seriously by management
	Information about undesirable incidents is effective in preventing their recurrence
	Emergency preparedness is good
	The safety deputies are good
	The organization conducts safety inspections frequently
	The organization investigates safety problems quickly
	The organization provides safety equipment
	The organization provides safe working conditions
	The organization always responds quickly to safety concerns
	The organization keeps employees informed of hazards
	The organization has explicit safety targets
	The organization has a section responsible for safety management
Subjective Evaluation of Safety Performance	The frequency of accidents decreased last year
	The failure rate of railway equipment also decreased last year
	Work-related causalities likewise decreased in the previous year
	The emergency response ability of the TRA was enhanced

Figure 5-16 List of leading indicators identified from literature

Source : Cheng (2019)

5.8.Summary of leading indicator operationalization study

In this chapter, an attempt is made for developing a generalized methodology for implementing an early warning sign program in an organization. The methodology developed in this study is an improvement from the existing methods are many aspects including its applicability for organizational and human components, generally applicable for all system stages, i.e., System Development as well as System Operation stage.

However, the generalized approach developed in this study builds on already existing concepts described in previous studies on STAMP and EWaSAP. In EWaSAP method, controllers enforce awareness actions, when they observe the signs matching accident causal factors, to make other controllers in the system aware of potential movement of the system to an unsafe state. So, if the awareness actions are not enforced correctly, the accident could still occur. The current study builds upon this concept and introduces the suitability criterion to identify appropriate controllers who should receive the awareness actions (as this is not strictly defined in the EWaSAP approach). While the proposed suitability criteria were identified from one of the generalizable mechanisms of system evolution based on the existing safety theory, the criteria were applied to several systems for confirming their applicability. Detailed examples from two different accident cases were first used to confirm the applicability of the suitability criteria. To further generalize, the effectiveness of the proposed criteria in ensuring safety for a variety of systems, as classified by (Pariès *et al.*, 2019), was discussed at length. The proposed suitability criteria are surely necessary for complex systems involving a higher degree of centralization or where the system relies on a high degree of pre-determination. The approach implemented in this study then reveals new generic accident causal factors that the accidents can also occur when the corrective actions are not effectively enforced. The generic method thus developed, called GEWaSAP, in this study can be visually represented as shown in Figure 5-16, as the system can be made to continuously move towards higher safety state by repeating the cycles of enforcing awareness actions and corrective actions.

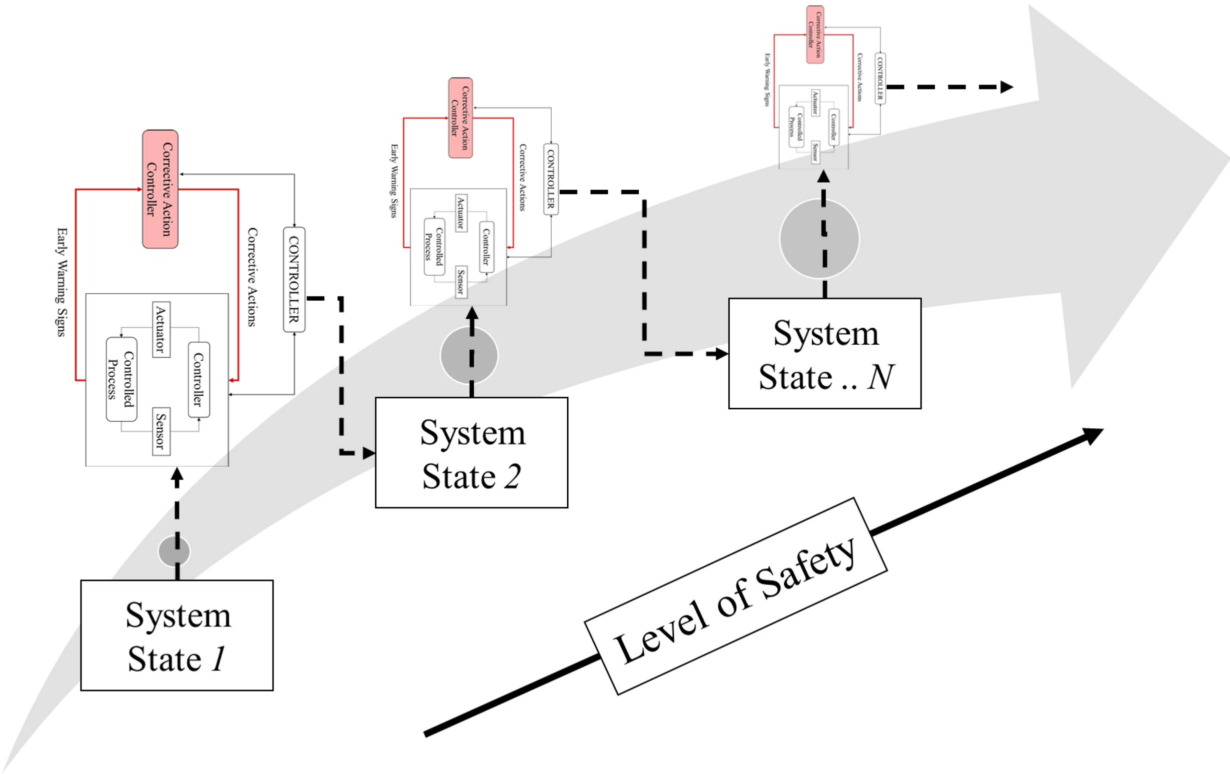


Figure 5-17 Visual representation of the GEWaSAP approach

The practical usefulness of the GEWaSAP approach was then confirmed through a case study for Johkasou in Japan. For the scope of this particular study, the Johkasou inspection agency was chosen for its critical role as an independent system monitor, practically serving as eyes and the ears of the governor's office for providing necessary control actions. The GEWaSAP approach was useful in identifying 36 unique leading indicators, whose monitoring could provide the governor with a better understating of the effective functioning of the inspection agency itself. However, the interview with the experienced Johkasou professional revealed that not all the identified indicators are readily accepted within the given context in Japan. The interviews mainly revealed the presence of several additional social, economic, and institutional contextual factors that may cause the increased monitoring capabilities enabled by the identified leading indicators, unnecessary. In most cases, the potential vulnerability of the system, as reflected through the leading indicators identified, was recognized by the stakeholders. However, such recognition was not necessarily considered to be a risk in the Japanese context. The important trade-offs are the capability of the regulator to sustain the high level of monitoring necessary. Further, the high-level of monitoring can often be seen as a constraint to the autonomy of the operator.

The proposed methodology does not explicitly consider such trade-offs. Such a mixed experience of the practical application of the approach suggests the necessity to conduct the analysis multiple times, accommodating diverse perspectives every time, until convergence is reached. Nevertheless, the identified contexts should be clearly listed as they themselves could serve as potential leading indicators and should be monitored thereof.

The case-study application is also helpful in identifying that there could be several mechanisms to system evolution, which would then affect the suitability criteria. The comparison with the real world, thus, helps us identify the direction of future studies, i.e., system-evolution for the non-physical components must be studied in further detail for effectively implementing a strategy of the pro-active safety management.

5.9.Main Conclusions

The following are the main conclusions from this chapter–

C5-1. **The proposed generalized leading indicator operationalization method is shown to be grounded in several theoretical and practical safety-related aspects**, including its suitability to be applicable for accidents in multiple systems, and its underpinning with the recent management theory **(Section 5.5, O2, R3).**

C5-2. **The proposed generalized leading indicators operationalization approach is found to be effective in identifying leading indicators that are more comprehensive than the indicators currently being monitored for two complex systems, i.e., Johkasou and for HSR (Section 5.6.7, and Section 5.7, O2, R3).**

C5-3. **However, the indicator operationalization requirements, as identified by the proposed method, received a mixed response in the real-world verification. In reality, there are several contextual factors and trade-offs that affect the desired level of system monitoring and hence the choice of indicators to be monitored**. In some cases, risks may be known to the stakeholders in the system, however they may not be considered adequate for monitoring due to the "trade-offs", and hence are often not listed in the official documents as potential risks. The capacity constraints for the regulator and the operator's autonomy are all considered important to identify a suitable number of leading indicators; however, the method proposed in the current study does not explicitly consider such factors, and hence needs further improvements. **(Section 5.6.7, O2, R3).**

C5-4. The important leading indicator for HSR TOCs can be identified through rigorous implementation of the GEWaSAP method for Japanese HSR; however, even the macroscopic comparison has revealed a few leading indicators that are not part of the review of the safety management system of Japanese HSR TOCs. These indicators include the status of working conditions of the HSR personnel, early detection of conflict in procedures, etc. The preliminary comparison of the leading indicator thus marks the usefulness of the approach in identifying new indicators and thus makes a strong case for implementing a thorough GEWaSAP exercise for Japanese HSR TOCs in the future **(Section 5.7, O2, R3).**

Chapter 6. Modeling of the reporting behavior in Organization

While reviewing the state-of-the-art safety theory, the current study has highlighted that the reporting of potential unsafe causal factors that do not lead to any tangible incidents, such as the near misses, is crucial for the safety of the ultra-safe systems such as HSR. Such near-misses provide a valuable learning opportunity for the organization to maintain the adequacy of its safety defenses; otherwise, the defense may gradually become weaker in the absence of a sustained safe state of the system.

Further, by reviewing the accidents of the Japanese HSR, the current study has shown that one of the common accident causal factors is that the information "as practiced" gradually steer-away from information "as-approved." Such a deviation is clearly an indicator of the fact that organizational communication is weak. Such a deviation is a clear indicator that enough feedback is not reaching from the practitioners to the information approvers about the efficacy of the information in the real situation. Lack of such feedback can surely lead to short-term performance gain and may not be visible in the form of tangible accidents but may compromise safety in the long-term. Also, the leading indicator program developed in this study also relies on adequate reporting when a potential accident causal factors are detected. Hence, for the effective implementation of a leading indicator program, an understanding of its effective reporting is also necessary. This chapter is an attempt to develop a simulation model for the reporting behavior of the organization. Details on the need for a model, selection of appropriate modeling strategy, etc. all are discussed in this chapter.

6.1.Reporting behavior in centralized organizations: A Literature review

Several academic discussions have focused on identifying barriers to improved reporting culture. A few commonly reported barriers are the fear of being blamed, disciplined, or embarrassed (Williamsen, 2013). Management's complacent attitude towards the known deficiency in the system is another such barrier (Williamsen, 2013). Among the factors undermining the reporting culture, ineffectiveness of the middle-management in executing safety directives from the top, as well as their lack of interest in seeking more non-value added safety-related work, are considered prominent (Williamsen, 2013).Yet another barrier for efficient reporting is associated with the characteristics of the reporting system itself. Williamsen (2013) has discussed five L's for effective reporting forms. These five L's are Literacy (easy to read forms), Language (forms available in multiple languages if necessary), Length (forms should be short and concise), Location (forms should be easily accessible to workers), and Logistics (forms should enable solutions). Leveson (2011) suggests that an inflexible form involving additional steps to report, and the one that is not part of the normal operating procedure will likely discourage people from participating in the incident reporting process.

Academic discussions have also focused on potential solutions to overcome barriers. To overcome the barriers of fear of blame, the confidentiality of reporting is regarded as extremely crucial (Reason, 1997, 1998; Barach and Small, 2000). Research has also looked at the importance of confidentiality and anonymity of the reporting culture. Barach & Small (2000) have discussed that the application of anonymity should be considered carefully as an anonymous reporting system can create difficulty in the follow-up. Generally speaking, the confidentiality of the reporting system is considered more important than anonymity (Barach and Small, 2000). To overcome the barriers of the top management's complacency, Petersen (1993) describes top management's visible commitment, middle management's active involvement is also described as criteria for achieving "safety excellence." Based on his extensive industry experience, Williamsen (2013) has advised on implementing a four-step process to improve accountability in the reporting system. These steps are Define, Train, Recognize, and Measure. Define refers to set the expectations of all employees about what constitutes a near miss. Train refers to a safety-orientation for employees about the importance and methods to report near-misses. Measure refers to defining near-miss reports as a leading indicator, and finally, recognize refers to programs for rewarding good reporting behavior.

Despite the long-standing notion that reporting culture is developed through interactions with people, structure, and control systems within an organization (Uttal, 1983) and is thus dynamic, it is only recently the discussions have been targeted at the underlying dynamics of these interactions. Leveson (2011) suggests that efforts to provide organizational training to utilize the reporting system are likely to have short-lived effects. Hopkins (2019) has also discussed the short-term effects of Hearts and Minds approach in the absence of clearly defined performance indicators and rewards corresponding to the factors included in the training. Hearts and Minds approach assumes that cultures of safety could be created using educational workshops.

Also, it is also only recently, that culture is analyzed through its relationship with existing organizational structure and controls. Park (2018), in his study for the Korean railway sector, has identified that managers at a different level of hierarchy within an organization may have different perceptions and thus priority about safety. Based on his extensive safety experience, Hopkins (2019) has demonstrated that it is the organizational structure that can institutionalize and thus create a stable culture. Hopkins (2019) argues that even though the top management's visible commitment to safety is essential, the effect is also short-lived, and the desired culture is achieved only when leaders create the structures that support these cultures, such as through clearly defined organizational goals and policies, and performance indicators. Based on this, Hopkins (2019) has stressed the importance of centralized organizational control for managing catastrophic hazards.

Centralized control refers to a situation where important decisions regarding the management of the catastrophic hazards are made as close to the top of management as possible, and these decisions are kept free from the influence of other competing demands of business such as profitability. The idea of centralized control affecting culture is also evident from a recent reorganization of railway operators in Japan (MLIT 2007). To improve the safety culture of railway operators in Japan, the railway regulator of Japan mandated a change in the organizational structure of the operator. The regulator mandated the appointment of a Chief Safety Officer who is responsible for implementing safety management systems in their respective organizations and is involved in all critical business decisions. This appointment was deemed meaningful even in the Japanese railway, where the conventional practice of safety management could also be argued to be highly centralized (Saito, 2002).

However, reporting culture can still be a problem even in organizations exercising a high degree of centralized control. In a recent incident in Japan, the driver of a High-Speed Rail failed to report an abnormal noise or bump, which came from the front of a train operating at high speeds. The driver thought that an animal must have hit and did not consider it worthy of reporting. HSR tracks in Japan are grade-separated, and such obstructions on the track are instead a rare event. Nevertheless, the driver failed to communicate despite the recent addition of a rule mandating the reporting of abnormal situations. When the train arrived at the next station, the station staff noticed that the nose of the train was heavily damaged, even then, the station staff reported this incident to control center only after the train left that station (The Asahi Shimbun, 2018). The event demonstrates that even in centrally controlled organizations, with adequate means of reporting available, the reporting practices could still be ineffective. The event also suggests that a consideration of interplay among various causal factors may be necessary to explain the reporting culture of an organization fully.

6.2. Methodological limitations and necessity of organizational modeling

The issue related to reporting behavior is also challenging with respect to the methodological aspects. Several studies rely on conducting survey-questionnaire across departments for employees at a different level of hierarchy to develop a culture profile of a given organization. The challenge with such methods is that they do not consider the dynamic view of the culture but tend to provide a static snapshot of the prevalent practices.

For approaches relying on the systems perspective, Hopkins (2019) has highlighted a number of methodological limitations. The before-and-after statistical studies have limitations in providing a conclusion on the effectiveness of organizational change, due to reasons such as low frequency of the major accident to serve any significant purpose, delays in the reflection of safety concerns after the changes have taken place, etc. Alternatively, Hopkins (2019) examined the possibility of cross-sectional studies in which the safety performance of multiple industries could be compared within groups, where one group of studies have implemented a specific type of organizational structure, and others have not. Even the cross-sectional studies have limitations as it is extremely difficult to make a scale that can compare the organizational characteristics of multiple organizations. Even if such a comparison of organizational characteristics as possible, the correlation between the organizational characteristics and the accident rate would still be faulty as already described for the before-and-after type studies. To compensate for the drawbacks described above, Hopkins (2019) thus has proposed to utilize expert opinions, well-considered judgments, and anecdotal evidence. However, Hopkins (2019) did not consider the possibility of using the simulation models that can prove useful tools precisely when the statistical methods are sometimes not reliable.

The present study attempts to answer the question of how the reporting culture of already centralized control organization could be further improved. The objective of this part of the study is to develop a generalized theoretical model which can qualitatively explain the reporting culture of an organization and help identify the focus areas of improvements. In the next section, various modeling perspectives are discussed, and justification has been provided for selecting a suitable methodology.

6.3. Organization theory and modeling perspectives

6.3.1 Essential concepts

Organization theory is the study of structures and the dynamics of human organization. The related research methods come from multiple disciplines such as economics, sociology, psychology, and systems theory. Consequently, a multitude of definitions of organizations exist. A detailed review of these definitions is given in (Stroeve, Sharpanskykh, and Kirwan, 2011); however, the key concepts that emerge is that organization is a system of highly integrated parts (*Systems theory)* and that organizations are driven towards the accomplishment of an overall goal.

Stroeve et al. (2011) have elaborated on aggregation levels that are used to study organizations. Three levels, namely micro, meso, and macro levels, are described. At the micro-level, the behavior of individuals and groups in an organization is studied. The structures and dynamics at the level of the whole organization are topics of interest for the meso level. The macro-level interactions between the organization and its environment, including interactions with other organizations, governments, etc. are considered. A detailed review of subtopics in each of these levels is discussed in (Eurocontrol III, 2007; Stroeve, Sharpanskykh, and Kirwan, 2011).

Efforts have also been made to develop a multi-view hybrid organizational modeling framework, one that can analyze across different perspectives at various aggregation levels of an organization (Sharpanskykh, 2008). This hybrid view of the organizations considers both material characteristics of the organization and the immaterial characteristics of its constituent agents. Agents are representative of various software, and hardware components in a socio-technical system are able to perceive from their environment and act upon it. The 4 views of this hybrid framework are *Organization-oriented view* that considers the relationship between roles at various aggregation levels within organization as well as describes the authority relations; *Performance-oriented view* that describes goals and performance indicators for various organizational roles as well as the relationship between various sub-goals to overall organizational goals; *Process-oriented view* describes tasks, dynamic relations between tasks, etc.; and *Agent-oriented view* then considers the relationship between roles and agents performing these roles. Variation in agent types, their capacity, their capabilities, their behavior all can contribute to the dynamics of the agent's interactions as well as the behavior of the organization.

6.3.2 Existing methods for organizational modeling

Various methodological frameworks to study organizations have been developed. The earliest computational organizational modeling approaches were developed in the field of System Dynamics

(SD) (Forrester, 1997) and Operations Research (Marlow, 1993). In recent years, agent-based modeling approaches have also been considered (Stroeve, Sharpanskykh, and Kirwan, 2011).

Since then, the use of SD with its characteristic feedback loops and time delays have been shown to analyze organizations at macro and meso levels for demonstrating general trends of organizational development (Sterman, 2000). The typical variables used in these models take an aggregated perspective on organizational dynamics. These views are simpler and known to be effective for communicating the key underlying dynamics to the relevant decision-makers (Sterman, 2000; Stroeve, Sharpanskykh, and Kirwan, 2011). Further, SD models are known for their capability to consider variables and behaviors that are difficult to measure or observe through survey questionnaires, and thus can prove effective for facilitating decision making (Sterman, 2000).

On the other hand, Stroeve et al. (2011) have argued that SD models are limited in their ability to analyze at meso and micro levels of an organization and suggest using agent-based modeling approaches instead. Stroeve et al. (2011) argue that the high complexity of the social dynamics of interactions among various organizational actors may lead to unexpected emergent behaviors that are lost when considering aggregated views as adopted by SD. In that, multi-agent models are utilized to simulate behaviors relevant to the meso and micro scales of an organization (Stroeve, Sharpanskykh, and Kirwan, 2011). The hybrid framework discussed above is also shown to be comprehensive using the multi-agent modeling of organizations (Eurocontrol III, 2007).

6.3.3 Modeling of the reporting culture

Reporting culture is described as an organizational trait where workers will be willing to report near misses and accidents openly and honestly (Reason, 1997). Reporting culture is considered an integral sub-part of organizational safety culture (Reason, 1997). Hence, it also shares certain characteristics of safety culture. There is no universally agreed-upon definition of safety culture. However, key characteristics of the safety culture are that it is a system of shared values and beliefs within an organization (Antonsen, 2017). Naturally, reporting culture, like safety culture, also interacts with an organization's people, structure, and control systems to produce behavioral norms (Uttal, 1983).

Cooper (2000) was among the first to point out that despite the clear indication that interactive relationships between psychological, situational, and behavioral factors are necessary to describe the safety culture of an organization, changes are often made in one, without regard to the others. He then proposed a *dynamic reciprocal relationship* between "members' perceptions about, attitudes towards, members' goal-directed behavior, and the presence & the quality of organization's system to support goal-directed behavior" reflects the organization's culture. These dynamic reciprocal relationships have then been explored in subsequent studies for a range of fields.

Using SD, (Leveson *et al.*, 2005) was able to demonstrate the relationships between various safety culture-related aspects such as workforce and knowledge management issues, assigned safety priority on design, etc. and safety performance for NASA. (Leveson *et al.*, 2005) had utilized in-depth qualitative interviews to synthesize causal relationships and dynamic behavior among relevant to safety culture and safety at an organizational level (meso level). Goal-oriented safety improvements considering the dynamic of underlying sub-systems have also been analyzed for a variety of sectors, such as construction. Jiang, Fang, & Zhang (2015) utilized SD for the construction industry, considering the effect of individual conditions, management conditions, and environmental conditions on safety performance. However, this study is at the meso level and does not consider the goal-driven nature of the organization. Further, this study considers the effect of incident report explicitly; however, the relationship between reporting and incidents are not explored in detail. Yet another related study, has analyzed the dynamics between key enablers of cultural change in an organization such as Leadership, Policy and Strategy, People, etc. and safety performance in a goal-driven organization (Mohamed and Chinda, 2011). However, the model can surely be categorized as a meso level as it fails to include any interactions at the individuals in an organization. Shin, Lee, Park, Moon, & Han (2014) developed a micro-level SD model on construction workers' safety attitudes and behaviors. However, the model fails to fully account for underlying causal factors for a number of variables and thus fails to generate any recommendations on organizational policies. All of the above-mentioned SD models have been successful in assimilating information available through existing literature as well as experts mental models etc., however, despite considering the dynamic relationships, even these models have missed one or more *reciprocal relationships* (Cooper, 2000) across levels (macro, meso, and micro) (Sharpanskykh, 2008) and are thus limited.

On the other hand, agent-based modeling techniques have been used for analyzing safety culture in the aviation field (Stroeve, Sharpanskykh, and Kirwan, 2011; Sharpanskykh *et al.*, 2013; Sharpanskykh and Stroeve, 2014). All of these studies consider the interaction of agents (at the micro-level) and consider the relationships among meso and macro levels to identify related policies for culture improvement. They offer valuable organizational level models that can generate policy recommendations using simulations. However, in any agent-based modeling exercise, definitions of the characteristics of the agent themselves affect the accuracy of the model, and such definitions are inherently erroneous, as demonstrated by Stroeve et al.(2011) in their phase 1 analysis. It is only when the additional information such as ethnography data (Sharpanskykh *et al.*, 2013), safety culture survey (Stroeve, Sharpanskykh, and Kirwan, 2011) or cultural classification framework (Sharpanskykh and Stroeve, 2014) is combined, such models become useful in generating recommendations.

6.3.4 Selection of the modeling method

The present study aims to develop a theoretical model explaining the reporting culture of HSR TOCs in Japan by considering dynamic causal relationships among factors across the individual and organizational levels. Based on the literature review presented in section 2, a modeling framework suitable for our research is chosen here. Agent-based modeling is undoubtedly shown to be an effective approach for performing detailed analysis and considering interactions across multiple levels of the organization. The existing literature has shown the effectiveness of these methods in highlighting unexpected organizational behaviors at the macro and meso levels due to complex interactions at micro-levels. However, it is also shown that rigor ensured by the agent-based models is inherently erroneous, and it is only when the information obtained through detailed culture, ethnographic surveys is the accuracy of these models improved. Nevertheless, it is equally difficult to find good relations between the dimensions measured in these surveys and variables adopted in the models (Stroeve, Sharpanskykh, and Kirwan, 2011). The availability of such a comprehensive questionnaire may not be true for all organizations and even available; the correlation between results of the surveys and safety performance, which is the goal of such research, is shown to weak. SD, on the other hand, is known to assimilate the wide range of available information in literature as well as in the rich information on process models of the employees of the organization and can generate reliable behavioral trends of aggregate variables at the meso and macro scales. Further, the results of the SD models are shown to be effectively incommunicable to the wider range of stakeholders and are very effective training tools (Sterman, 2000), thus enabling organizational learning. The aggregated level analysis is often criticized as the limitation of study for understanding the key dynamics at the agent-level (Stroeve, Sharpanskykh, and Kirwan, 2011); however, recent studies have shown that modeling at the micro-level through SD is effective in analyzing numerous policy scenarios (Shin *et al.*, 2014). Considering the reasoning described above, we henceforth use SD as an organizational modeling framework. The model in the study is aimed at considering dynamics across multiple levels within an organization, i.e., micro, meso, and macro considering the comprehensive multi-view hybrid framework (Sharpanskykh, 2008), however, instead of an agent-based approach, an aggregated perspective on an individual in an organizations is adopted to consider the Micro perspective of modeling, as consistent with the SD modeling framework.

6.4.Overview of the modeling framework of this study

Essential elements of SD are *feedback loops* and *delays*. Feedback loops are loops made using causal relations between two or more components that can be of two types *reinforcing loops* are self-reinforcing while *balancing loops* counteract changes and seek equilibrium. Positive (+) sign on a causal relationship between variable 1 and variable 2 indicates that a change in variable 1 in one direction (increase or decrease) will cause the change in variable 2 in the same direction. A negative (-) sign means that variables change in opposite directions. The third element of SD is a delay, which is used to model the time elapsed between cause and effect. In SD, Causal Loop Diagrams (CLD) are used to institutively explain the behavior of the model. These CLD also are then useful in developing the Stock-Flow Diagram (SFD), used to generate a numerical simulation of the behavior. Stocks are variables that represent a quantity existing at that point of time, which may have accumulated in the past, whereas flow is measured over an interval of time. Flow is also analogous to the "rate of change." In SD, every feedback loop must contain at least one stock, stocks are changed only by rates, and in-turn rates are dependent on the current state of the stocks, making it possible to generate dynamic behavior of the interacting variables (Sterman, 2000).

The model developed in this study aims to improve upon the drawbacks highlighted in reported SD models in literature so far. A few common drawbacks include lack of cross-level view of models (especially at the micro-level), lack of goal-oriented view of the agents in the organization and for the organization as a whole, and lack of due consideration of existing functional structures such as hierarchies and formal processes in the organization.

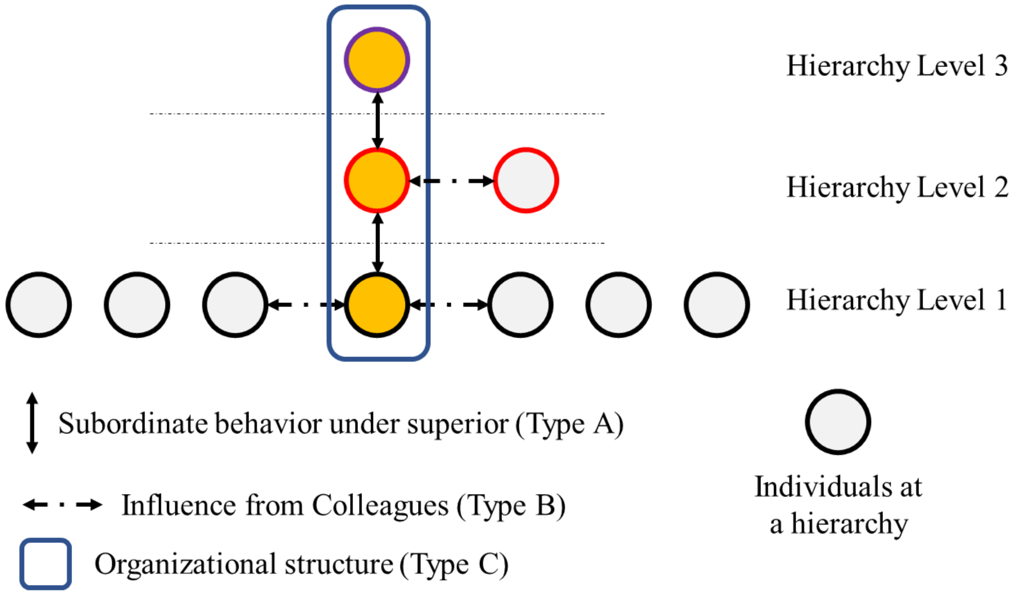


Figure 6-1 Modeling framework for reporting behavior

Figure 6-1 shows the modeling framework adopted in this study. The theoretical model consists of three types of relationships. Type A relationships explain the reporting behavior of an individual in an organization by considering the interactions between an individual and the decisions taken by the immediate (or even higher) managers. The causal relationships needed for this model are developed using the information available from existing literature. These causal relationships are then also verified for the specific context in which the model is applied using information obtained through expert interviews.

Type B relationships examine an individual's own characteristics such as its goals, behavior, capabilities, etc. and the influence of other individuals at a given hierarchical level of organization. Modeled dynamics at this stage are in alignment with the agent-based modeling approach, as described (Stroeve, Sharpanskykh, and Kirwan, 2011). However, as the current study does not adopt an agent modeling approach, an aggregated perspective on such *Micro*-interactions is taken. Once again, the existing literature is referred to as developing these causal relationships.

Finally, the two types of relationships are combined considering the organizational structure, formal processes, and the goal-seeking behavior of the organization specific to the case being studied (Type C). Numerous possible combinations of the organizational structure etc. are possible, as shown in Figure 6-2. The structure could be unique to the organization being modeled, and hence, the information for case-study should be obtained for each case for which the validation is sought.

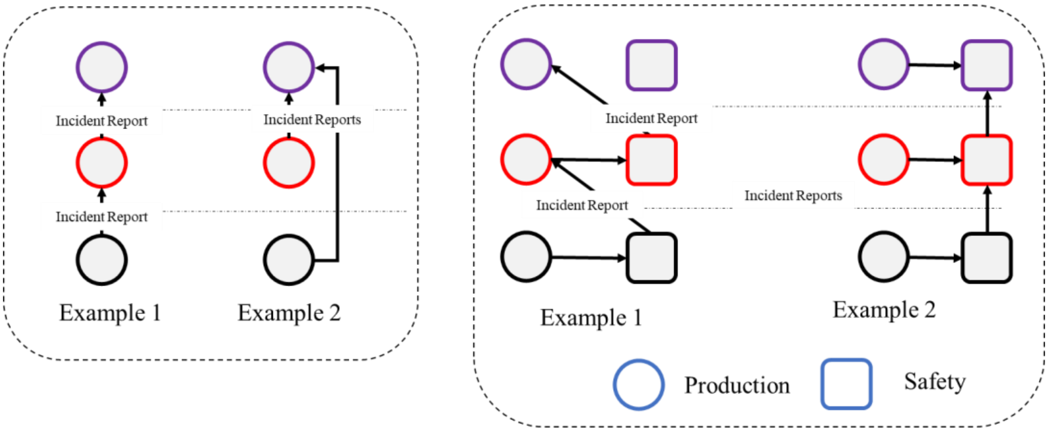


Figure 6-2 Possible variations in the organizational structure

6.4.1 Overview of the Incident Learning System using SD

The current study builds upon the existing SD models on the related issues. Some of the early studies explaining the dynamics of the *incident learning system* in an organization examined the accidents in the mines of Westray (Cooke, 2003a, 2003b; Cooke and Rohleder, 2006). The models thus developed, provide elaborate discussions on various Macro and Meso perspectives on organizational factors affecting the incident reporting, organizational learning, and management's commitment to improving safety. The basic feedback structures governing the dynamics of the incident learning system is described in Figure 6-3. While the original system was discussed for the small incidents, the basic model structure is modified to suit to represent the "near-miss" or the "leading indicators."

Figure 6-3 shows the important feedback loops involving management's commitment to safety. In total, there are 4 feedback loops that govern the dynamic behavior of the management's commitment to safety. As per the *Production Pressure* loop, Management's commitment to safety is decreased by the increasing production pressure, as an organization has limited resources, and safety is often not the key-value generation activity for an organization, at least in the short-term. Any decline in management's commitment to safety would then decrease the safety improvements implemented in the organizations, which in turn affects the number of incidents. Generally, incidents also have an implication for loss in production, and hence, they lead to an increase in production pressure. Such an increase in production pressure would then lead to a further increase in the management's commitment to safety, thus forming a reinforcing loop. As per this loop, if the management of an organization can sustain its commitment to safety, it will be continuously able to achieve higher states of safety as well as keep their production pressures to a minimum. A second *Production-Pressure* loop is also created by the Incident Severity. The higher the incident severity is, the greater is the production loss, and thus lower is the perceived accomplishment. Incident severity is also affected by the *Safety Improvements* implemented by the management, and the level of *Organizational Learning*. However, incidents leading to a loss in production is an important assumption that may not hold true if the incidents were "near-misses" or the "leading indicators." Near-misses often go unnoticed, as they do not have an immediate effect that would indicate the presence of accident causal factors. It is this characteristic of the near misses that make them invisible to the management, thus having a weak effect on the management's commitment to safety. To account for such a variation in assumption, the link between the incidents and perceived accomplishments is shown using a dashed causal link (Figure 6-3).

The management's commitment to safety often does not remain high all the time, as an improvement in safety through management's actions would decrease the incidents, which can relax the management from taking further safe actions, i.e., once the management completes its responsibility of *Meeting the safety goal*, it its commitment to improving safety decreases. There is also a significant delay in realizing the effects of safety improvements on incidents, and in some cases, it may take a long time before many incidents are observed after the safety improvements have been neglected for long. Such a delay weakens the effect of the balancing loop *meeting the safety goal*, and the management may succumb to the production pressure. A similar *Meeting the Safety Goal* feedback loop also exists through incident severity.

Management's commitment to safety also improves the Worker's Safety Perception after a delay. Management's actions such as improvement in safety training, safety awareness campaigns, improving the effectiveness of the reporting channel, increasing the feedback from management about reported incidents are all influenced by the management's commitment to safety, and in turn, they influence the efficiency of the incident reporting. The more the incident reporting increases, the more

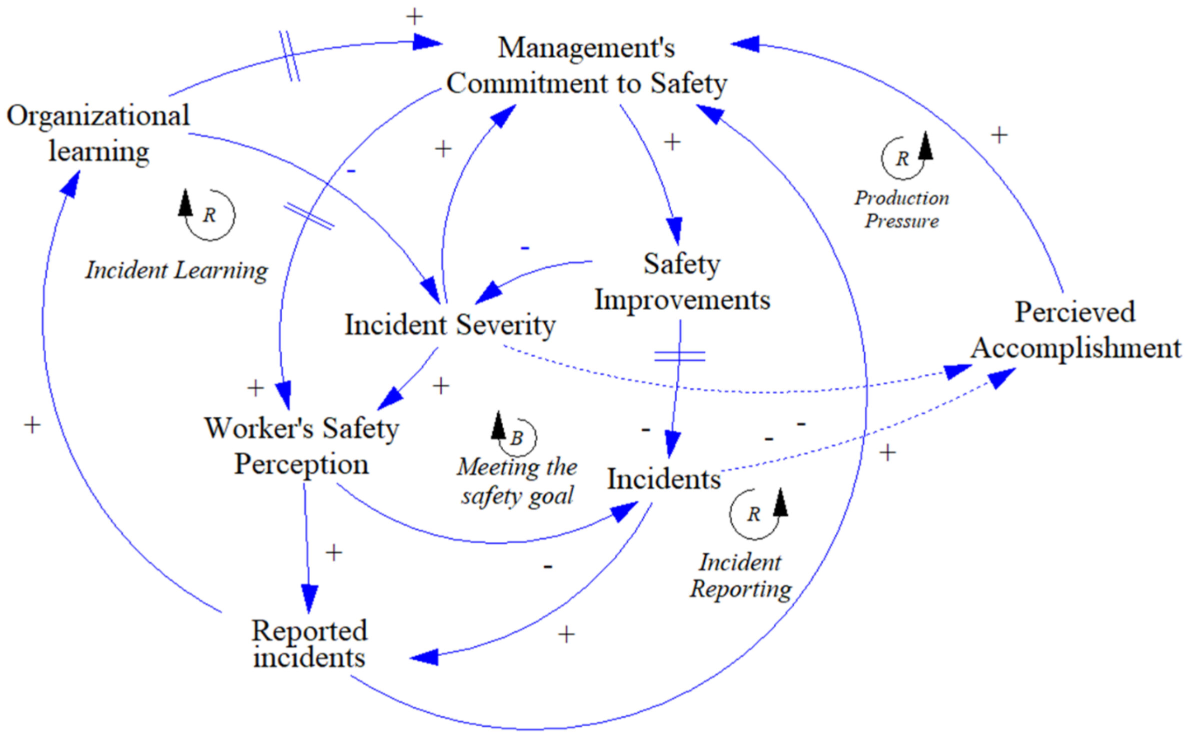


Figure 6-3 Overview of the incident learning system for "near-misses"

the management's commitment to safety increases through the reinforcing *Incident Reporting* loop. Worker's Safety perception is also known to be linked with the number of incidents (near-misses in this case). In any complex socio-technical system, human plays an important role, and their actions have a profound effect on the overall safety of the system. The safety-related incident can also occur from many other factors, including often unpredictable effects coming from out of the system boundary. However, the human operator's safety perception is surely one of the components affecting the incidents.

Finally, the reported incident improves the organizational knowledge of the company and, in turn, further increases the management's commitment to safety (*Incident learning loop)* as often reflected in policy statements of the organization as not to repeat the past accidents. Organizational learning can decay after some time, and hence, sustaining organizational knowledge is an important activity for accident-prone organizations.

While the focus of the original studies by (Cooke, 2003a, 2003b; Cooke and Rohleder, 2006), were on modeling the dynamics of the incident learning system, the causal link between the management's commitment to safety and its effect on worker's perception was not modeled in detail. The subsequent improvement in the model by (Shin *et al.*, 2014; Jiang, Fang and Zhang, 2015), have attempted to overcome this limitation by modeling the factors affecting worker's safety perception in great detail. Their model focuses on the worker's safe behavior in general but does not focus specifically on the "near-miss" reporting the behavior. Hence, the specific focus given to the reporting behavior is also an important academic contribution. The next section reviews the literature to identify factors affecting reporting behavior.

6.5.Type A relationships

A great number of studies in a variety of sectors such as medical, aviation, construction have focused on the issue of organizational reporting culture, and many of the lessons derived are arguably transferable across sectors (Barach and Small, 2000). In this study, we have attempted to develop the generic reporting culture model by combining the concepts form a variety of studies conducted across sectors and across disciplines. The generic model will then be verified for its applicability for the context where the model will be applied.

Shin et al.(2014) have described a feedback structure for a worker's mental process of safe behavior. This feedback structure is considered to be generalizable for reporting behavior due to the existence of other similar frameworks in sectors such as in medical (Kingston *et al.*, 2004) and in aviation (Stroeve, Sharpanskykh, and Kirwan, 2011). This feedback structure is shown in Figure 6-4. The feedback structure in Figure 6-4 is a simplified representation, and there are numerous feedback structures that govern the behavior.

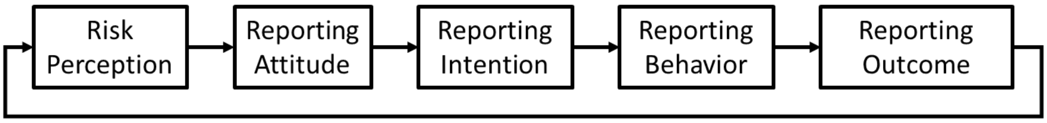


Figure 6-4 Generalized mental process model for an individual

The generalized mental process then can be adapted to specifically represent the reporting behavior in an organization. From the modeling perspective, it makes sense to represent the diagram in a way that represents the tangible actions associated with each of the steps, as described in the generalized mental process model for an individual. Such tangible actions, such as reporting, then allows tracing the number of reports reported by an individual, making it easier to apply some of the information conservation laws in the model as well as use the data as collected by the organizations. The reporting behavior corresponding to the individual process model is thus shown in Figure 6-5.

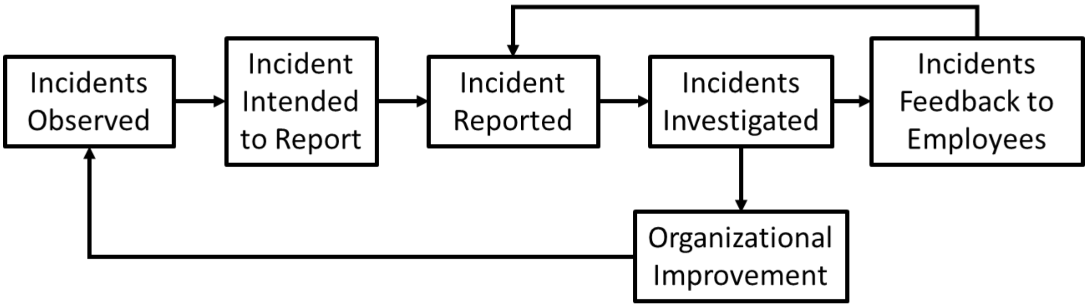


Figure 6-5 Reporting behavior corresponding to the process model of an individual

6.5.1 Risk Perception

The main premise for this process model is that Unsafe acts (such as not reporting) are often intentional, and thus worker's attitudes are key factors affecting this intention. These attitudes are, in part, formed from the risk perception of the worker, which in turn is developed through accumulated knowledge over the years. The outcome of the worker's own action also becomes important for the perception of future intentions and behaviors (Shin *et al.*, 2014). The existence of this mental process is also justified through the comments of an interviewee as reported in (Park, 2018) as *"I am afraid that my site will be harmed related to my reporting, so I do not report if I think I can handle it."* highlighting the importance of reporting outcome in determining the reporting behavior.

Risk perception can be described as the "subjective" judgment on risk, and thus it may differ from individual to individual even for the same risk. Risk perception is developed based on the accumulated previous experiences. For an individual, if the severity of the accident attributable to unsafe behavior of the worker is very high, the risk perception can be changed to being pessimistic (i.e., more cautious about the risk), at the same time, less severe risks can be perceived as pessimistic in the beginning but turn optimistic (underestimation of risks) over the time.

Effect on risk-perception on the reporting behavior is well documented in the academic literature. When risks are perceived as being optimistic, they are less likely to be reported, as the workers may have a tendency to manage them on their own (Park, 2018), or not consider them having serious consequences. (Williamsen, 2013) have described that more severe events are easily reported.

For an individual, the risk perceptions are dependent on an individual's safety knowledge (ability to understand risk), safety awareness (vigilance to risk), and physical conditions (physical states such as fatigue) (Jiang, Fang, and Zhang, 2015). In an organization, such risk perception can develop based on a number of rules, processes, and guidelines, such as whether the said risk is included in the protocols of the organization (Lawton and Parker, 2002; Prang and Jelsness-Jørgensen, 2014). Further, management actions such as leadership's commitment to safety, level of safety communication, regular inspections, safety training, incident learning can all affect safety knowledge and safety awareness of employees (Jiang, Fang and Zhang, 2015). Feedback from the manager can then improve safety awareness but not safety knowledge (Cameron and Duff, 2007). Worker's physical state, such as fatigue, may have a further effect on worker's vigilance to safety, i.e., its safety awareness (Chang and Mosleh, 2007).

Figure 6-6 shows the SD conceptualization of the risk-perception in the current study. In the current study, the Risk Perceiving coefficient (PC) is modeled as a stock whose value can range between 0 and 1. The PC is increased by the PC increment rate and is decreased by the PC decreasing rate. PC increment rate is dependent upon incident observation rate, the severity of the observed incident, risk perception compared to management's decision, and risk perception compared to colleagues. For all of the above-mentioned effects, if their numerical value is more than the current value or PC, the difference between them is added to the stock of PC, following the first-order equation with average Risk perceiving time (30 days in the base case). In the current conceptualization, the effect of incident observation and incident severity is modeled assuming the exponent law as described by (Sterman, 2000). Hence, incident observation effect on PC can be calculated as =

(Perceived Incident observation rate/Reference Perceived Incident Observation rate) ^Observation rate exponent for effect on PC.

Time to form perception for incidents is a parameter that is used to determine the Perceived incident observation rate using the first-order information delay as described in (Sterman, 2000). A similar model is also assumed to work for perceived incident severity calculate the Severity effect on PC. The effects of incident observation and incident severity, when combining with maximum PC (set as 1) determine the target PC. The gap between target PC and PC then added to the PC increment rate using the first-order delay for Risk Perceiving Time. Risk perception compared to management decision is the difference between the average of the level of safety awareness (a value between 0 to 1) and Risk communication (a value between 0 to 1) and the PC. Such a formulation ensures that the PC increases (following the first-order delay with average risk perceiving time) when the management's actions affect the level of safety awareness and safety communication in an organization.

On the other hand, risk-perception can decrease with time, as the memory of the minor incidents fades away. In this model, we do not consider the possibility of a serious accident; hence, the risk-recovery is independent of the type of near-miss in our model. However, an inverse relationship of the risk recovery is conceptualized, implying that it is more difficult to recover the risk perception when the PC is already high, while if the PC is small, the recovery tends to be even faster. Such conceptualization is synergetic to the effect described in (Shin *et al.,* 2014), stating that workers may have difficulty in recovering from the state of high-risk perception, analogous to experiencing a tragic event personally.

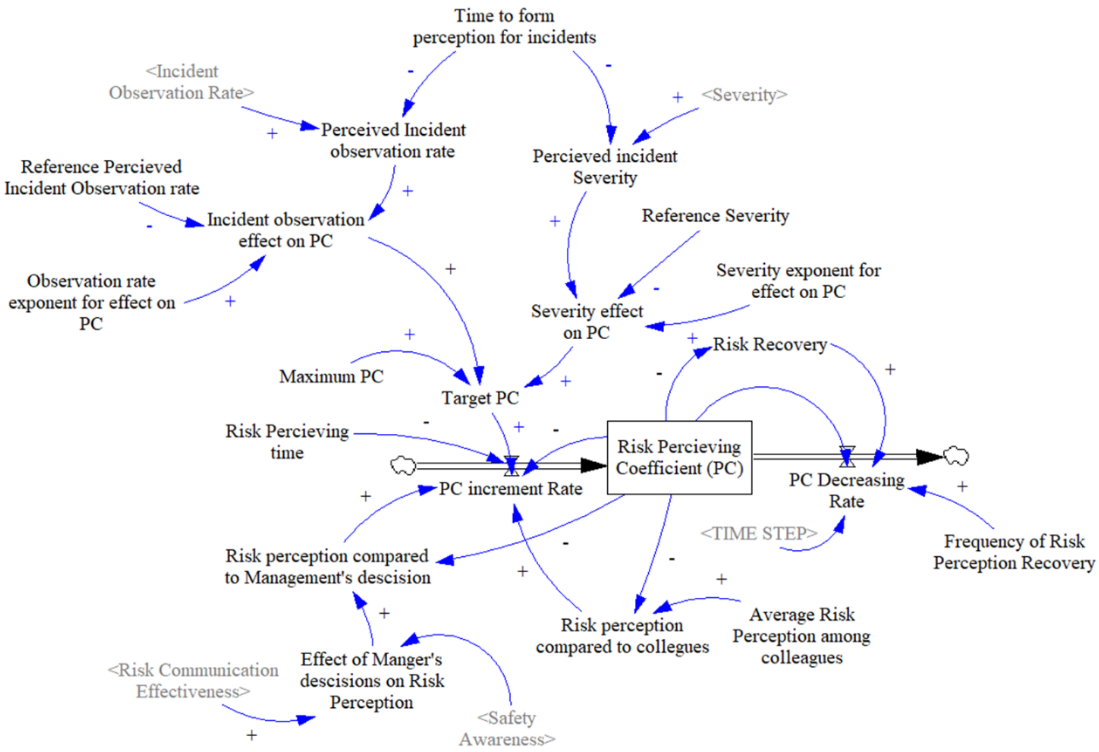


Figure 6-6 SD conceptualization of Risk-Perception

Figure 6-7 shows the simulated pattern for the change in risk-perception with the variation in incident observation rate and severity. In this simulation, the incident observation rate increases at around 490 days (due to an external policy), and an increase in PC with a delay can be seen in Figure 6-7. Before the simulated policy input, the risk-perception gradually starts decreasing as the severity of the incidents and the observation rate all decrease as a result of increased management's commitment to safety and their effort to take necessary corrective actions for improving safety. At the beginning of the simulation, when the severity and incident observation both are high, the risk perception of the employee quickly reaches a maximum value of 1 and stays there for the time the severity and the incident observation rate are not controlled by the efforts of the management's actions. The results of the simulation in Figure 6-7 are consistent with the previous SD models (Shin *et al.*, 2014).

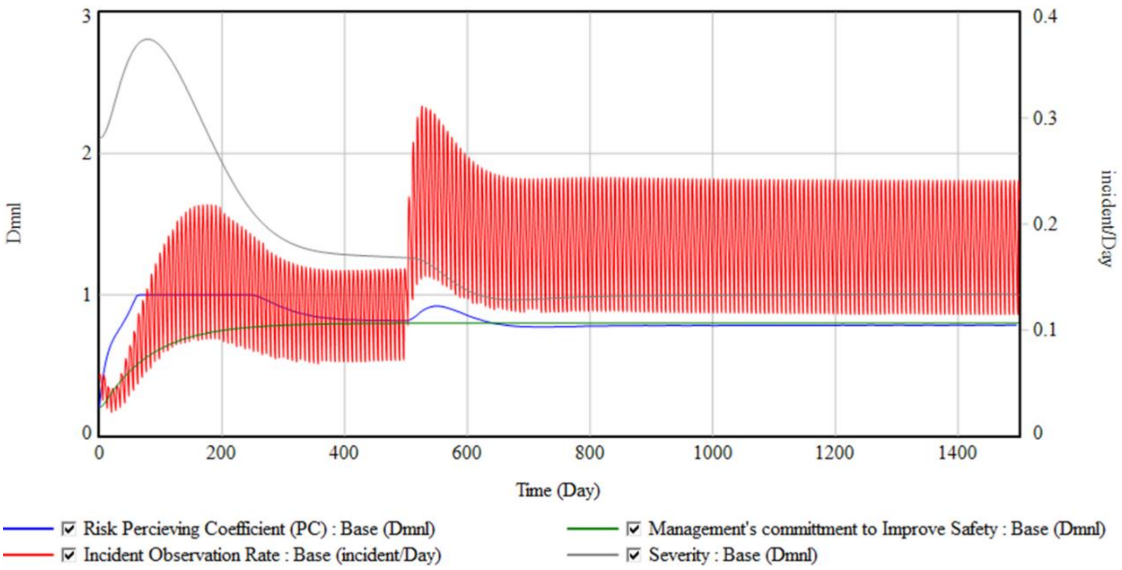


Figure 6-7 Pattern of changing risk perception

6.5.2 Habit of reporting

Eagly and Chaiken (1993) describe that attitude towards a behavior is affected by five factors, i.e., habit, attitude for target, reward and punishment, approval from significant others, and self-identified outcomes. All of the above factors have indeed been verified in certain contexts. Shin et al. (2014), through their SD model, observed that habits are powerful and slow to change. In that, early development of a habit favoring a certain behavior tends to affect the long-term trend of safety behavior. Such difficulty in changing the habit highlighted by Shin et al. (2014) is in coherence with the ideas proposed in a recent elaborate discussion on the power of habits in the organization (Duhigg, 2012). Kingston *et al.*(2004) have discussed the effect of habits in the context of incident reporting and concluded that habitual reporting is dependent on the type of incident and location etc. The presence of detailed rules, procedures, directives, etc., also helped nurses form the habit of reporting the incidents (Kingston *et al.*, 2004). If the concept of habit-loop, as proposed by Duhigg (2012), are to believed habits are formed and executed by certain specific triggers, and are reinforced through a rewarding system. Thus, the reporting habits of employees will vary significantly under different organizational contexts and other factors.

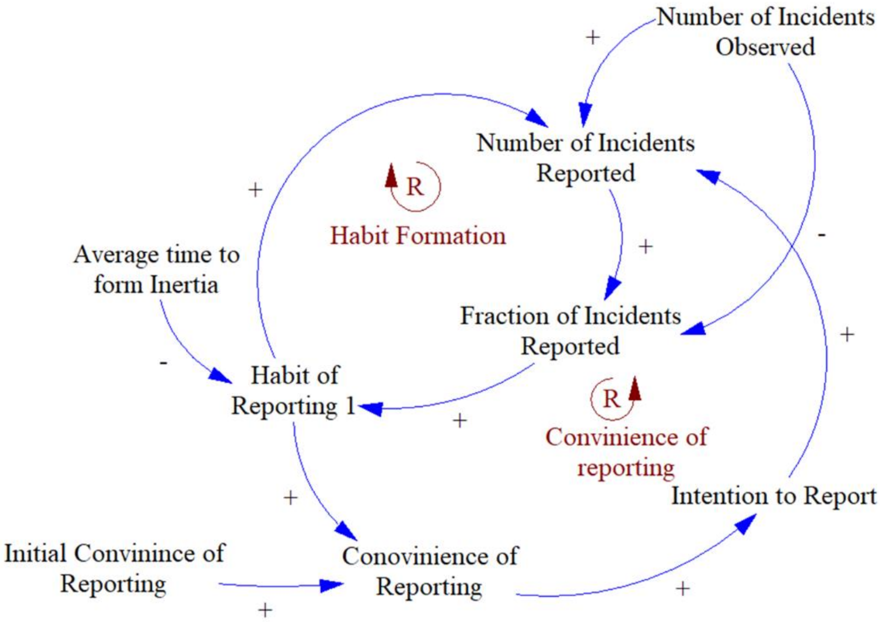


Figure 6-8 Effect of habits in guiding reporting behavior

Figure 6-8 showcases the causal loop diagram as implemented in our model for considering the effect of habits in guiding the reporting behavior, which is based on the previous similar model (Shin *et al.*, 2014). There are two reinforcing loops affecting the behavior here. The reporting rate, as defined by the fraction of incidents reported as opposed to incidents observed, is dependent on the habit of reporting. The habit of reporting develops over a time (defined by Average time to form Inertia), based on the historical values of Fraction of Incidents Reported. The relatively long time to form inertia makes it difficult to change the habits quickly. If the worker is suddenly asked to report a larger fraction of the incident, he will face difficulty in changing his habits; for example, he/she may forget the rules, etc. The second reinforcing loop is about the convenience of reporting. If the habit of reporting has been low historically low, it will be very inconvenient for the workers to change. That inconvenience than could affect their intention to report negatively.

Figure 6-9 demonstrates the effect of the two reinforcing loops. In the simulation, the average time to form habits is taken as 120 days. The graph on the left half of Figure 6-9 shows the two simulation results, one when the effect of habit on reporting is considered, and in another, the effect of reporting is not considered. It is evident that the two loops are working in a negative-spiral, and the fraction of reports declines gradually. In the graphs on the right-half demonstrates the effect of the early formation of habits. In Scenario A, for the first half of the simulation, 20% of incentives to reporting are provided, and these incentives are then increased to 40% in the second half. For scenario B, higher incentives are provided earlier. At the end of the simulation time, the average reporting fraction for scenario B is considerably higher than scenario A. This result shows that early formation of good habits pays in the long-term as changing of habits usually takes a long time, a result that is consistent with the previous studies on SD (Shin *et al.*, 2014).

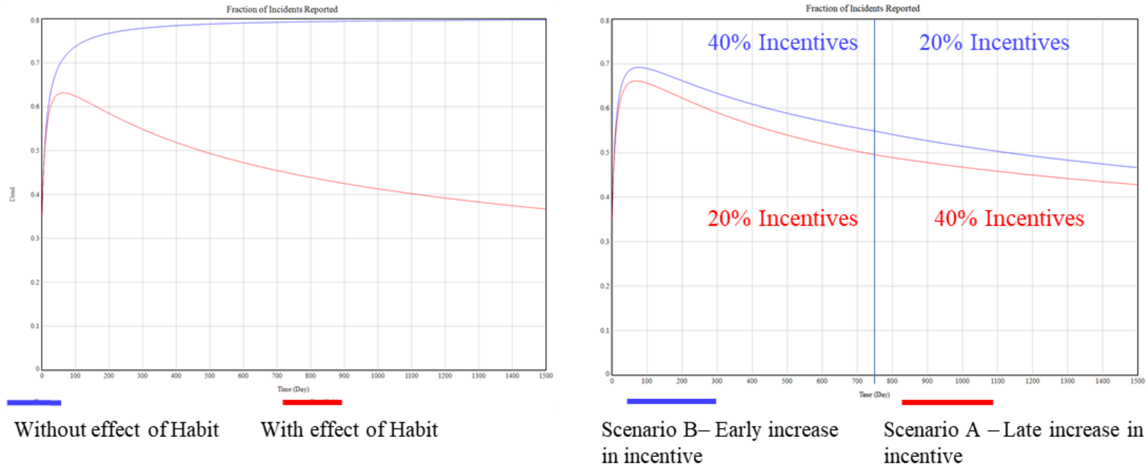


Figure 6-9 Simulation for effect of Habit on reporting behavior

6.5.3 The utility of Reporting – Time pressure and fatigue effect

Shin et al. (2014) have provided evidence to support the claim that attitude towards a behavior (Reporting attitude in this case) has been closely linked to the expected utility of the behavior, such as the combination of costs and benefits associated with the behavior. Shin et al. (2014) have considered this utility through the benefits for safe behavior such as monetary rewards and costs associated with the inconvenience of safe behavior. However, in a social setting of an organization, the rewards could also be associated with social prestige in the organization (Williamsen, 2013), whereas the costs could also be associated with fear of vilification (corresponding to factor on approval from significant others by (Eagly and Chaiken, 1993)) in the absence of a confidential reporting system (Kingston *et al.*, 2004). A quote from nursing staff in a study by Prang and Jelsness-Jørgensen(2014) as saying, "*I mean, we are not only colleagues, but we are also friends. That makes it difficult",* further supports the importance of subjective norms (Zhang and Fang, 2013) in reporting behavior.

In the SD model, the utility of reporting is calculated as the average of Risk perception coefficient, Acceptability of the reporting among peers, Convenience for reporting, and the incentives for reporting. Each of the above-mentioned parameters varies between 0 and 1, and thus utility also varies between 0 and 1, thus representing the fraction of incidents intended to be reported once they are observed.

The calculation for the Risk Perception coefficient has already been discussed in section 6.5.1. The modeling of the incentives for reporting is discussed as follows. The level of incentives is assumed as a fraction of base salary and is assumed to vary between +-0.5. Further, it is assumed that when no incentives are given, i.e., the worker is always receiving the base salary, then the corresponding reporting fraction is at a 66% level.

However, the issue of incentives needs further deliberation and detailed understanding. Having a reward or a punishment for an individual's behavior is not enough. In an organization, the positive incentive for promoting reporting behavior should be determined such that they should not create any conflicting views for other aspects that an employee considers important. For example, even when there is an incentive for reporting, if the employee expects a reduction in another aspect as a result of reporting, loss of reputation of the firm, or among colleagues, etc., the reporting behavior may still not change. However, such detailed modeling of the incentive structure should be done on a case by case basis, and a generalization at this stage is not possible. In SD, incentives are often modeled as reinforcers to the behavior. Indeed, incentives, once received by the employee, will motivate him/her to repeat the same behavior later. However, here for simplicity purposes, the perceived incentive level is modeled as a product of the theoretical incentive level and the management's commitment to safety. Through such a treatment, the assumption of the model is that all incentives, as promised, are immediately given to the employee in proportion to the commitment of management. In situations where often there is a delay from management in rewarding the promised incentives, the reporting behavior may dwindle as the employees lose trust in management's sincerity in preventing accidents (Williamsen, 2013).

Acceptability for reporting among peers is assumed to be constant for Type A relationship. The influence of the peers can be modeled in more detail as part of Type B relationships.

The framework for modeling the effect of reporting convenience is described here. As described in Figure 6-10, reporting convenience is surely related to the habit of reporting. However, there are other factors that affect reporting convenience. A commonly reported factor affecting reporting behavior is linked with the organizational work pressure and lack of time for reporting. Often in organizations, there is no separate time given to report, making it difficult for employees to report during their busy schedules. Further, the follow-up on reports could also be seen as a burden or hindrance to their regular work (Williamsen, 2013). Comments from interviewee for a construction site (Park, 2018) confirms the same-

"*Under-reporting happens to avoid the burden of punishment and the preparation of various materials that is necessary after reporting.*"

In the SD model, the work pressure is linked with the Energy level of the employee. The energy level of the employees then affects the overall reporting behavior as per the two-balancing loops shown in Figure 6-10. The energy level of an employee determines the convenience of reporting and, thus, the reporting rate. Also, the energy level of an employee affects the worker's attention, which can affect the incident observation rate of the employee. The energy level of an employee is directly linked with its workload, which in part is also dependent on his/her participation in the investigation of the reported incidents. The two balancing feedback loops are named *"Reporting as Extra-Work Effect,"* as well as *Fatigue Effect.* In general, if the employees are overworked, the fatigue effect can hamper efficient reporting.

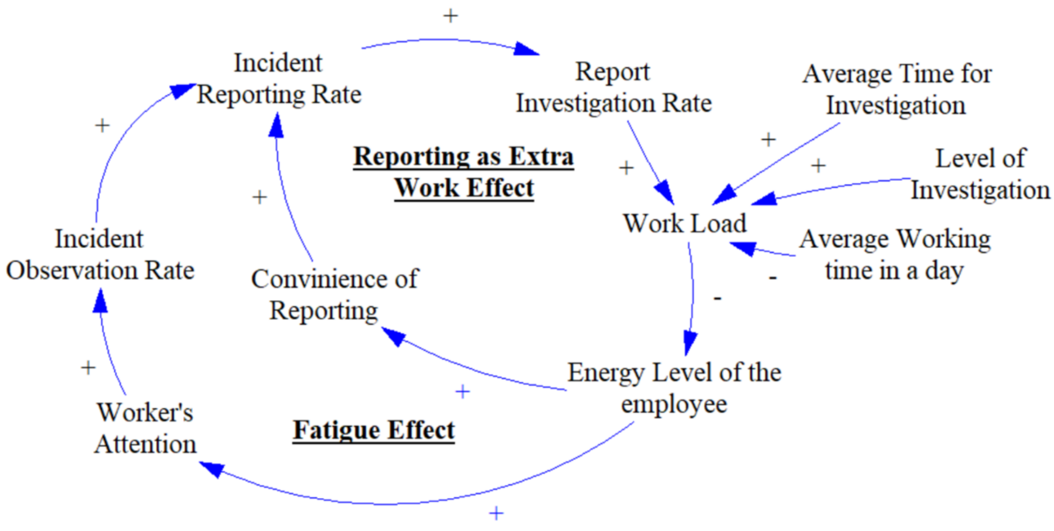


Figure 6-10 Convenience to reporting and fatigue effect

An SD model for the dynamic behavior, including the workload and the energy level of the employee, was modeled by (Homer 1985) using four major elements. These elements are the accomplishment rate on an employee, expected accomplish rate for an employee (goal set by the organization), hours worked per week and the energy level of an employee. The energy level of an employee depletes from the work pressure as well as from the frustrations arising when the accomplishment rate of an employee is not at par with the expected accomplishment rate. While the worker's energy is replenished in a relaxing time. Similarly, the energy level of the employee influences his/her work accomplishment rate. Such a nested structure leads to cycles of fatigue (low energy) and increasing working hours. The 5 causal loops are shown in Figure 6-11.

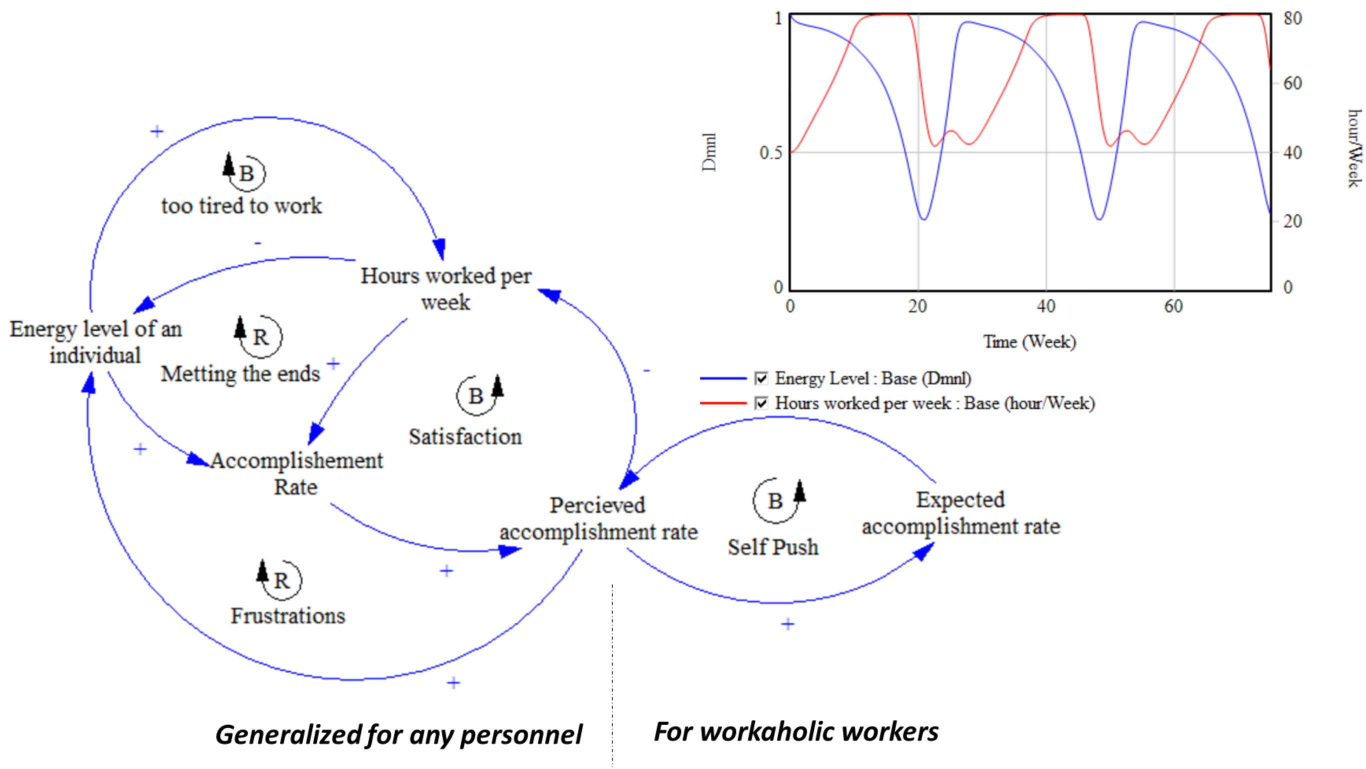


Figure 6-11 Dynamics of worker's fatigue

Simulated based on Homer (1985)

Meeting the ends is reinforcing loops, where more working hours lead to decrease energy levels for an employee, thus reducing their accomplishment rates. To compensate for this reduced accomplishment rate, the employee then tends to work more, thereby being present in a negative spiral. Often when the energy is too low, the employee tends to break from the cycle as they are too tired to work and thus choose not to work more, as represented by the too tired to work loop. Also, the more an employee work, the more likely he/she is going to achieve his/her goals, thus reducing the need for further long-working hours (represented with satisfaction loop). Another important feedback is related to a low perceived accomplishment rate that leads to a decrease in the energy as often the low accomplishment creates frustrations. Homer (1985) had developed the dynamic model for workaholic individuals, who often adjust their goals to a higher level once they feel that they have managed reasonably well to accomplish their current goals. In his analysis, Homer (1985) showed this particular tendency to be a stronger reason for working long-hours (close to 80 hours a week as opposed to normal 40 hours a week) and then feeling burned out. The dynamic behavior, thus obtained, is also shown in Figure 6-11.

For the purpose of the current study, a few assumptions are taken while adapting the original burnout cycle presented by (Homer 1985). In the original model, the self-push behavior was assumed for workaholic persons, who raise their own expectations as they achieve things. In the context of organizational modeling, we expect a similar phenomenon to happen because many times, the organizational incentives reward the high accomplishment rates. Hence, a similar feedback structure, as shown in Figure 6-11, is adopted while modifying the parameters related to the rate of change of expected accomplishment rate (slow by a factor of 15 or 30 from the base case of (Homer, 1985)). The second assumption in the present study is that the work arising from reporting (in the form of employee participating in investigation process etc.) is not considered as part of the regular work by the organization, hence the perceived accomplish rate could be related to working hours on production-related activities while the level of energy etc. will be governed by the total work done by the employees (production-related work and the work arising from reporting).

The effect of the burnout cycle on the reporting convenience and the worker's attention is then simulated. The preliminary assumption is the reporting convenience retains the numerical value of the worker's energy level after a first-order information delay of time period 10 days. While the effect of the worker's energy level (E) on the incident observation rate is determined, as shown in Figure 6-12. It is assumed that even when worker's energy level is very low, his/her attention to incident observation does not go down significantly as they are much likely to focus on safety risks compared to other risks even when they are burned-out. The effects of worker's burn-out on reporting thus obtained is shown in Figure 6-13.

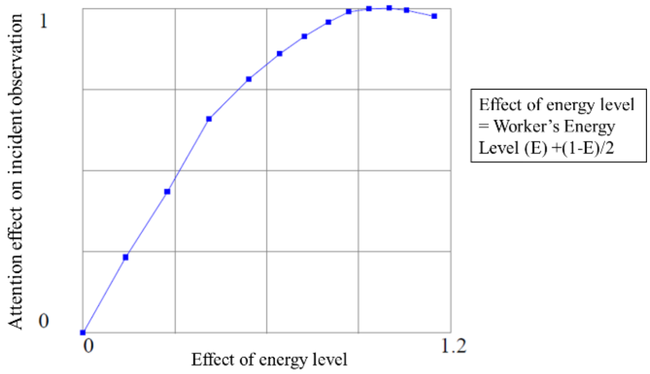
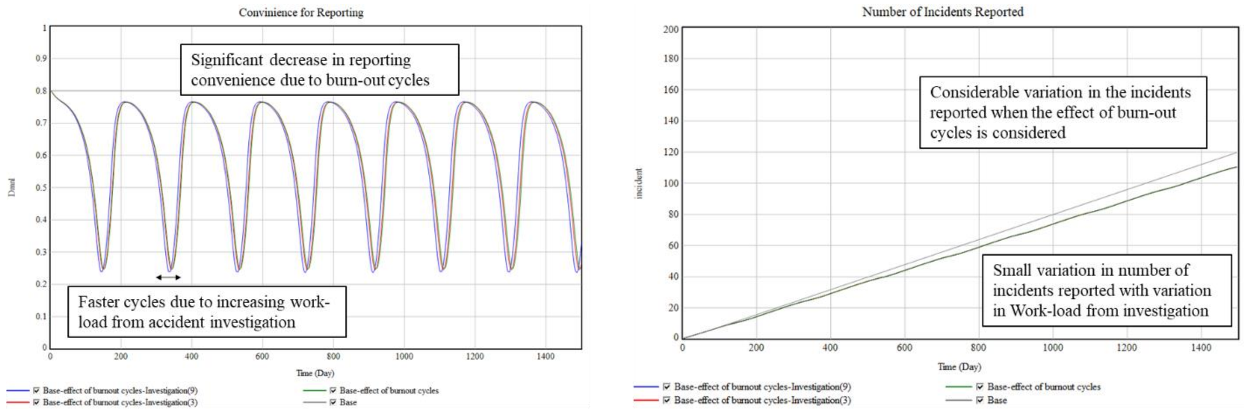


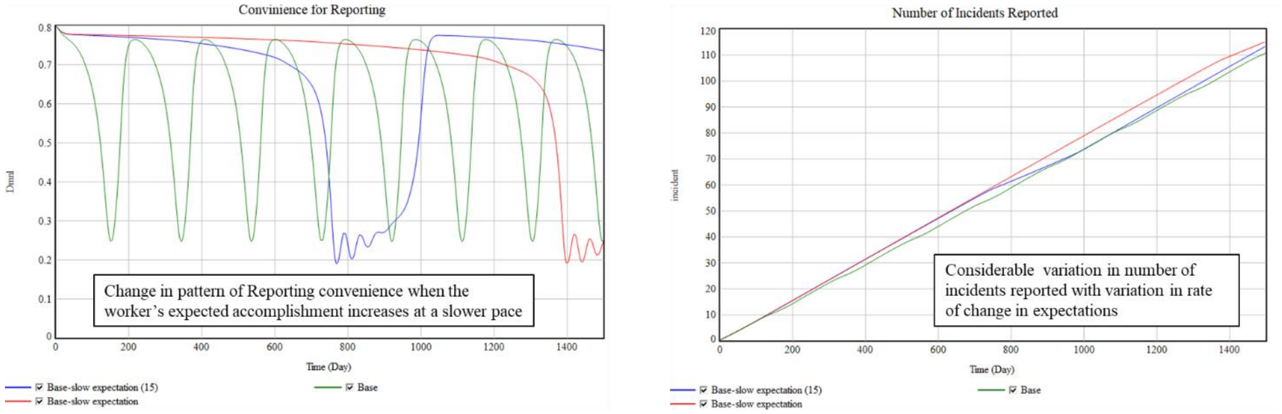
Figure 6-12 Effect of Worker's energy level on attention to accidents

As shown in Figure 6-13 (a), the effect of the workload coming from incident reporting is not significant, although the higher level of investigation (as represented by longer duration of investigation per day) may cause a shift in the frequency of the burnout cycle. When, compared to the scenario, when the effect of work-burnout is not considered at all, the effect is considered significant, several incidents reported by an employee decrease by about 5% at the end of the simulation period, i.e., 1500 days.

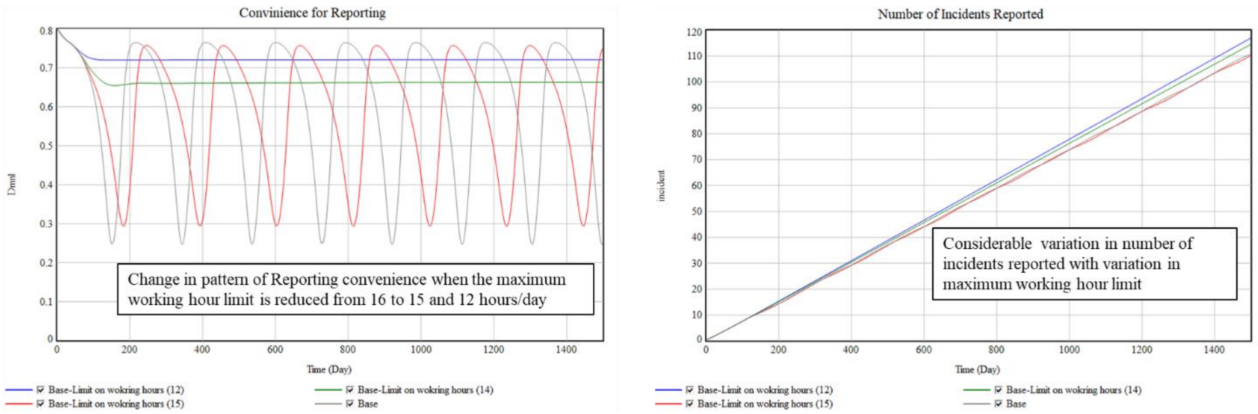
Figure 6-13 (b) demonstrates the effect of the rate of change of accomplishment increment rate. Compared to the base-scenario, the base-slow expectation (15) and the base-slow expectation reduce the expectation increment rates by a factor of 15 and 30, respectively. The corresponding change inconvenience or reporting is evident in Figure 6-13. The convenience of reporting remains stable until it suddenly crashes when the worker's reach at a work level corresponding to the allowable limit on working hours. At this stage, the feedback loops "too-tried to work," "satisfaction," and "meeting the ends" do not work, as the number of working hours cannot be increased further. However, the increasing work expectations lead to a poor perceived accomplishment rate and thus leading to frustrations reducing the energy level significantly (signifying the drop in the convenience level). However, in the long-term, such a slower rate of increasing expectations is shown to be useful for the number of reported incidents, thus signifying that removal of employee burnout cycles has a positive effect on the number of incidents reported. Similar, conclusions can also be drawn from Figure 6-13 (c), where the reduction in maximum working hour limit, removes the employee burnout cycles and contribute more incidents being reported in the long term.



(a) Effect of level of investigation on reporting



(b) Effect of rate of change in expected accomplishment rate



(c) Effect of working hour limit on reporting

Figure 6-13 Effect of worker's burn-out on reporting behavior

6.5.4 Intention to report

The intention is a decision to execute a certain behavior. However, despite the right intention, there may be a failure from an individual in executing safe behavior. Triandis (1977) have described the potential causes as *motivation* and *facilitating conditions*. Motivation describes the interest of a person in an activity and is closely related to *positive consequences*. In that, appropriate feedback from top-management on the reported incident is one of the prominently cited positive consequences (Kingston *et al.*, 2004; Williamsen, 2013; Prang and Jelsness-Jørgensen, 2014) affecting reporting behavior. Academic literature has also identified a number of facilitating conditions for reporting, such as easy to use, accessible, universal reporting forms, not requiring additional efforts to report (Kingston *et al.*, 2004; Leveson, 2011; Williamsen, 2013).

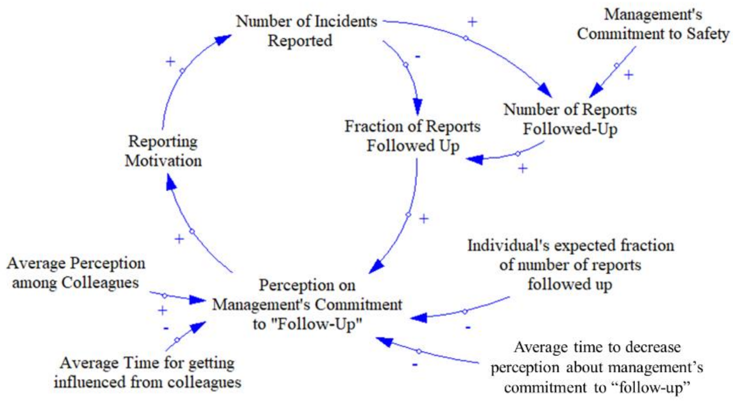


Figure 6-14 Effect of feedback from the management

The SD formulation for the effect of management's feedback is formulated, as shown in Figure 6-14. In the SD model, the reporting motivation by an employee is dependent upon his/her perception of the management's commitment to "follow-up" on an accident. A worker's perception increases when the real fraction of reports followed up by the management is greater than a worker's expected fraction of several reports followed up. The decrease in the perception of management's commitment is proportional to the difference between the two fractions and inversely proportionate with the average time for perception decrease. Similarly, the perception of management's commitment increases when the average perception among all colleagues is higher than the individual's own perception. In the modeling framework presented here, the real fraction of the report followed up is actually determined by the management's commitment to increase safety. In a simplified assumption, management's commitment directly influences the fraction of reports to be followed up (by assigning appropriate resources for the same).

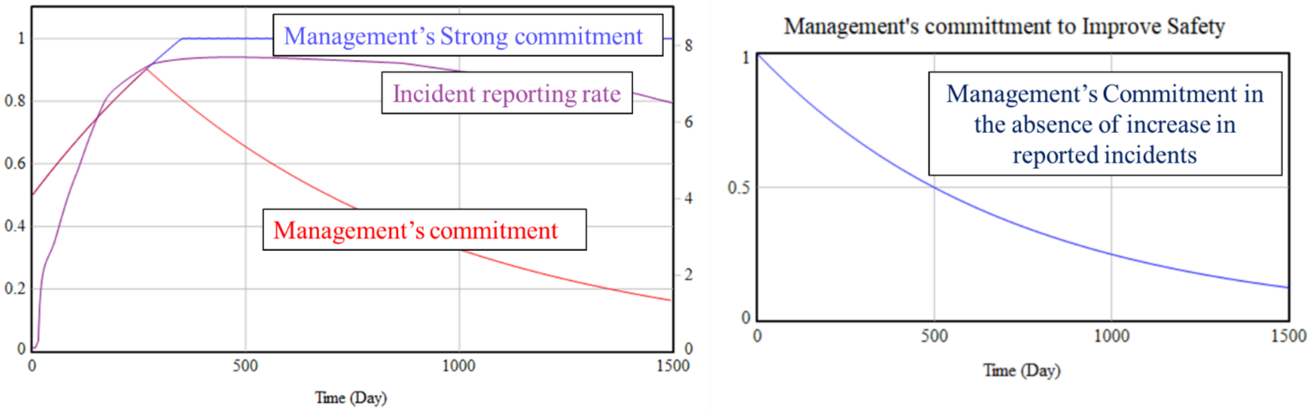


Figure 6-15 Variation in Management's commitment to Safety

In the modeling framework adopted in this study, management's commitment to safety is considered to be between 0 and 1. The decision on a number of reports to be followed-up is then directly proportional to the numerical value of the management's commitment to safety. Further, there can be multiple ways in which the management's commitment to safety can be formed; one of them is the trend in a number of reports. In many organizations, the trend of the number of reports is an important consideration for improving management's commitment. If the number of reports appears to be increasing, then management would become vary in the situation, and its commitment to safety is expected to increase. Whereas, the decrease in reporting trend can be seen as a testimony that the measures implemented by the management are working. In such organizations, the management's commitment to safety can also decrease if, for a long time, no increase in the number of reported incidents is observed. In other organizations, the management's commitment to safety may always remain high irrespective of the trend in a number of reports observed. The two types of organizations are graphically represented in Figure 6-15. More details on management's commitment to safety are discussed in the next subsection.

Figure 6-16 shows the results of the numerical simulation from considering the effect of management's follow-up on the incidents. The fraction of incidents reported, decrease significantly when considering the effect of management's follow-up. The results are shown in Figure 6-16, also show the effect of reduction in average time for an individual to perceive the real follow-up fraction. When the average time to perceive the follow-up fraction is reduced from 15 days to 10 days, the individual's perception about the management's follow-up tends to decrease faster (as the worker's become less optimistic about the management's commitment in following-up the specific incident) and thus their commitment to report also decreases. Similarly, in a case where management shows a strong commitment and focuses on following up on almost all possible incidents, the worker's perception about the management's commitment also increases, thus leading to an increase in their reporting motivation (as shown in the blue line in Figure 6-16).

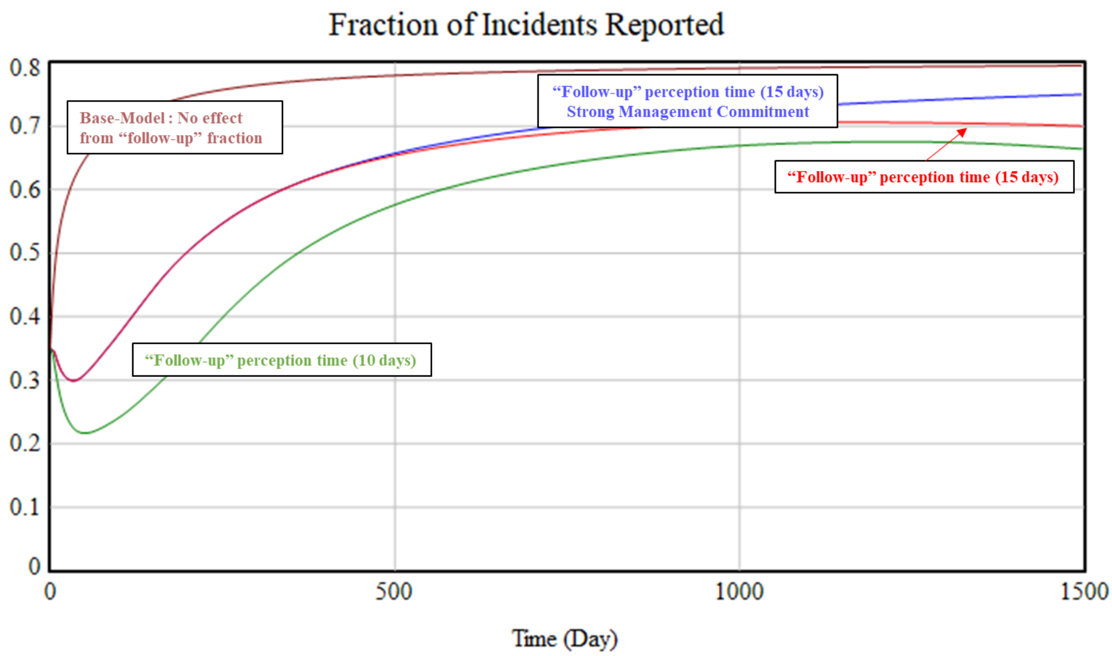


Figure 6-16 Effect of follow-up from management

Intention to report also depends on the ease of the reporting channel as perceived by an individual worker. In the current model, the ease of using the reporting channel can either be assumed as an external constant or can also be dependent on the management's commitment to improving safety.

6.5.5 Management's Commitment to Safety

An overview of the factors affecting management's commitment to safety was shown in Figure 6-3. The detailed relationship is shown in inf Figure 6-17. The factors affecting management's commitment to safety are the relative organizational knowledge, the effect of incidents (number and their intensity), and the effect of production pressure. All relationships are conceptualized to follow the power-exponent law, which is consistent with previous such studies (Sterman, 2000; Cooke, 2003a, 2003b; Cooke and Rohleder, 2006).

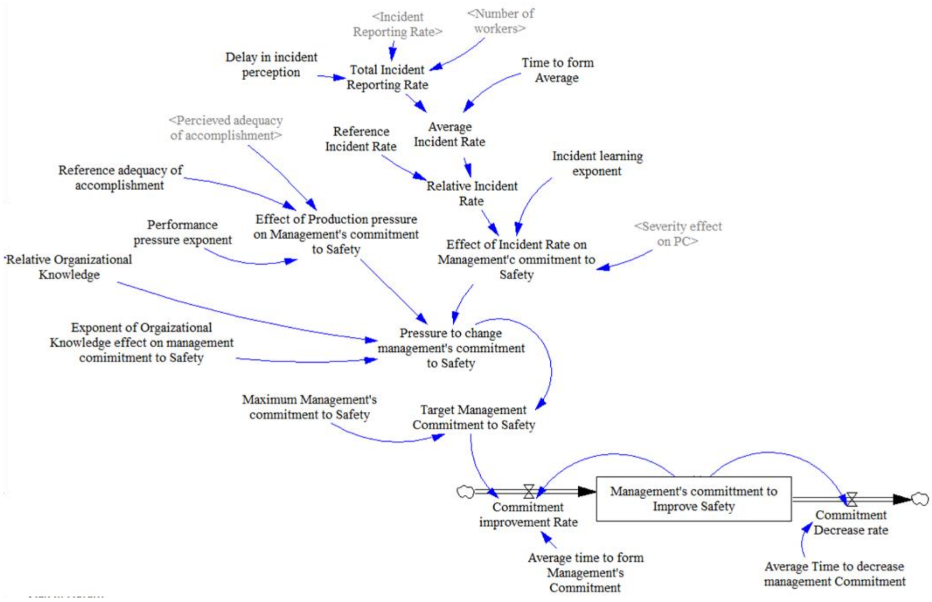


Figure 6-17 Management's Commitment to Safety

6.5.6 Management's action

The last important component of the Type A relationship is management's actions upon knowing the reports of the incidents. Managers in any organization may take many different actions to improve safety in their respective organizations. In the SD modeling framework adopted in this study, the Management's action is assumed to be limited to 4 activities, i.e., increasing safety training, making efforts for hazard mitigation, improving the risk communication within the organization, and increase the effectiveness of the reporting channel. Each of the above-mentioned actions is also modeled as taking numerical values between 0 and 1. Where the gap between the Management's commitment to improving safety and the current level of the action, feedbacks to the level for a given action in an average time to improve the specific action. At the same time, often the quality of the above-mentioned management actions decays with time (Average time for decay), for example, the level of safety training for an employee would decrease with time, if the training is not refreshed periodically. The simplified SD model for hazard mitigation efforts is shown in Figure 6-18, and the same structure can be generalized for other actions mentioned above. If necessary, the effect of the budget constraints can also be modeled in determining the maximum improvement rate for a given action.

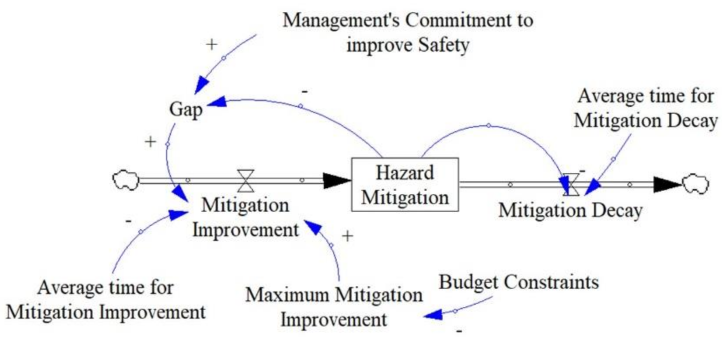


Figure 6-18 Actions taken by the management (example of hazard mitigation efforts)

6.5.7 Effect of management's actions

The impact of management's actions (as described in section 6.5.5) is conceptualized in the form of improved safety awareness of the employee and the overall hazard level of the workplace or the process for which the current model is being developed. Safety awareness and Safety knowledge are often differentiated in research, and often parameters affecting them are different; however, they tend to work in similar ways, and hence, for simplicity, only one notion is adopted.

Safety awareness is known to be dependent only on the management's commitment to safety and the management's actions targeted at improving safety awareness. While safety awareness can also degrade over time with the average time for awareness depreciation.

The various management actions also contribute to the hazard exposure of the process or the workplace. The hazard self-accumulates, as characterized by an average time for accumulation, as well as the new hazard, keep on coming to an organization. On the other hand, hazard exposure can be mitigated through corrective actions whose quality depends on the efforts on safety training, risk communication effectiveness, efforts for hazard mitigation, and relative organizational knowledge. The SD modeling framework for hazard exposure and organizational knowledge is shown in Figure 6-19. The quality of corrective actions also determines the severity of the hazard, and the severity is inversely proportional to the quality of corrective actions.

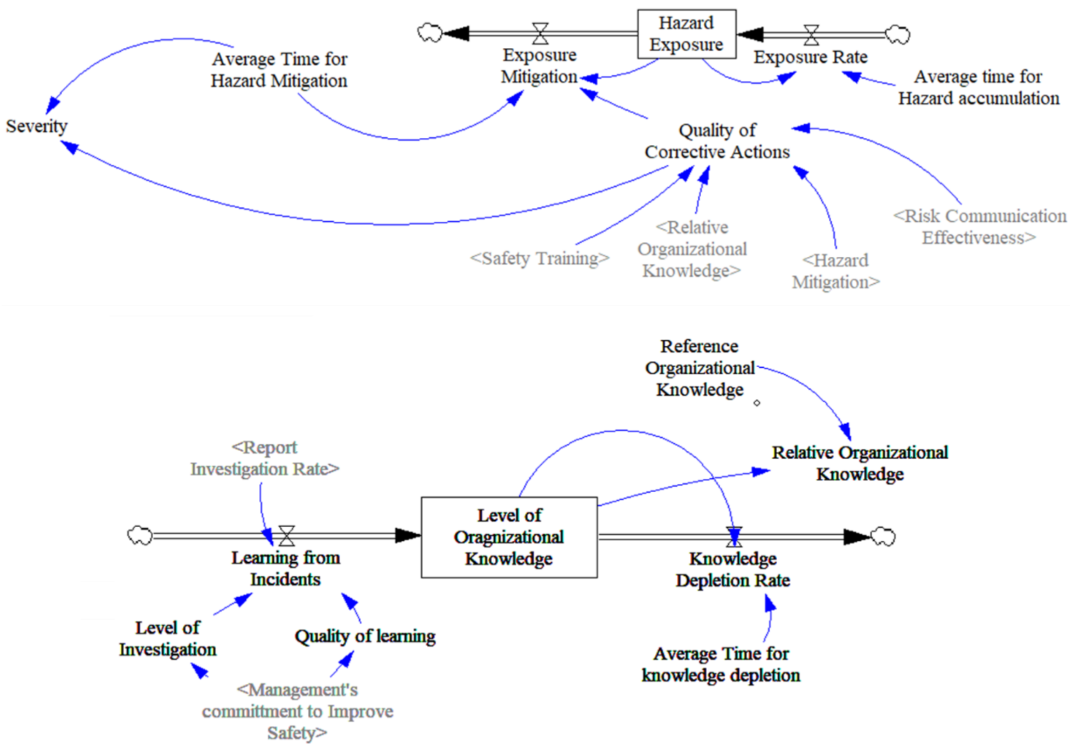


Figure 6-19 SD model for hazard exposure and Level of organizational knowledge

6.5.8 Summary of Type A relationships and Comparison with existing SD models

Figure 6-20 summarized the important Type A relationships introduced in the study so far. The integrated model summarizing the important variables related to organizational learning, worker's energy level, and effect of management's commitment to safety on safety improvements as well as the improvement in worker's risk perception is shown first in Figure 6-20. Then, figure 6-20 provides the detail for *Incident Learning* and *Meeting the safety goal* loops, as introduced in Figure 6-3, which is also the most important contribution of the current study when compared to the previous such models on safety culture in organizations. The current study puts a greater emphasis on modeling the effect of management's commitment to safety and its effect on worker's safety perception. Earlier studies had assumed a delay in improving the worker's perception of safety and in management's commitment to safety but had not provided further details for the same (Cooke, 2003a, 2003b; Cooke and Rohleder, 2006). Jiang, Fang, and Zhang (2015) had attempted to develop the link between the two up to a great extent; however, their study was generalized for the safe behavior and not specific to the reporting behavior, which also is dependent upon many factors such as the incentive of reporting, etc. Shin *et al.* (2014) model further considers the factors that are known to have an impact on worker's reporting behavior such as the reporting habit or the incentives for reporting etc. The model developed in this study makes an attempt to improve upon the limitations of all of the models stated above and has developed a model specific to the reporting culture of an organization. The key relationships that were missing/or not modeled effectively in previous SD models, but are included in the current model include the effect of Management's feedback on reporting intention of the worker, the ease of using the reporting channel, the detailed dynamics of the effect of fatigue, the impact of accident investigation on reporting convenience, and are habit of reporting (Shown in Figure 6-20).

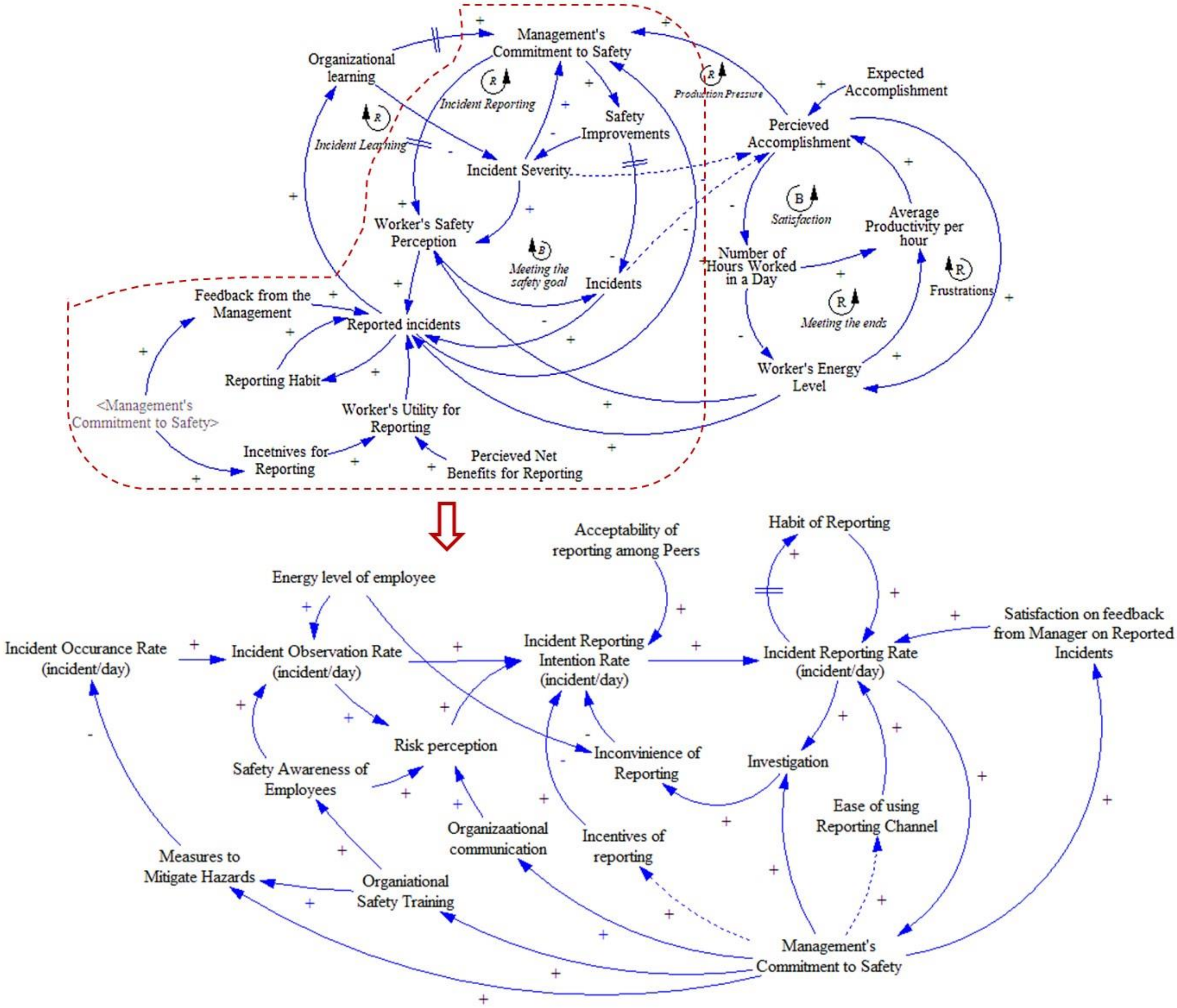


Figure 6-20 Summary of Type A relationships

6.6. Type B relationships

Type B relationships examine an individual's own characteristics such as its goals, behavior, capabilities, etc. and the influence of other individuals at a given hierarchical level of organization. Modeled dynamics at this stage are in alignment with the agent-based modeling approach, as described (Stroeve, Sharpanskykh, and Kirwan, 2011). However, as the current study does not adopt an agent modeling approach, an aggregated perspective on such *Micro*-interactions is taken.

While we could not find any study stating the effect of influence from co-workers on the reporting behavior, numerous studies have documented the effect of the workmates on an individual's safe behavior. A detailed review of such studies can be found at (Mohammadi, Tavakolan, and Khosravi, 2018). Guo, Yiu, and González (2015) have documented the effect on peer-pressure on affecting an individual's safety behavior. Positive peer-pressure enhances safety attitudes and thus enhances safety behaviors, and the negative peer-pressure affects a worker's in a way that they tend to risk their personal safety over the social conflict. The exact mechanism of how the peer-pressure develops is not discussed in the literature; however, a general consensus is that it is dependent on the level of communication within an organization (Shin *et al.*, 2014). Consequently, how exactly the peer-pressure affects an individual's behavior is also not known. Considering the paucity of the related literature, the current study also considers an aggregated perspective on Type B relations, where the level of communication between the colleagues is thought of as an important proxy affecting the peer-pressure and subsequent safe behavior of the employees.

6.7. Model Validation strategy

System Dynamics models can be validated using numerous qualitative and quantitative validation methods (Sterman, 2000). The primary objective of the qualitative validation is to validate the structure of the model, including the dimensional consistency of the model, the causal-feedback relationship, and confirmation of the mental model validation. Similarly, the purpose of the quantitative validation is to confirm the adequacy of the model-simulation with the real data as much as possible. Other quantitative validation schemes involve validation of model performance under extreme values of the variable and confirm if the model can simulate these extreme values with reasonable accuracy. Since one of the objectives of this part of the study is to develop a generalized model on near-miss reporting behavior, the model should be able to suitably applicable to a variety of sectors. In the present study, an attempt is made to test the SD model developed so far, using various tests for the organizations in two-different sectors, i.e., for Construction Industry as well as for HSR. As per the classification proposed by (Pariès *et al.*, 2019), the construction industry also relies on a high-degree of predetermination to improve safety. Even in such a system, the information on near-miss reporting is very important as it allows the organization to learn and improve safety. In such a context, the construction industry is similar to that of HSR. Further, the use of the construction industry is also necessary from another important aspect, i.e., the availability of Data. In general, the current thesis faced challenges in accessing HSR specific information. Hence in order to develop a simulation-based SD model, the available information from a construction industry was deemed necessary. The next section describes the validation attempt of the SD model developed so far in the context of the HSR organizations.

6.8. Model causal structure validation for Japanese HSR

6.8.1 Structural validation methods

Any model is as good as it is trusted by its users. The same holds true for the System Dynamics model. The primary objective of developing the model is to be able to generate policy recommendations that can be trusted and implemented by the relevant organizations. In the ideal form, the model development stage itself should be collaborative, where the structure of the causal links should be extracted using the rich information, experiences that the people engaged in the system possess (Sterman, 2000). However, for the current study, such a collaborative effort was not feasible due to numerous reasons. These include the study being an independent academic endeavor as well as the language barrier in the Japanese HSR industry. To compensate, a cross-industry literature review was first carried out (as described in the previous sections) to identify the key factors influencing the reporting behavior. Semi-structured interviews with HSR experts were then thought as a meaningful way to validate the structure of the model. The next sub-section thus summarizes the efforts put into validating the structure of the SD model prepared so far.

6.8.2 *Interview scheme*

All the HSR TOCs in Japan have emphasized the near-miss reporting, especially after the safety management system was mandated by the MLIT in 2006. All HSR TOCs have reported establishing such near-miss report collection systems in their respective organizations; hence, potentially all the HSR TOCs were eligible for the interview. However, accessibility to private companies proved to be an important bottleneck for selecting the organizations for interviews. Identification of suitable personnel for an interview in the private HSR TOCs was thus mainly dependent on personal relationships. Further, in our previous experience, we noticed a tendency of the HSR operators to discuss only those relationships that are publicly available. In the previous experience, HSR TOCs also expressed their inability to have in-depth discussions on the organizational management related topics. While the author realizes the issue of selection bias impacting the potential conclusion of the study, we also expect the similarity in the incident learning systems of various HSR TOCs in Japan, mainly because of their common origin before privatization. Further, as highlighted above that the practice of formally collecting the "near-miss" mainly started after the mandate by the MLIT; it is likely that their respective systems have similarities with that of the officially prescribed systems. Hence, the generality of the causal structure can be generally assured for the HSR TOCs in Japan.

To compensate for the apparent hesitation of the manager's in HSR TOCs to have an in-depth discussion on sensitive topics, experienced HSR professionals, who have already retired from their respective organizations, were identified, as they were more willing to support the study. Two HSR professionals, who retired from JR Central after serving for their entire service life in the same organization, were identified. Both had extensive experience working at various mid and senior management positions in the JR Central. In addition, expert interviews were conducted with 3 experts from JR Kyushu, including one former president and chairman of JR Kyushu, and two current officials responsible for managing the "near-miss" reporting program at JR Kyushu. The interviews were semi-structured, were recorded, and were conducted in the Japanese language.

Interviews with JR Central were conducted using the dis-confirmatory strategy for SD models discussed in (Andersen *et al.*, 2012). Interviewees have first introduced the basic SD notations of the positive and negative causal links, reinforcing and balancing feedback structures, delays, etc. Once the interviewees expressed understanding of the basic loop-structure, they were shown various feedback-structures one-by-one and were provided with brief statements describing the dynamic behavior for that particular loop, as well as for each specific causal relationship. Questions were then related to how strongly they agreed to the with the brief statements. Interviewees were then asked to describe other factors that could affect the behavior in the given specific loop. The question sheet was sent to the interviewees in advance for their understanding and to account for the perceived language barrier. The interview was conducted in an interactive manner, and questions and clarifications from both sides were sought and resolved during the interview. Because of such interactions, interviewees provided rich examples from their experiences to support to negate the statements presented to them. In recollecting such experiences, valuable information regarding how the management principles of the Japanese HSR TOCs changed before and after the privatization, was also revealed. Most of the causal factors described above were validated during the interview at the JR Central. Interviewee's had highlighted a few causal factors which they could not understand, and the naming convention used for the parameters were revised accordingly. This interview was useful in highlighting some of the important trade-off behaviors applicable to overall reporting behavior in an organization.

For JR Kyushu, a simplified structure for the Type A relationship was discussed. The simplified presentation was prepared, which showcased the development of the key feedback structures using simple examples for each causal relationship. For this interview, the standard SD notations were not used, but the dynamic nature and the feedback structure was well explained to the interviewees. After showcasing the model, they were asked the generic questions, such as if they agreed to the shown relationship? If they would like to add/remove any specific relationship? What is the most important/least important relationship among the one shown? In addition to the discussions on the dynamic hypothesis, questions were asked about the publicly available near-miss reporting data for JR Kyushu. The trends in the number of reports (available on a yearly level) and associated management's actions were discussed. Interviewees were also asked questions exploring the potential trade-off identified through previous attempts, to which the interviewee's supported or negated the causal factors by providing specific examples from their experiences. Questions were also asked about the activities related to managing a system of "near-miss" reporting, such as collection methods and information coordination methods, etc.

The in-depth qualitative interview methodologies adopted in this study, thus allowed us to gather valuable information on factors affecting reporting behavior in an organizational context. While the interviews at the JR Central were thought of as a more focused interview at the HSR operations (as this is the main business of the company), examples at the JR Kyushu had focused more on conventional train operations. Even after such a difference, the findings of the two interviews were consistent with each other and, thus, provide more confidence in the results despite the possibility of the selection bias. While the dis-confirmatory strategy adopted for JR Central, had forced the causal structure over the interviewees, the objective of the simplified strategy adopted for the JR Kyushu was to be able to develop the similar causal structure based on the input provided from the experts and check the consistency between the two. As discussed in the next section, the findings from both the interviews were consistent and thus provided more confidence in the causal structure of the model.

6.8.3 Factors affecting "Near-miss" reporting in Japanese HSR TOCs

Table 6-1 provides an overview of the factors affecting the "near-miss" reporting within the HSR TOCs. The factors that were identified in the literature and their confirmation by the experts from the two JR Companies are summarized in the table. In addition, a few newly suggested factors that were revealed during the interviews are also listed in Table 6-1. Specific comments and examples, explaining each of these factors are briefly discussed in this section.

6.8.3.1 Factors affecting Risk Perception

In both organizations, the severity of the incident has an impact on the worker's risk perception and, thus, their reporting behavior. Incidents that are known to materialize into bigger accidents are easily identified by the employees and are thus reported more. In this regard, the safety knowledge, imparted through the various training within the organization, plays a very important role. Interviewee's from both the organizations agreed on the fact that employees can observe and report those incidents better that are regularly reminded to them as being safety-crucial through various training (Safety Awareness and Safety Knowledge) within the organization. Hence, an important focus of the HSR TOCs is to broaden the definitions of the "near-miss" to make employees aware of a greater number of factors that could have safety implications.

Table 6-1 Factors affecting the reporting behavior within HSR TOCs

Factors	*Identified in literature and Confirmed*		*Newly Suggested*	
	JR Central	*JR Kyushu*	*JR Central*	*JR Kyushu*
Risk Perception				
-The severity of the incident	✓	✓		
-Safety Knowledge (Training)	✓	✓		
-Safety Awareness	✓	✓		
-Workload/fatigue	✓	✓		
-Work-experience			✓	
-Perception among co-workers	✓	--		
Habit of Reporting	✓	✓		
Utility of Reporting				
-Incentives	✓	✓		
-Acceptance of peer-reporting among Co-workers	✓	✓		
-The inconvenience of Reporting (Workload, investigation load)	✓	✓		
-Employee Interactions combined with incentives			✓	✓
-Organizational Culture/Values			✓	✓

Motivation				
-Feedback from the management	✓	✓		
Facilitating Condition ***(****Easy to use reporting channel)*	✓	✓		
Organizational Knowledge		✓		
Management's Commitment to Safety				
-Trends in the incident reported	✓	✓		
-Organizational Knowledge	✓	✓		
-Pressures (Delay, Profitability)	×*	×*		
-Feedback to Management (from other cases, external sources)				✓

The issue of employee fatigue and its adverse effect on risk perception and even unsafe behavior is considered crucial by the interviewees from both the HSR TOCs. The work-load level for front-line staff is closely monitored within these organizations, and appropriate policies are implemented to keep the stress level at low levels.

In addition, interviewees from JR Central highlighted the importance of the employee's work-experience and interaction between the experienced and inexperienced personnel within the company for the risk perception. A more experienced person has better abilities to sense the potential safety-related implication for a small incident. In an example, the interviewee informed us that while the small delays for trains coming from the depot, often go unnoticed by the traffic controllers, however, by observing the actual time-performance of the train, experienced traffic controllers are able to point out the positions where some near-miss events must have taken place, and they are often found to be right.

On the other hand, the perception among co-workers (for example, experienced and in-experienced personnel working together) have interesting underlying dynamics associated. While in-general, the intra-personnel communication improves the risk-perception of young employees as they learn from the experienced staff (such as through On-the-Job Training), however, experienced personnel can also develop the habit of "cutting corners" for some rules, based on their experiences. In such cases, the in-experienced personnel is not able to point out the mistakes of the senior members and accept it as a "way to work from now on," thus negatively affecting their own safety perception.

6.8.3.2 Habit of Reporting

Both JR Kyushu and JR Central, recognize the importance of habits in ensuring near-miss reporting. Hence, an approach common to both the organization is to institutionalize the near-miss reporting through the day-to-day organizational processes, etc. For example, in both the TOCs, when a change in a shift for front-line staff, such as the drivers and the conductors, they are asked about any near misses that they encountered during the latest trip. In some cases, such a question is asked directly by the head of the personnel, or in cases, it is asked by the new person taking over the driving operation. Further, both the organizations have group-meetings, where they can share their experience of "near-misses" and discuss potential solutions to such "near-misses" without having to worry about any punitive actions by the management. The interview with the JR Central also provided examples from the transition-phase during the HSR privatization in Japan in 1987.

During the pre-privatization phase, an organizational culture existed, where an informal agreement among the employees existed such that the reporting against your workmate was not acceptable for the employees. However, after privatization, a new set of reforms was initiated by the top-management of JR Central, in which the punishment was given for the employee, who observed but did not report the near-misses experienced by their workmate. In addition, the JR Central opened it is to more scrutiny from the public or through developing informal feedback channels within an organization, which allowed to top-managers to gather information on such near-miss reports. The interviewee's recall that indeed changing such old habits was not an easy task, as often there was strong resistance from the employee unions against such measures, however, top-management's firm commitment to ensure the success of the reform was very important. The information thus obtained, reaffirms the modeling structure adopted in this study, which characterizes the change in habits with a long-time delay.

6.8.3.3 Utility of Reporting

The interviews revealed several interesting dynamics governing the reporting behavior for both the organizations. Generally, a combination of the positive incentives to promote reporting behavior while reducing the negative consequences of the reporting is essential in promoting the "near-miss" reporting level within the HSR TOCs.

During pre-privatization, there were strong negative consequences for a person against whom the report has been made, leading to a situation where employees mutually agreed to not report against each-other. To which, post-privatization, HSR TOCs introduced the punishment for not -reporting the observed near-misses; however, such a system by itself does not incentivize the reporting-behavior. There are many other perceived consequences of reporting, that affects the reporting behavior of an employee. Often, the HSR TOCs also operate many subsidiary companies, and these group-companies are assigned safety-related targets. In such a case, employees will not likely report incidents as it will incur negative scores for their subsidiary company, thus inhibiting their reporting behavior. Having realized the importance of providing positive incentives for reporting, both JR Kyushu as well as JR Central, have started reward systems, where an individual is rewarded for reporting near-misses. However, the negative consequence on the workmate, in lieu of reporting, is also important creating conflicts for employee decision-making. In JR Kyushu, employees prominently think about the added work-pressure on their colleagues, in terms of implementing the necessary corrective actions, while reporting. Often, a more serious lapse by a workmate, when reported, will result in punishment for the workmate, thus inhibiting the individual's reporting behavior. Both the HSR TOCs also try to highlight the perceived positive effects of reporting, such as the image of the organization when an accident occurs, or the responsibility to maintain the public trust by ensuring safety, etc.

On the other hand, the perceived consequences are also related to the aftermath involving the incident reported. When HSR TOC conducts a very in-depth investigation, it may often be perceived as a "*policing action"* by the employees, and thus they may lose the willingness to report. At the same time, the investigation is an important process for organizations to learn. Both the HSR operators are aware of the trade-off here and have set the level of investigation accordingly.

A necessity to tailor the incentive structure for different types of near misses was also identified in the JR Kyushu. JR Kyushu categorizes the data of incident reports based on "realized near-miss" and a potential near-miss while keeping the incentives the same for both types of reports. While it is difficult for employees to observe the "realized near-miss" and the "potential near-misses" can be speculated, as a result, the trend of potential near-misses reports is increasing for JR Kyushu.

6.8.3.4 Feedback from the management

Feedback from the management, on each reported incident, is also thought of as an important means to sustain the employee motivations for reporting. JR Kyushu has a system of publicly posting the countermeasures enacted upon the incidents reported. In addition, employees also receive a thank-you card from the president for taking safe-actions. Both organizations see the feedback from the management as an important means to demonstrate the management's commitment to safety.

6.8.3.5 Facilitating Conditions

Ease of using the reporting channel is also recognized as a potential bottleneck for reporting by the interviewee from both the organizations. Hence, a simple and easy to use reporting system is put in place within the organization. The interviewees from the JR Kyushu highlighted that while the simplified reporting system often hampers the quality of the report, however, JR Kyushu has insisted on a simple system, and have relied more on a report-management and coordination team to analyze the contents of the report. The team comprises 5 people with a different skill set to develop a comprehensive understanding of the contents of a reported near-miss.

6.8.3.6 Management's Commitment to Safety

The interviews at the JR Kyushu had specifically addressed the question of understanding the factors affecting management's commitment to safety. In our interviews, the importance of safety as a key management policy was stressed again and again, and it was mentioned that safety is not in a trade-off with the operation-delay performance or profitability performance. While the trend of the number of reports also served as an input for management's decision making. For example, in JR Kyushu, in the year 2017, the number of "realized near-miss" declined. From a manager's perspective, it is difficult to know whether the decline in reports is due to decrease risk-perception of the employees or the effectiveness of the corrective actions. However, in this case, the management expects that the number of reports should be higher than the level currently being reported, and hence they have sustained their commitment to increase the number of near-miss reports. However, if the declining trend continues for some time, it may lead the management to believe that their measures are working effectively and thus will generate confidence in their own actions. Interviews also revealed that one important source of management's commitment to safety was the feedback provided to the management from the external sources such as the MLIT, or accidents in other railway organizations.

6.8.4 Key factors affecting reporting behavior for Japanese HSR TOCs

Table 6-1 summarizes the important factors affecting the reporting behavior of employees for the context of Japanese HSR TOCs. Most of the factors match the factors identified through the cross-industry literature, thus validating the cross-industry transferability of the reporting behavior-related factors. While the factors could be the same, their dynamic interactions must be understood in detail to identify the suitable strategy for the effective implementation of the near-miss or leading indicator reporting program in Japanese HSR TOCs.

The expert interviews were useful in identifying a few trade-offs arising because of the underlying dynamic interactions of various factors, which are particularly relevant to the Japanese HSR TOCs. As mentioned previously, many of the HSR TOCs had started the program for near miss reporting about a decade ago, and now their program has relatively matured. The lessons from this journey will be of great help when implementing a new leading indicator management program. In that, HSR TOCs have already understood the importance of factors such as reporting habits, employee motivation, facilitating conditions, management's commitment to safety, and have institutionalized management actions corresponding to these factors. However, there are a few more issues that need attention. A few of them are listed as follows:

1. Issues of employee risk perception – As highlighted in our interviews, approaches are needed to improve the employee's understanding of the factors that could cause accidents. Employees can identify only those factors, which they understand and learn through various safety-trainings etc. Hence, new approaches to improve employee's understanding of the risk factors are necessary, and as shown in Chapter -4, systematic risk-assessment approaches could be of great help.

2. Trade-offs – As pointed out through the interviews that the interactions among the factors affecting reporting are such that they can lead to numerous trade-offs for the management decision making. For example, the issue of incentives and the perceived consequences. While disciplinary actions are needed to ensure that several rules are enforced (which is indeed a very important step for organizational control), the perceived consequence of the coworker facing disciplinary actions are known to inhibit the reporting behavior of the employee.

While numerous other trade-offs could be identified through expert interviews, their interactions can quickly become complex for understanding due to non-linearity in interactions and time-delays in cause-effect relationships. It is here that a numerically executable SD model would be useful to serve as an important management tool. While the qualitative information obtained through the expert interviews is helpful in validating the structure of the causal relationship for the proposed SD model in this study, more information for quantitative validation could not be obtained for the context of the Japanese HSR. Hence, more efforts are needed to convert the causal structure developed, and validated, so far to a numerically executable model.

For this purpose, information from a construction company was obtained for detailed parameter estimations. The cross-industry validity of the SD model, as proven in this study and also shown in (Barach and Small, 2000) thus allows us to study the interactions and transfer lessons using the semi-qualitative method.

6.9. Validation for a construction-organization

6.9.1 Overview of the construction safety

Despite the long-term safety performance improvement for the construction sector, it continues to be one of the most unsafe workplace environments. To validate the SD model presented in this study, company A with a proven safety record was selected. A detailed review of the prevalent safety management practices in the construction-industry is beyond the scope of the current study, and readers are directed elsewhere (Zhou, Goh, and Li, 2015). An important trend highlighted by the study of (Zhou, Goh, and Li, 2015) is that construction-safety has been widely studied during the construction phase of the project, and very limited attention is given to the impact of planning and design stages on construction-safety. In this sense, the construction-safety has been considered as a decentralized safety management problem, where safety is dependent upon the factor local to the site. However, as part of the focus on "process safety" of the current study, the focus of the current study was also on identifying the necessary organizational factors affecting the safety performance of company A. The details of the data collection and analysis methodology from company A is described in next section. The subsequent sections then summarize the information obtained and steps for further analysis.

6.9.2 Data collection and analysis method

The SD model framework, as described previously, also known as *Dynamic Hypothesis*, was first discussed with an officer from the Health and Safety department located in the headquarters (HQ) of company A. Along with the dynamic hypothesis, simple steps involved in model construction and simulation of some of the results of the model were demonstrated. The purpose of this exercise was to invite interest from Company A in the overall model building and model validation stage. The positive initial response from the officer led to another presentation, where the officer had introduced the existing safety management practice in the company, including the latest strategy on the Behavior-Based Safety (BBS) program[17]. Details of the BBS programs will be discussed in detail at a later stage. However, one of the key components of the BBS program included its acute focus on promoting near-misses reporting at the construction site. Because of the synergy between the BBS and the objectives of the study, further discussions were with company A focused on BBS.

For the next stage, a few important aspects related to the analysis of the factors affecting safety and near miss reporting at company A were focused. The first aspect focused on analyzing the BBS program at a specific construction site. The purpose of studying this aspect was to assess the factors affecting the effectiveness of the "near-miss" reporting program. The second aspect had focused on assessing the relationship between the construction site and the corporate HQ for safety management. The objective of studying the second aspect was to assess the effectiveness of communication, resource allocation, goal setting, and prioritization between the corporate HQ and a given construction site.

The officer at the HQ then helped in establishing the contact for conducting interviews with two experienced safety professionals working at Company A. Person 1 was the Health, Safety, and Environment (HSE) manager at a construction site and was an experienced safety professional. Person 2 was an experienced HSE manager located at the company Headquarter.

The project considered in the case study for this study is a construction site belonging to a clean fuel project located in a country in Western Asia near the Persian Gulf. Since 2014, the project is being developed by a joint venture company ABC, led by its partner companies A, B, and C to provide engineering, procurement, construction as well as commissioning assistance and testing services for the

[17] The name of the program has been omitted to ensure the confidentiality of the information

clean fuel project-related work. Total share for the project is 40%, 30%, and 30% respectively for companies A, B, and C. All three companies have jointly set up a Health-Safety and Environment (HSE) organization at the site. As a project leader, HSE efforts of the joint organization are led by company A at the site.

A general set of guiding questions were prepared for person 1. However, the interview was unstructured, and the interview was kept as interactive as possible. The interview revealed factors relevant to the safety management system established at the site, including responsibilities of various stakeholders in managing safety, the hierarchical relationship between various stakeholders, the responsibilities of the HSE department at the site, the relationship between the HSE department and the project management team at the site. Such a focus on analyzing the structural relationship of safety management was to identify the possibility of the conflicts in addressing the safety-related concerns at the site, the time-bound improvement in the safety management system, and the issues related to effective enforcement of the safety-related rules, etc. at the site. The interview lasted for about 3 hours, was conducted using a video-conferencing service, and was recorded. A disconfirmation approach was used for the interview, where Person 1 was asked questions describing hypothetical situations that could affect safety and was asked to comment on how the safety is managed at the site in question, or why such a situation could not occur at the site in question. For example, upon realizing that at the construction site, the HSE department also reported to the project management team, the interviewer asked if such a situation could lead to declining priority over the production pressure at the site? In response to this question, person 1 described the organizational culture at Company A, which helps in avoiding such a decline in safety priority. Further, when the interviewer received information about a daily HSE meeting where the risk related to the construction activity is discussed, even in the absence of an HSE staff, the interviewer asked can it be possible that such a daily HSE meeting is not being conducted effectively? The response to this question then led to a further explanation of how the quality of the daily activities is ensured. The relevant details obtained from the interview will be summarized later. The dynamic hypothesis of the study was not discussed with person 1 at this stage.

Upon completion of the interview, Person 1 was asked to share data available on the near-miss reports, at least for the duration of a year's duration. The author received the monthly data about a total number of observations each month from January 2017 to December 2017, along with a number of personnel working at the site in that month. In addition, detailed observation data for three months, i.e., Jun, July, and August 2017, was also obtained. The observation data contained information such as date of reporting; reporter's name; name of the company; the subcontractor; area of the site; classification of observation (as Unsafe Acts (UAs), Unsafe Conditions (UCs), and Good Observations (GOs)); description of the observation; proposed corrective actions; classification such as related to Personal Protective Equipment (PPE), Compliance with Safe work, Equipment and Tools, and housekeeping related; and time for resolving the observation, etc. Such data was then analyzed, and certain assumptions and hypotheses were formed. A summary of the data analysis, the assumptions, and the specific hypothesis were then once again presented to Person 1 for his comments. The dynamic hypothesis of this study was then shown to Person 1, and he was asked to comment on missing or additional factors present in the dynamic hypothesis. Person 1 was also asked to point out the most important factors, and the reference was given to him based on the information obtained from the previous interview with person 1. Person 1 confirmed the structure of the dynamic hypothesis presented in this study, and hence, the structural validity of the dynamic hypothesis was confirmed. The interview then continued to seek confirmation on key assumptions and hypotheses on results from the preliminary data analysis. The confirmation thus received helped obtain the parameters for the quantitative validation of the SD model.

On the other hand, Person 2, from the headquarter, was also interviewed to discuss the role of the safety department at HQ in managing safety at a specific site and at the organization. Specifically, the relationship between a project and the HQ at all stages of the project were discussed. The discussion focused on monitoring, resource allocation, etc. functions. A similar approach to Interview 1 with Person 1 was adopted, and hypothetical scenarios were discussed to provoke discussions. This interview further highlighted the organizational safety culture prevalent at Company A.

Parameters for the SD model were obtained based on the information obtained from the multiple interviews as well as analyzing the data of near-miss reporting. The parameters were put in the SD model, and simulations were run for testing alternative policy solutions to further improve the near-miss reporting behavior at the construction site. The simulation results were then once again discussed with the HSE managers of company A to test the suitability of the results and develop confidence in the model thus built. In the subsequent sections, results obtained from the interview and their implications for the model parameters are summarized.

6.9.3 Organizational safety culture at Company A

Company A is one of the leading construction groups for the oil and gas industry with their project experiences across the globe. While creating value for the client is surely among the missions of the company, the focus is also on creating a prosperous future for the people involved in the business activities. The emphasis on safety for all is deep-rooted in the corporate value system of Company A.

The organizational structure of Company A is also supportive of the value system. The HSE department finds its place very high in the organization and very close to the board of directors. The interview suggested that such a structure makes sure that safety is an important aspect to be considered during the key decisions of the organization. HSE is a functional department that works closely with all other business and geographical divisions of the company across the life cycle of the projects, right from the contract stage, through the design and implementation stage. The impeccable safety record of the company is considered to create business value, as it helps to get new projects with high-safety requirements as well as retain the human-resources. Hence, safety planning is integral right across the project life-stages right from the bidding, to design to construction to commissioning stages of the project.

The HSE department takes numerous activities to promote safety awareness among all its employees, including the family members of the employee through activities such as annual health and safety day, social recognition of the safe behavior, etc. At the mid-to-top management level, social recognition for safety is valued highly, and there are no monetary incentive mechanisms in place. Despite this, visible efforts from the top-management are implemented to deep-root the importance of safety for each of the employee.

The corporate HQ is closely involved with the individual sites through project monitoring for both the production-related goals as well as safety-related goals. The number of safety-related leading and lagging indicators for company A is often way more than those prescribed by the client, and their regular monitoring helps the HQ coordinate the various activities at the site. Implementation of BBS on all the project sites involving company A is mandated by the top management of company A. The interview also revealed that, for projects involving joint-venture companies, where the other partners do not buy-in for implementing BBS program, the Company A leads the implementation through utilizing its own resources and when the other partners see the benefits of the BBS, their willingness to implement BBS at the site improves. Similar was the case for the specific project studied, where company A was the leader for HSE management at the site and had actively implemented site-wide BBS programs. While the implementation of BBS at a site is the first step, BBS programs are required to be Taylor-made for each of the construction sites, and hence, a Plan-Do-Check-Act (PDCA) cycle, known as the BBS health-check is implemented by company A to periodically monitor and improve the BBS program. Top management's commitment to safety is also reflected by the fact, the highest-ranking officials visit each project site at least once a year to participate in the safety activities and implement the BBS health check at the site.

The positive safety culture created at the organization level is sustainable only when it is also matched through adequate resource allocation prioritizing safety. In this regard, although it is the responsibility of the project manager to balance the various performance and safety goals, the safety-related concerns of the site are given due priority, and budgets are allocated in a timely manner.

With respect to the theory proposed by Hopkins (2019), i.e., Structure creates culture, the lean structure of Company A, and the presence of safety team at the highest level of the decision-making process are surely indicative of the high priority assigned to safety. However, Hopkins (2019) discusses the stability of the organizational culture, which can be affected when the culture is not supported by the appropriate structure. For example, at any given site, the project management team has the final say about the safety-related decision making local to the site. Hence, the safety decision making may become vulnerable in extreme production-related pressures. So far, at Company A, it is expected that the project management team has been prioritizing safety because of the positive organizational culture; however, there are no structural measures that would stop the project-management teams from decreasing the safety priority of the site. Although, as per the current practice of the highest-ranking officials visiting to the site and conduct BBS health check-up would ensure that safety-related issues are captured at least once a year, however, the current process of safety management at the company A do suggest that they are dependent upon the individuals acting as safety leaders within the organizations.

Such a vulnerability was also pointed out during the interviews by asking "What if the CEO of the company changes, and how likely it is going to affect the safety culture of the company A," to which the interviewee had responded that the next-in-line for becoming CEO is also a person, who has truly imbibed the value-system of the company A. In this regard, the in-house development of next generation of leaders could be seen as one way to protect the organizational culture of the company. Despite these vulnerabilities present in company A, for the purpose of this model, it was assumed that the resource allocation and delay arising from the decision-making from HQ do not affect the safety performance at the site in question. The assumption is also supported by the statement from the HSE site manager where he mentions that "*Despite being the HSE manager, I rarely know about remaining HSE budget, because if I have to implement any safety measures, the project manager and the senior leaders at Company A, always assure that my requirements get fulfilled.*"

6.9.4 Safety management at the construction site

Having described the harmonious relationship between the construction site in question and the HQ of the company A, the attention should also be given to factors local to the site that have implications for the success of the "near-miss" reporting programs and safety in general.

HSE is given a very high priority in the overall scheme of the project. HSE record of the companies was an important selection criterion during the bidding stage. The client organization has set a detailed list of various HSE related leading and lagging indicators, and their time-bound monitoring is enforced effectively on the site. Based on the results from the periodic monitoring, various HSE related risks are jointly identified by the client, and the three project companies and corrective actions are taken accordingly. In addition, the list of leading and lagging indicators itself is periodically revised to suit the project needs. In addition to the indicators mandatory for the project, each of the companies A, B, and C have their own set of indicators as part of their own safety management system. Often, the indicators used by the individual firms are more comprehensive than the requirement of the project, which is a general trend to improve safety across the construction companies of the world.

Some of the key initiatives taken at the site to ensure safe performance are discussed here. Acute focus is given on providing general training to all employees at the site, and task-specific training is provided for the people involved in special activities such as working at height, working at confined spaces, handling welding tools, etc. The entry-permit to the site is issued only when the mandatory training programs have been successfully completed. Further, the training needs to be attended periodically. In order to further enforce the training completion by all, customized personal protective equipment (PPE) are issued with the name of the employees written on each of the PPE. Further, the training completion stickers are on the helmet for easy monitoring by colleagues and supervisors, etc. Tool-box meeting is an important means for the HSE managers at the site to provide special instructions and possible hazards. A big tool-box meeting, in large groups, is conducted for half-an-hour on every Saturday (beginning of the week), where potential risks associated with the construction activities are discussed. The content of the tool-box meeting is planned by the HSE department based on the feedback received about the safety issues at the site and the possible risks in the ongoing construction-related activities. In addition, a *pre-job meeting* is conducted every day, where the supervisors discuss the safety risks associated with the activity every-day.

All the safety-related enforcement practices are supported by an active BBS system. The BBS is a behavior-based safety approach program that focuses on improving safety-related beliefs, attitudes of the employees, and on improving the organizational culture. The focus is on improving worker's beliefs and perceptions about safety. The key focus of the BBS program is on building relationship among worker's providing them a sense of belonging to the site such as through promotion of shared responsibility of safety, care of each other, removing the communication barriers between the management and the workers, allowing the workers to share issues, and concerns on not only how to promote safety but also to about well-being of each-other (Sugimoto, 2010; Zou, 2010). The details on how BBS is implemented at site in-practice is discussed in detail by (Zou, 2010) and a similar strategy for introducing the BBS program at the site was implemented by Company A for the whole site. An important step in BBS is to promote reporting of "near-misses" at a construction site. While the conventional near-miss reporting programs focus only on reporting of Unsafe Acts (UAs) and Unsafe Conditions (UCs), BBS features reporting a unique metric, i.e., reporting Good Observation (GOs) at the site. UAs refer to the acts of the individuals that could have safety-related implications such as not wearing PPEs etc. UCs refer to the conditions that are inherently dangerous and could lead to accidents, e.g., a dig at the construction-site without barricading. GOs refer to the good-behavior or the good-conditions observed at the construction-site that are helpful in promoting safety at the site.

As part of the BBS, the emphasis is given on recognition and praise for other's safe behavior. It is considered an utmost responsibility of an individual to find a safe act, tell others why they think it is a safe activity, and praise the colleague while thanking them for their safe contribution. Such a practice greatly enhances the communication between the group of employees and strengthens the relationship among the workers. On the other hand, UAs and UCs are also very frequent on the construction sites, and BBS emphasizes reporting these as well. However, the purpose of reporting UAs and UCs is not to attribute blame to an individual but is to ensure that appropriate corrective actions are identified and implemented at the site. As part of the BBS program, when reporting the UAs and UCs, it is the responsibility of the reporter to also provide details on what corrective actions were identified and whether these corrective actions were implemented effectively. Once again, the focus is on noticing the unsafe acts, discuss the concerns among each other, and collaboratively find the corrective actions. Such collaborative efforts further enhance the safety awareness and safety perception among all the employees.

The interview also revealed one of the potential drawbacks of the introduction of the BBS system. Since the focus of the BBS program is on promoting the relationships among the workers, this also decreases the social acceptability of reporting among the colleagues. While, in general, there are no negative management actions or punishments to people involved in UAs, reporting against your colleague is known to have a negative connotation, and the connotation can become even stronger when the relationship among the workers is strengthened. Such a negative connotation can further become stronger when the reporting system does little to prevent the identity of the reporter or is non-anonymous. At the current construction site, the reporting system is non-anonymous, which in theory, may prevent a number of reports from being lower. However, such a non-anonymous reporting is considered essential at this particular site, as it enables ease in reporting, such as through an easy to use safety observation card (SOC), enables easy monitoring and following up of the reported UAs or UCs, and helps in quickly deliver the rewards as promised by the weekly reward system (in terms of goodies such as iPads, or TVs, etc.) combined with the tool-box meeting every Saturday. The interview also revealed that the faster following up of the reported UAs and UCs, the weekly reward system are all perceived as the strong management's commitment to safety by the workers, which is seen as the essential element for the success of BBS program. The interview also revealed that the reporting of GOs help weaken the negative connotation against the reporting within the peer-group. For example, when an employee notices the UAs by their colleague, they are encouraged to discuss the UAs with the person involved before reporting. Instead of directly confronting the colleague, the employee is encouraged to start discussing the GOs about the colleague and then gradually provide constructive feedback to make the colleague aware of the UAs. Such a healthy discussion then helps in removing the negative connotations against reporting.

While, in theory, the BBS program is expected to improve the reporting behavior of the employees up to a great extent, the implementation of the BBS program is not always smooth. At the current site, the BBS implementation started since the beginning of the project in 2014, and as per the information obtained from the interview, during the year 2015, there were significant ups and downs in the efficiency of the BBS program. As part of the BBS programs, BBS leaders are developed for smaller areas of the project sites. The role of these leaders is to encourage the involvement of all personnel in his/her block to participate in BBS activities. The BBS leaders themselves undergo practical training, and then they undertake BBS related activities in their respective areas. In 2016, from the month of January to March, it was deemed that the BBS implementation was not working smoothly as the uptake by company B and C was slower. Hence, an assessment method was developed, where the quality of the BBS activity, as delivered by the BBS leaders, was evaluated on a 4-point scale, where Level 1 corresponds to Poor and Level 4 corresponds to Great. Table 6-2 shows the relative performance of the BBS programs as the management interventions were implemented.

Data for May and June is set to be the baseline data, where about 70% of the evaluations were considered as L3 or L4. As the management's commitment to launch the BBS program increased in July and August, the total number of BBS evaluations increased as well as the proportion of L3, and L4 among all evaluations also increased. In the month of September, the initiative lost pace, and correspondingly the status of L3 and L4 also decreases. Once again the management's commitment to improving the BBS increased in the month of October, as the company A, B and C all joined hands to improve the BBS program and they launched an incentive program for best BBS leaders, etc. and finally a significant improvement in the overall quality of BBS activities was sustained. Table 6-2 summarizes the information on the performance of the BBS initiative at the site.

Table 6-2 Performance of BBS initiative

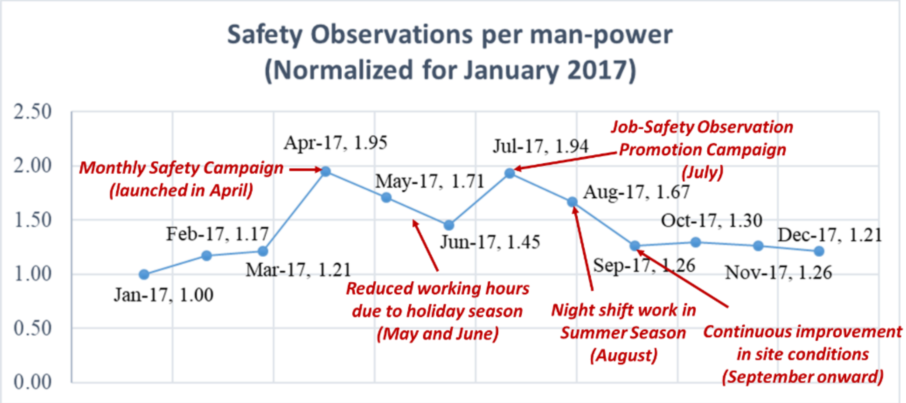
Heading	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Evaluations	Setup	979	929	875	1517	973	1389	1390	1798
L1 = Poor		2%	2%	1%	1%				
L2 = Average		21%	13%	21%	20%	21%	12%	13%	5%
L3 = Good		50%	37%	44%	54%	52%	60%	67%	71%
L4 = Great		27%	48%	34%	25%	27%	28%	20%	14%
Key Points		Baseline Setup		BBS intervention		Lost Pace	A big push from senior management with the incentive program		

Form table 6-2, it is evident that the management's commitment to safety is of utmost importance for the sustaining the safety-related initiatives in a construction site. Further, the time-lag between realizing the effect of management's commitment to safety is also not very long, and the effects can be seen very quickly (of the order of a few days).

The data obtained in this study is for a period from July 2017 to December 2017. It is expected that the BBS program has now matured at the given construction site, and hence a large variation in management's commitment to safety is not expected for the period of the study used for model validation. The same understanding was also confirmed during the interviews. Hence, the factors such as level of incentives, social acceptability of reporting among colleagues, the effect from the habit of reporting, ease of using reporting channel are all expected to remain constant throughout the period of study. In the next subsection, details of the data obtained on near-miss reports are discussed.

6.9.5 Trends in near miss reporting at the construction site

Figure 6-21 shows the normalized trends for a number of reported safety observations/manpower. The data has been normalized for the month of January 2017. While, in general, safety observations/manpower increased by about 21% in 12 years, a steep hike is seen in the month of April and July. Information was sought whether the trend was likely affected by any policy decisions implemented during the same time. The preliminary interview suggests that these large variations are likely to arise from external factors; for example, sweltering heat in the month of July and August could lead to more UAs being occurred at the site. It was also noted, that the potential decline in the month of May and June is due to celebration of the big festival in the region where the site is located, in which the number of working hours are drastically reduced, and energy level of employees are likely to be lower as they are often fasting, prompting lower response to incident observation, etc.



Month	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Number of Safety Observations	1883	2432	2585	4335	3908	3532	4754	4142	3191	3434	3466	3435
Man-Power	16679	18412	18848	19697	20228	21502	21751	22017	22455	23457	24350	25067

Figure 6-21 Trend in the number of safety observations/manpower on the site

Figure 6-22 shows the distribution of the safety observation reports for the month of June, July, and August 2017. A detailed safety record of only these months could be obtained. About 20% of all the observation made is Good Observations (GOs), a slightly higher proportion is for the Unsafe Acts (UAs), and more than 50% of the observations are categorized as Unsafe Conditions (UCs). Such a proportion is slightly different from the general trend observed in the construction industry, where the large proportion of the reports is for UAs (>70%) (Zou, 2010; Jiang, Fang and Zhang, 2015). Based on the interview, such a variation is attributed to the BBS program, where the closer relationship among the construction workers working in a team, may prevent them from reporting UAs while reporting the GOs to clarify the safety-related risks, etc. (as described in section 6.7.4). Another factor contributing to the high proportion of UCs is thought to relate to the hierarchy of the construction work. For example, an unbarricaded excavation site will be an unsafe condition from the worker's perspective; however, from the perspective of a manager/supervisor, it will be the case of an unsafe act. Here the data is from the reporting behavior from the worker, and hence, a large proportion of UCs are thought to be a rationale. However, such a finding is not new. Oswald, Sherratt, and Smith (2018) reported a similar trend of a higher proportion of the UCs as opposed to expected UAs in the literature. They contended that the UAs might be difficult for the workers to notice, because of their fluid nature in time. Further, it may be possible that not all UAs were observed as they were happening in the time, and hence, for the workers reporting these events, they are often reported as UCs (Oswald, Sherratt, and Smith, 2018).

About 50% of the reported UAs are related to PPE, while about 38% of the reported UAs belong to compliance with safe work. The proportion of reports for compliance with safe work for UCs is as high as 55%, while 30% of all reported UCs belong to the housekeeping category.

While discussing the possible explanations for such distributions with the HSE managers during the interview, an important perspective was highlighted. The number of reports for any of the UA, UC and GO, will depend upon the number of UA and UC and GO actually present at the site, as well as the worker's perception on the same. For GO, an important assumption can be made that a large number of

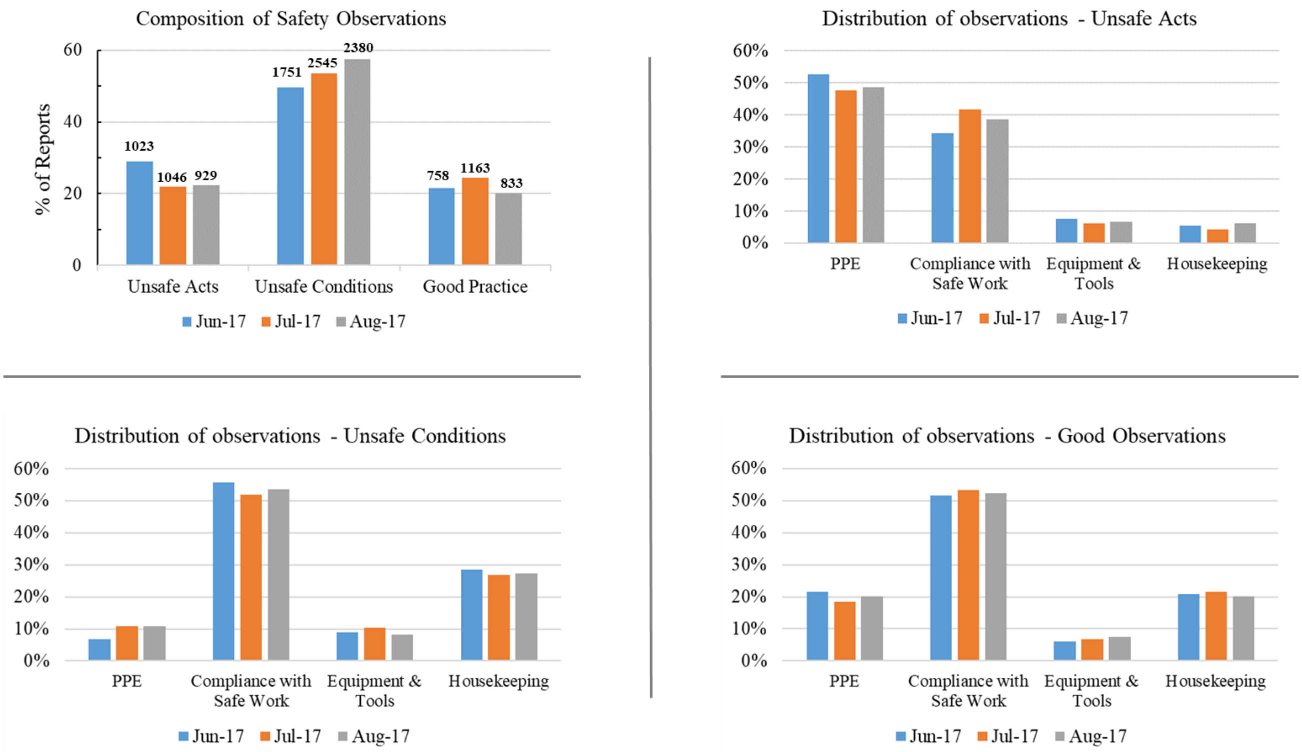


Figure 6-22 Distribution of Safety Observations

good behaviors exist at a site all the time, and hence, the trends of GOs are expected to capture the perception effect. Under this assumption, the relative trend of UAs with respect to GO would then be a good indicator of the absolute number of UAs.

As per the SD model conceptualized in this study, the perception effect will comprise of the effect from fatigue, the safety awareness as well as the Risk perception dependent upon the severity of the event and organizational communication. Such an assumption has a strong basis in the distributions observed for the safety observations on unsafe acts. The importance of PPE as a safety tool is always highlighted during all safety training, tool-box meetings, as well as the pre-job meetings. Hence, it is likely that unsafe acts related to PPE get noticed more than the other categories. In order to understand the details about the observed distributions of the UAs, UCs, and GOs, more information about the

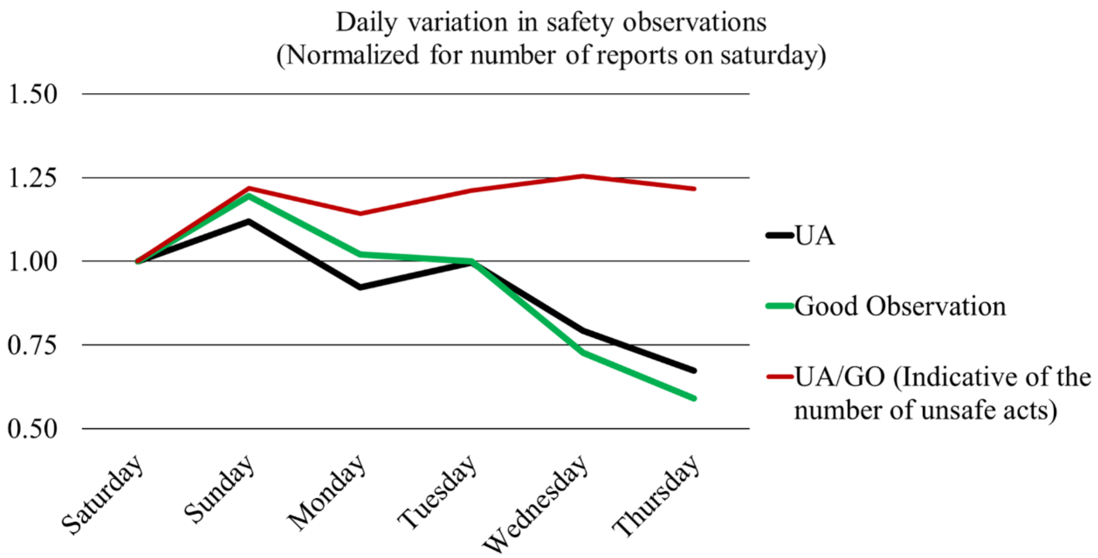
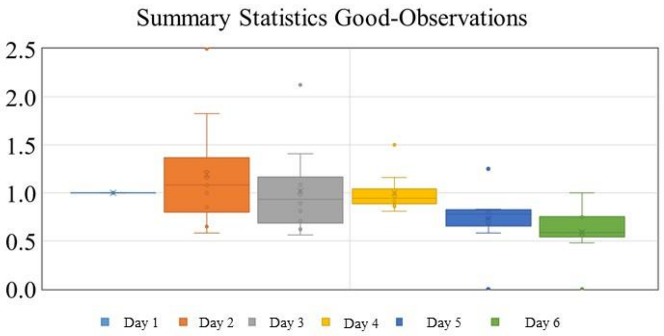


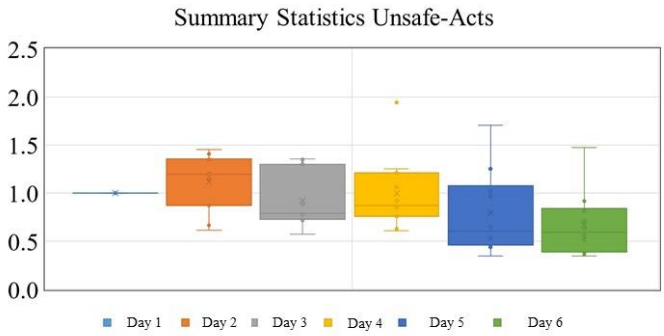
Figure 6-23 Variation in the safety observations as the day passes in a week

training curriculum, the content of the toolbox meetings, etc. should be collected, which is beyond the scope of the current study. For the scope of the study, further attention is directed at analyzing the trends of the UAs and GOs (to observe the perception effect).

The safety observation data obtained for the three months, i.e., Jun, July, and August, also includes information on a date at which the specific report was made. Such a detailed information is unprecedented and thus allows us to obtain some of the interesting trends on the variation of reporting variation as the week passes by. A total number of observations made in a day can be counted. At the given project site, Friday is a holiday, and the workers work for the remaining 6 days. Normalizing the number of safety observations in each day with respect to the number of safety observations on the Saturday of the same week then provides interesting insights. Figure 6-23 shows the trend obtained by averaging the information for 10 weeks. To consider the effect of any specific event happening in a week, the trend of UA/GO is also obtained by first dividing the UA/GO and then averaging. Figure 6-24 shows the summary statistics for the GOs data at a daily level for the 10 weeks.

As seen in Figure 6-23, the number of GOs declines by about 40% as the day of the week passes by from Saturday to Thursday. In between, a slight increase in the number of GOs reported is observed on Sunday, i.e., the second day of the week. Based on the SD model conceptualized in this study, such an effect was hypothesized to directly result from the effect of safety awareness (tool-box meeting on the first day of the week) as well as the effect of fatigue as the workers may get tired as the week passes by. The other factors contributing to the perception effect can be considered as constant within a week, for example, the effect of the risk-awareness program run by the management or even the effect of safety habits and incentives.





Day wise differences, 2-tailed student's t-test

Full-Sample (10 weeks)

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Day 1	NA					
Day 2	0.536	NA				
Day 3	0.236	0.226	NA			
Day 4	0.165	0.328	0.544	NA		
Day 5	0.011 **	0.064 *	0.416	0.056 *	NA	
Day 6	0.005 ***	0.019 **	0.113	0.015 **	0.298	NA
Significance level - *** 99%, **95%, *90%						

Adjusted for missing values (9 weeks)

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Day 1	NA					
Day 2	0.277	NA				
Day 3	0.420	0.170	NA			
Day 4	0.245	0.168	0.778	NA		
Day 5	0.024 **	0.040 *	0.398	0.113	NA	
Day 6	0.013 **	0.013 **	0.120	0.035 **	0.312	NA
Significance level - *** 99%, **95%, *90%						

Full-Sample (10 weeks)

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Day 1	NA					
Day 2	0.389	NA				
Day 3	0.192	0.125	NA			
Day 4	0.930	0.640	0.405	NA		
Day 5	0.166	0.099 *	0.579	0.254	NA	
Day 6	0.014 **	0.010 **	0.138	0.054 *	0.501	NA
Significance level - *** 99%, **95%, *90%						

Adjusted for missing values (9 weeks)

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Day 1	NA					
Day 2	0.190	NA				
Day 3	0.304	0.092 *	NA			
Day 4	0.778	0.580	0.409	NA		
Day 5	0.270	0.101 *	0.659	0.298	NA	
Day 6	0.033 **	0.011 **	0.203	0.079 *	0.557	NA
Significance level - *** 99%, **95%, *90%						

Figure 6-24 Summary statistics for the Good-Observation data

To validate the hypothesis, Person 1 was asked to comment on the trend. In our interview, he confirmed the presence of the effect of fatigue, causing a decline in the number of GOs as the week passes by. He also pointed out that the slight increase in the number of GOs on Sunday could be attributed to the big toolbox meeting being organized on Sunday. In this toolbox meeting, rewards are also distributed, and hence, the effect of the safety awareness is expected to last for a while, after which the declining trend in a number of observations can be attributed to fatigue caused by the hard work conducted as the week progresses. Thus, the trend obtained through daily observations follows the expected trend based on the special activities undertaken at the site.

Further, the statistical significance of the differences of observations for each day of the week is shown in Figure 6-24. Significance was calculated using the student's t-test, assuming a 2-tailed distribution. Figure 6-24 shows that the GOs at day 5 and day 6 are statistically significant from day 1, day 2, and day 4 of the week at various confidence interval levels. A similar trend was also obtained for UAs. Such trends support the presence of the fatigue effect affecting the reporting behavior of the employees as the week progresses. However, the difference between Day 2, Day 3, and Day 1 is not found to be significant, and hence enough support for the effect of the tool-box meeting could not be immediately confirmed. However, the data showed here is generated from 4 construction areas where each of the three (almost equal partner) companies have been functioning. In that, several observations are occasionally missing. In one particular case, observations from week 2, no-observations are available for 1 of the companies for any of the construction area for one full week. Such missing data could have affected the quality of the results, and hence when such adjustment for the missing-data was made, the significance of the difference between day 2 and day 1 improved, although the difference is still statistically insignificant. However, such observations provide the support that the effect of tool-box meetings may be present, and if long-term data trends are utilized, such variations could be observed. On a project of the scale of 5-7 years, data for 10 weeks cannot be considered sufficient to capture the effects.

Qualitative validation of this model has important implications for the SD model. First, the effect of safety awareness can be modeled as second-order decay function (not a first-order, which allows the safety awareness to immediately start decaying), with an average time of decay being of the order of 3-4 days in the context of construction work. Further, the effect of fatigue should be modeled so as to consider the impact as the week progresses. Such model implementation will be discussed in the next section.

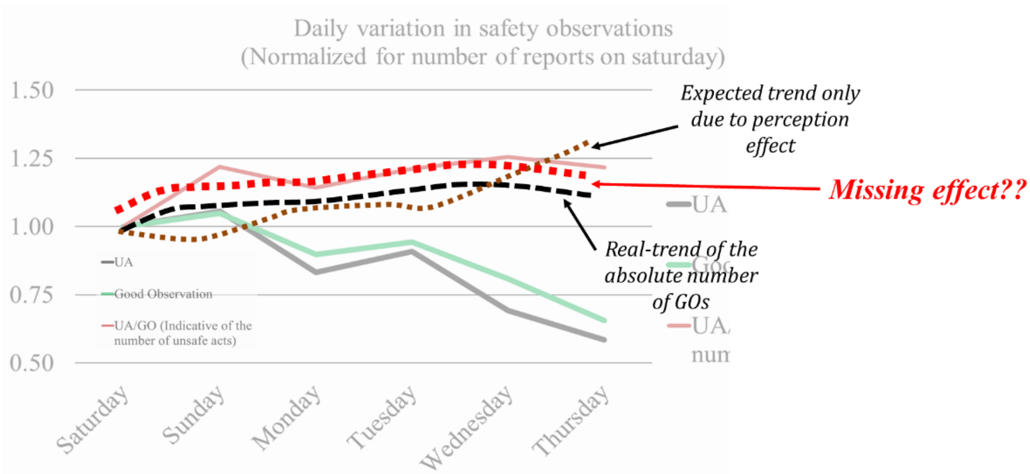


Figure 6-25 Comparison of the expected vs Real trend in UA/GO

Based on the assumption that UA/GO is expected to represent the absolute number of unsafe acts being committed on a given site, the average weekly trend is also consistent with the effect of fatigue affecting the unsafe acts (as well reported in the literature). As the week progresses, the fatigue accumulates on the workers, and they are likely to commit more unsafe acts when they are tired. However, the obtained trend for UA/GO does not have a steady increase as the week progresses. If the effect of fatigue is the only persistent factor, we would expect a trend, as shown in the brown dotted line in Figure 6-25. However, based on the observed trend of UA/GO, it can be guessed that behavior such as the one shown in the red dotted line in Figure 6-25, is not accounted for. As per the trend shown here, there is about a 25% increase in the number of unsafe acts as the week progresses, and the behavior closely resembles that of the first order gap-closing behavior. Such a gap-closing behavior can be expected under the implementation of BBS, where the more unsafe acts that a particular worker commits, the more feedback that he/she is likely to receive from his colleagues prompting him/her to not commit more unsafe acts, however, the effect of fatigue can increase the possibility that an unsafe act is likely to happen. Typically, in a BBS program, the feedback provided by the colleague can be thought to be effective at a time scale of within a week, and hence can be thought of as an explanation for the stabilizing trend of UA/GO as the week progresses.

Trends similar to as shown in Figure 6-23, can also be obtained when summarizing the data from numerous other perspectives such as average by different companies, or averages for different areas, etc., Such similarity then further strengthens the confidence in the general trend obtained here and thus is considered typical of a construction project.

While the daily variations within a week can be obtained, data is also checked for the presence of any other cycles, etc. To eliminate the effect of the weekly variations, the data for 10 weeks was considered as one single time-series. The data for all Fridays were removed. Form the total of 12 weeks (3 months), the data from Week 4 and Week 9 had to be removed due to the presence of missing values. The 10-week time-series was then taken, and a 6-day moving average was taken to detrend the time series from the weekly variations. Figure 6-26 shows the trends for the 6-day moving average trends for GOs and UA/GOs. The trend clearly indicates the presence of a cyclic behavior with a frequency of about 14 -16 days for both GOs and UA/GOs.

Considering the SD modeling framework presented in this chapter, such a cyclic behavior can be hypothesized to be emanating from the fatigue effect (see section 6.5.3). Further, the effect of fatigue is likely going to affect the trends of GOs and UA/GOs in a pattern that is shown in Figure 6-26. The cycles of energy level (caused by the fatigue-burnout cycles) effect are going to have a direct impact on the perceived effect of the employee (as discussed in previous paragraphs of the same section). Similarly, the trend of UA/GO (indicative of the total number of UAs being committed on the site) is likely to vary with fatigue cycle, as it is evident from the literature that employees are going to commit more unsafe acts, as they become tired (Fang *et al.*, 2015). In this way, it can be expected that the trend

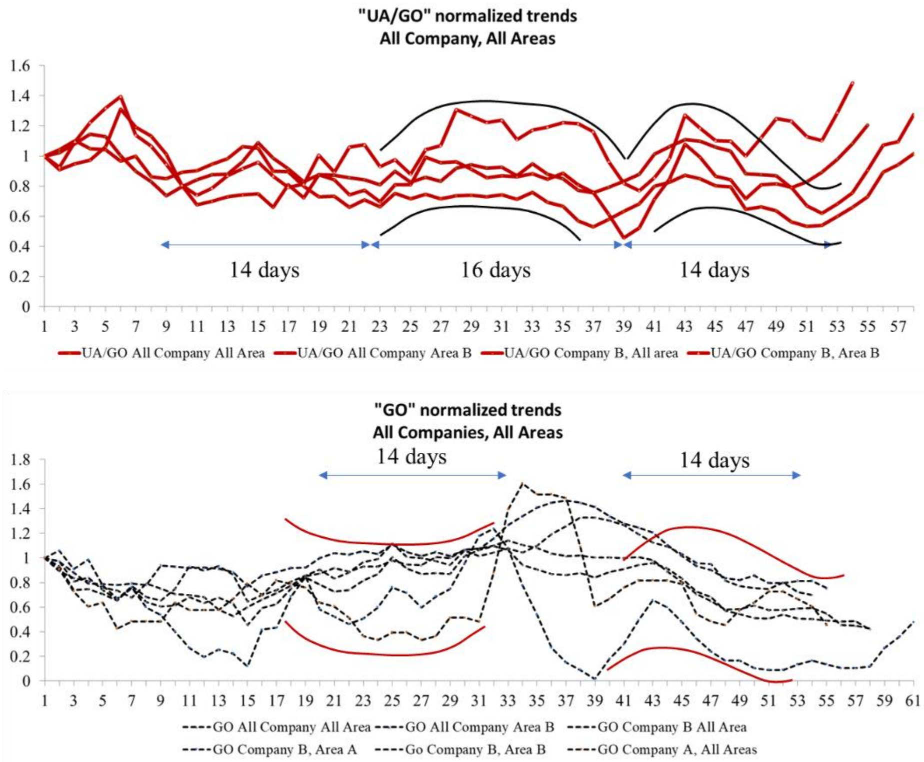


Figure 6-26 6-day moving average trends for GOs and UA/GO of UA/GO will be out-of-phase compared to the trend of GO, which is the case, as shown in Figure 6-23. Person 1 was also asked to comment on the diagrams shown above, and he also agreed that such an effect could be attributed to the fatigue effect. Hence it can be reasonably assumed that 2-3 weeks of fatigue cycle exists for the construction industry workers.

However, so far, the presence of fatigue-effect is only hypothesized from the data on near-miss reporting, but not from the actual data related to hours worked by the employees. To further confirm the presence of the fatigue effect for the workers at the specific site, working-log data for each worker was requested. However, such detailed information was not available to share, and only the aggregated trends in Manpower and Manhours could be obtained, as shown in Tabbl3 6-3.

Table 6-3 Average working hours for the site

Month	June - 2017				July - 2017				August – 2017			
Manpower (A)	21502				21751				22017			
Week	1	2	3	4	1	2	3	4	1	2	3	4
Manhours (000s) (B)	876	891	908	921	922	923	961	977	1004	1007	1037	1051
Average Hours (B/A)	40.8	41.4	42.2	42.9	42.4	42.5	44.2	44.9	45.6	45.8	47.1	47.8

Average working hours at a weekly level could be calculated using the data shown in Table 6-3. The average number of working hours at the given construction site is about 44 hours, while, in principle, the workers are expected to work at least 60 hours per week. With the written consent of the workers, the working hour for a day could also be increased to two additional hours per day, allowing for a maximum working week of 72 hours. Compared to the maximum allowable 72 (or 60) working hours per week, the average of 44 hours/ week does present a point worth being curious about.

Such a trend could surely result due to the presence of fatigue cycles at the construction site. As shown in Figure 6-11, the average working hours of the worker will be close to 60% of the maximum working hour limit when the fatigue and the burnout cycles are present (Homer, 1985). Hence, a significantly smaller number of working hours obtained from the real data on the field compared to the theoretical maximum hours at the site does hints at the possibility of effect emanating from fatigue. Together, with the trends obtained from Figure 6-23, and Figure 6-26, makes a stronger case to qualitatively conclude that fatigue is surely playing an important role at this site.

Nonetheless, a smaller number of working hours could also be happening due to several other factors. First, we have assumed that the number of manpower working is fixed in a given month, which is an assumption that itself could be challenged. However, trends for manpower at the weekly level could not be obtained from the site. Further, certain variations in the working hour could also be due to the external factors, such as a shift from day-time work to night-time work in August, etc. In our analysis, we could not obtain any data to further confirm the effects of such factors and had to rely extensively on the practitioner's confirmation of the presence of the fatigue effect.

6.9.6 Key modeling parameters based on the interviews and Data analysis

Based on the analysis of the information obtained about the given construction industry project, the following assumptions and parameter estimations can be made, for the purpose of analyzing the SD model. These are-

1. The HSE and the project management team at the construction site can be assumed to be free from any resource and other related pressure from HQ about managing safety at the site. Hence, the management's commitment to safety can be assumed to be of generally high value and be dependent upon the endogenous factors such as the production pressure at the site and the safety performance of the site.

2. The construction environment can be characterized by the dynamic effects of the order of a few days. As clearly seen from Table 6-1 and Figure 6-20, results from the management's policy actions

are visible in a few days. From the perspective of safety, 7-10 days of delays could be considered as apt for SD modeling of the construction site environment. For example, it takes about 7 days for the HSE department to analyze the reports, provide feedback to the employees. The perception effect of any new incentive scheme can be thought to work on a timescale of the week, where the weekly tool-box meeting will be an effective means to dissipate such information. Factors such as fatigue, safety awareness can show variations within a week, and hence, the average time for their change can be characterized by an even smaller duration. Such variation observed from the interviews is also consistent with the previous examples in literature (Jiang, Fang, and Zhang, 2015).

3. While the effect of management's policies on workers is seen very quickly on a construction site, the time it takes for the management to plan and execute various activities may be relatively long. For example, the Average time for the management to form its commitment could be of the order of 30 days, as it resembles the decision-making process at the site. The HSE departments of all the contractors and the sub-contractors have monthly reviews of the safety performance with clients and accordingly can make important decisions to improve safety. Further, once the management's commitment to take certain actions has been formed, it will still take some time to implement them, for example, for improving the training, as they will have to make schedule adjustments, etc. for the employees to get such training.

4. The trends obtained from the GOs are assumed to mimic the perception effect, which is dependent on the energy level of an employee and his/her safety awareness. The perception effect declines for about 40% during the 6-day long working week at the given construction site. Correspondingly, the absolute number of unsafe acts are thought to increase as the energy level of the employee declines during a week. As an effect of BBS, feedback from colleagues is also considered to be important in slightly improving the unsafe behavior as the week passes by.

5. The burnout cycle is estimated to be 2-3 weeks long. The nature of the relationship of the burnout effect for a construction worker is thought to be similar to that originally envisioned by (Homer 1985) for a workaholic individual. Although there is no evidence that the construction workers are workaholic, however, the organizational incentives structure is expected to give rise to similar behavior. For example, there will always be a tendency for the construction worker to revise his/her expected performance in order to receive more salary (which is usually based on hourly wage). Further, if the management sees the workers perform more than they are expected to do, they are likely to assign more tasks to the person. The frustration effect characterized by frustration when the low perceived performance leading to further depletion in energy can also be observed in the construction industry, as the study reports that worker's poor performance evaluation can have an effect on his burnout (Poon *et al.,* 2013). Hence, it is assumed that the model structure provided by (Homer 1985), is applicable to the construction industry with slight changes in the parameters.

6. For the purpose of this analysis, the effect coming from ease of using reporting channel and effect of reporting habits can be characterized to be constant. The interview did not reveal any issue that the near miss reporting channel was considered to be inadequate for the workers. The non-anonymous reporting method can be justified when the quick disbursement of the award and management feedback is thought as necessary. Further, the construction sites are usually characterized by frequent changes in personnel, as the construction activities change. Thus, it can be assumed that the effect of habit is not so significant for the current case. The base-case of the SD model was then simulated using the assumptions and observations described above. The results of the simulation are discussed in the next section.

6.9.7 Identification of a new trade-off

The interviews with the expert helped in identifying one potentially important trade-off for behavior-based safety programs aimed at promoting the development of close relationships among employees and support each other. The general belief is that such acts help improve the safe behavior among employees, as the informal feedback received from other employees could be useful for improving various safety-related perceptions of an individual. The close relationships among colleagues may also influence the effectiveness of information dissipation within an organization, where informal communication among various colleagues could be a source of a number of other workers. However, such an acute focus on promoting stronger relationships among employees can also lead to decreasing acceptance of reporting against the colleague in a close group. On the other hand, such factors could mask the underlying systemic factors contributing to unsafe behaviors from the management's eyes and could also have an impact on organizational knowledge.

6.9.8 Behavior Prediction Test

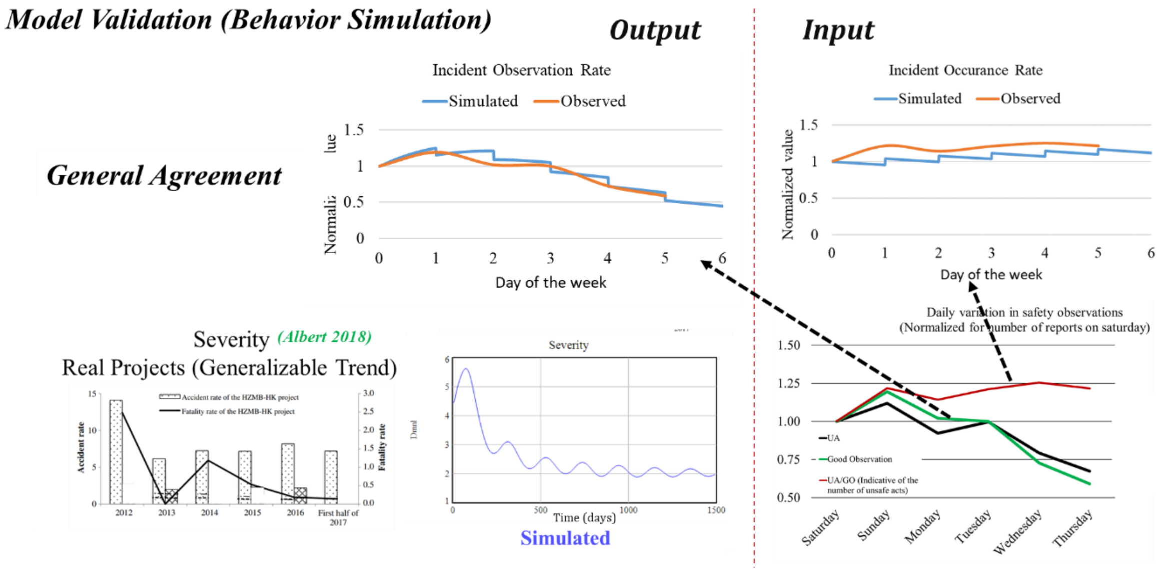


Figure 6-27 Comparison of Simulation vs the Data

Figure 6-27, 6-28, and 6-29 show the comparison of the parameters discussed in previous sections and the results from the simulation in the base case. The trends for observed and simulated trends for both the incident observation and incident occurrence are similar, as shown in Figure 6-27. The detailed site of model equations and the parameters used in the Base case are listed in **Appendix A**. The simulated behavior for key trends also shows similarity compared to data obtained from the field.

For example, the simulated periodicity of the burnout cycle is about 25 days, while the one observed from the data is about 2-3 weeks (Figure 6-28). The parameters can be further adjusted to further reduce the periodicity of the burnout cycle, but that would imply to have certain unreasonable assumptions, e.g., the average time taken for an worker to form perception about his/her own accomplishments is currently set at 28days, which is reasonable in the context of a construction worker, who is likely updating his perception based on his monthly income or feedback from the management. To further reduce the cycle, the average time taken for adjusting the number of working hours will have to be made <1 day, given the model works on a timescale of Days; such a short-time delay may not be appropriate modeling strategy.

In addition, the total number of monthly near-miss reports at around 2 years of the simulation time is also shown in Figure 6-29. While this simulation does not emulate the trend shown in Figure 6-29, the model does capture that overall variation of about 20% in the number of reports after 2 years of the construction period. As shown in Figure 6-29, the exact trend is likely affected by many external influences such as the holiday season or the summer season, whose effects are difficult to capture. Further, the trend shown in Figure 6-29, is also dependent upon a few management policies undertaken during these periods. However, information about how effective these policies were perceived by the workers is not available. In addition, the trend around 3-year at the construction site will also be dependent on accumulated effects from the past two years, in-that various dynamics such as a change in a number of employees at the construction site, their training procedures, etc. are all not simulated in the current model.

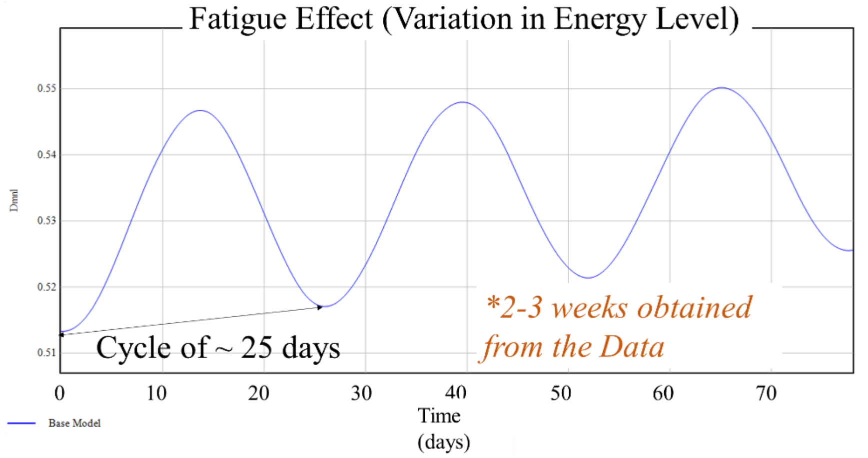


Figure 6-28 Comparison of the Fatigue-Cycle

The model also shows the similarity in the trends of the accident severity, which is high at the beginning of the construction work and gradually declines (Figure 6-27). The simulated trend closely resembles the severity trends obtained from the real-data in another construction site (Chan, Yang, and Darko, 2018), and is considered generalizable, as the severity of accident is likely higher in the beginning period as the site workers and managers are getting used to the new environment(Chan, Yang, and Darko, 2018). Despite the obvious limitations in the ability of the model to imitate the trend observed in the field, the model can be estimated to be reasonably model the behavior.

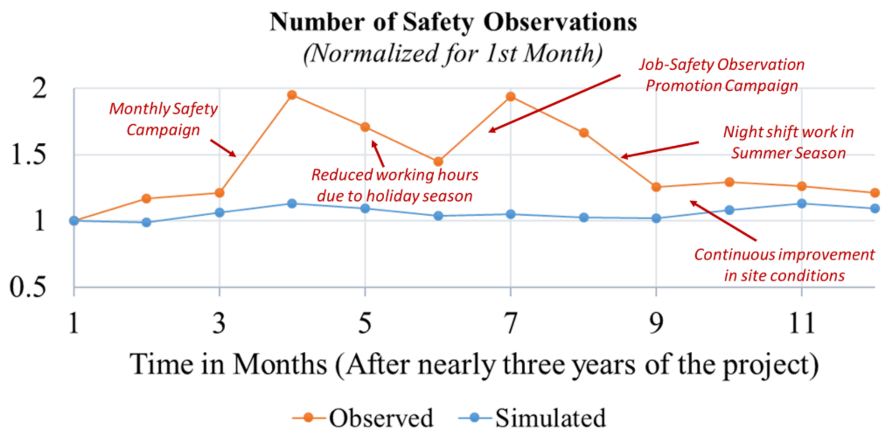


Figure 6-29 Comparison of Simulation vs the Data (Yearly Trend in Reporting)

Based on the discussion above, the developed SD model is effective in reproducing several aspects of the general behavior and hence, can be considered reasonably acceptable.

6.9.9 Extreme Value Test

Extreme value tests are also considered useful tests to confirm the reliability of the model. Table 6-4 summarizes the results of certain extreme values tests. A brief explanation of the test results is also shown in table 6-3. In all the extreme values tests conducted, the simulated behavior was found to be consistent with the behavior reported in several other academic studies, thereby providing more support for the confirmation of the developed SD model in simulating the reporting behavior in an organization.

Table 6-4 Results of the extreme value test

No.	Parameter Modified	Behavior Obtained	Test Result

1	Change in Hazard level Base – 0.1, Changed in 0.01, 1, and 10	1. No. of incidents increases as the hazard level increases 2. The severity of the accidents decreases as the hazard level increases	Consistent with the theory of high-reliability organizations, where the highly hazardous industries have a learning culture and able to avoid a severe accident (Roberts, 1990). Further, ultra-safe incidents may often experience a serious accident, as the organizational knowledge depletes (Marais, Saleh, and Leveson, 2006).
2	The initial level of organizational knowledge increased and decreased with respect to the base case	1. For a low initial level of organizational knowledge, high-severity accidents in early stages, thereby improving management's commitment to safety and stabilizing the severity trend 2. For the high initial level of organizational knowledge, initially, the accident severity is very low, thereby contributing to a decline in management's commitment to safety and leading to high severity accidents. Later the trends of severity stabilize.	Learning organizations can manage their safety very well. Consistent with the theory.
3	Performance pressure exponent affecting management's commitment to safety changed from 2 in the base case to 0.1 and 20.	1. Extremely high-value of performance pressure exponent creates a situation, where the organization is perpetually in a state of low-safety	Consistent with the findings in other literature (Cooke, 2003a, 2003b; Cooke and Rohleder, 2006)
4	Management's initial commitment is changed from 0.4 to 1	Same oscillatory behavior in management's commitment and severity is quickly regained	The high initial commitment is not sustained in the absence of reduced accidents etc.

6.10. Policy Analysis for construction Site

One important aspect of the developing SD model is to use the developed model as the simulator tool to analyze various policy measures (Sterman, 2000). Table 6-5 summarizes the policy scenarios tested for the current study. Policy 1 simulates the effect of the change in frequency of the tool-box meeting being conducted at the construction site. Tool-box meeting is an important meeting for promoting safety awareness at the site, and its frequency is a major policy decision for the HSE managers at the construction site. The timescale adopted in this analysis (at a daily level) thus allows exploring the optimum frequency of the tool-box meeting, for which only general guidelines are available. Having identified fatigue as an important factor worker's reporting behavior, an attempt to reduce the burnout cycle is simulated in Policy 2. The trade-off related to the behavior-based safety program, as identified in section 6.9.7, is also tested. A parameter passed as the level of interpersonal bonding is conceptualized to range from 1 to 0.2. Important to note here is that depending upon the context, the production, and the safety pressures may seem conflicting, and hence, the trade-off between the production and the safety is an important policy analysis; however, such policy discussions have been implemented in many other studies, and hence it is not emphasized upon in the current study. A general conclusion in this regard is that an extensive focus on production may invariably lead to a bigger loss in the manifestation of a big accident and hence, priority on safety leads to gains in the production as well (Cooke, 2003a; Cooke and Rohleder, 2006; Jiang, Fang and Zhang, 2015). Implications can also be drawn by analyzing the combined effects of multiple policies. In the next subsections, results from various simulations are summarized.

Table 6-5 Policy Scenarios

No.	***Policy Description***	***Parameters in the Base Case***	***Parameters in the Scenario Case***
1	Frequency of the tool-box meeting	Once in a Week (30 minutes at the beginning of each week)	Twice in a Week (15-minutes each) starting at the 490th day Once in two weeks (60 minutes) Starting at the 490th day
2	Limiting the burnout cycle	Maximum hours worked in a day limited to 12	Maximum working hours in a day limited to 11, 10 and 9.5, 8.5, 8 hours a day
3	Level of Interpersonal Bonding	Level of interpersonal Bonding 1	Changed from 1 to 0.4

6.10.1 Base case and Policy on the frequency of the tool-box meetings

Figure 6-30 and 6-31 show the results for the simulation results of Base Model (Red Color), Two toolbox meetings in a week (Blue color), and Toolbox meeting once in two weeks (Green color). The frequency of the toolbox meeting is changed at 490th day as an exogenous input.

The base model starts with a non-equilibrium stage, which closely resembles the early start of a construction project. In the beginning, the severity of the incidents is high, organizational knowledge is relatively low, and the number of incidents rises rapidly (which can be expected at a construction site where the safety management practices require certain time to stabilize). However, the rising accidents and the severity soon leads to increase in management's commitment to safety, leading to increase in safety awareness of the workers (through the effectiveness of the tool-box meetings) and thus putting a control on further increase in a number of incidents (*Meeting the Safety Goal* loop on Figure 6-3). The time-delay in improving worker's perception once the management's commitment to safety increases, as well as the delay in organizational learning affecting the management's commitment to safety (*Incident Reporting and Incident Learning* loop in Figure 6-3), then leads to the cyclic behavior of the management's commitment to safety.

However, in the current model, the *Production Pressure* loop (Figure 6-3) is not creating a strong effect, as it is assumed that the "near-misses" do not result in any production loss. Despite the absence of the production loss resulting from the "near-misses," production-pressure can change due to the burnout cycles as experienced by the employees. In the base model, management's expected level of production is kept constant at 9.5 work/day. The nominal work efficiency is assumed to 1 work/hr when the employee's energy level is set at 1. However, the number of working hours put by employee reduces his/her productivity, and the average productivity achieved is less than the set by the management's expected productivity. The maximum limit on working hours in a day is set at 12 hours in the base case. When the production pressure increases, management has an option to increase the number of working hours for each of the employees, resulting in a burnout cycle, gradually converging, as shown in Figure 6-30. Nevertheless, the total resources (Management's total time, or Money, etc.) for a given project are limited, and hence, if the production pressure increases, the resources from safety management could be diverted to the production activities. When the extreme focus is put on production-related activities, extreme accidents could also result, as shown in (Cooke 2003a). Such dynamic relocation of the production and the safety activities is not modeled here in detail, as it requires an assumption on certain simplified relationships between production-related resource allocations and an increase in production activities (Jiang, Fang, and Zhang, 2015). For ultra-safe systems such as the construction site in question with commendable safety record, resources to safety are not considered as critical, and hence a simplified relationship between the production pressure and decreasing management's commitment to safety is modeled, which is similar to (Cooke, 2003a).

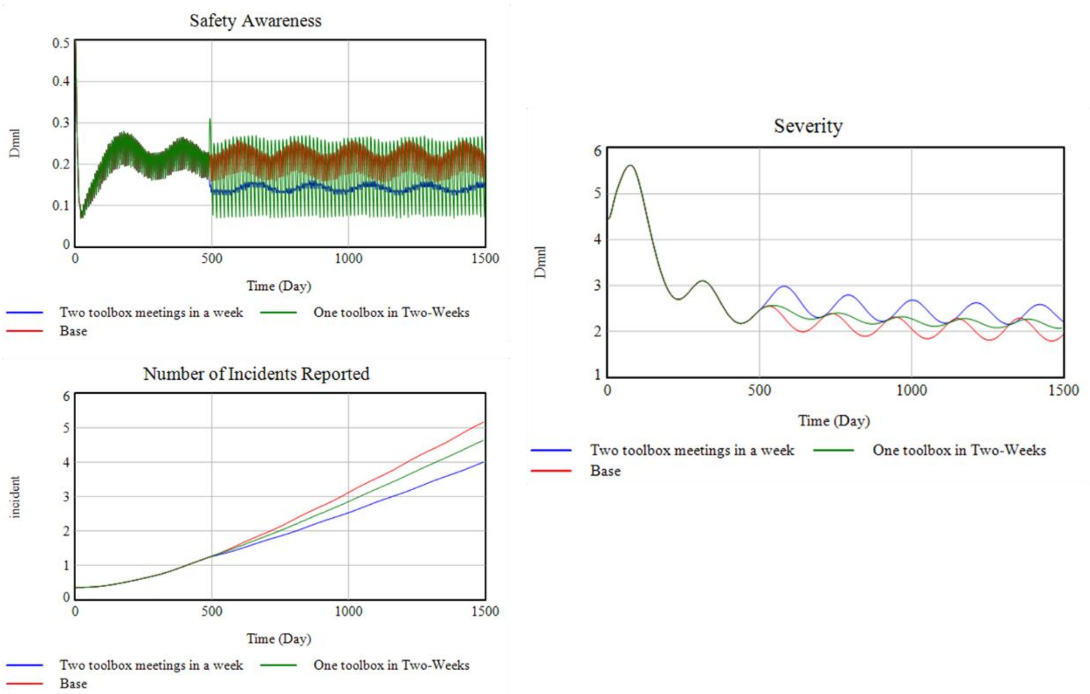


Figure 6-30 Key indicators representing the effect of toolbox meeting frequency

Now when the frequency of the toolbox meeting is made twice while keeping the total duration of the toolbox meeting as constant, the safety awareness of the employees starts decreasing (Figure 6-30). This happens because the safety awareness is assumed to follow a second-order delay (as validated using the data). The safety awareness will depend on the amount of safety awareness inserted for the workers and the decay constant. Due to this reduced safety awareness, the risk perception of employees decreases, and thus the reported incidents decline to lead to a slight decline in the organizational knowledge (effect from loops *Incident Reporting and Incident Learning)*. However, the balancing loop *(Meeting the safety Goal)* thus kicks in as the severity of the accident increases, and hence management's commitment to safety increases, leading to re-establishment of the cyclic trends at a level lower than the base model.

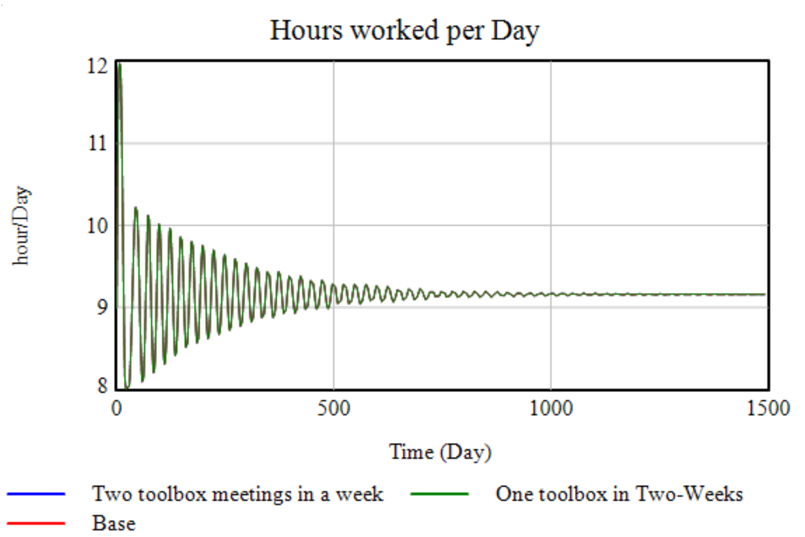


Figure 6-31 Fatigue cycles observed in the Base-Case

Now when the toolbox meeting frequency is reduced, to keep one big meeting (1 hour) every two-weeks. In this case, the behavior is still better than the two-small meetings in a week; however, is worse compared to the Base case. The trend thus hints at the presence of an optimum frequency of the tool-box meetings (30 minutes every week). At the same time, the model suggests that large size events could also have long-lasting effects. Thus, the weekly tool-box meeting can be considered as an optimum frequency of the tool-box meeting at the current site, and the same practice should be continued. However, the SD model developed can serve as an important policy analysis tool considering the various trade-offs originating due to underlying dynamic interactions.

6.10.2 Limiting the burnout cycle

Homer (1985) had suggested the measures to reduce the burnout cycle resulting from fatigue. One of the key variables to achieve this was a maximum limit to working hours. In the Base model, the maximum limit to the working hours is set at 12 hours per day (as stated in the interview that, with worker's permission, they can work for 12 hours every day). In the subsequent simulations, the maximum working hour limit is gradually changed from 12 hours to 8 hours per day. Form the management's perspective, one obvious expectation is that the total amount of expected work should not decrease. Hence, in all the simulations, the expectation work from employees is kept at 9.5 tasks/day, while assuming that the maximum achievement rate is 1 task/hour. Figure 6-32 demonstrates that the burnout cycle is stabilized when the maximum working hour limit is 10 hours. For a limit of fewer than 10 hours, cycles of fatigue are not observed, and the working hours per day remain constant throughout the analysis period. Consequently, a higher average energy level is achieved for workers for the lower limit on the maximum number of hours worked.

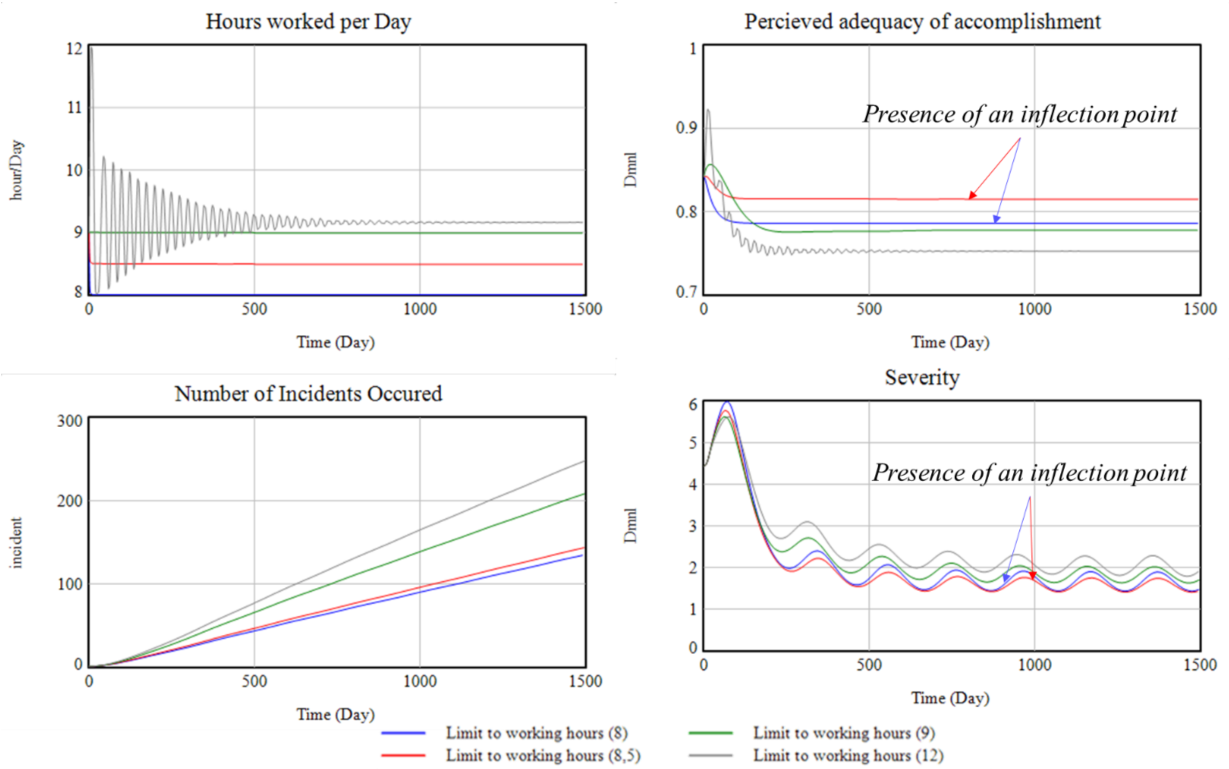


Figure 6-32 Variation in reporting behavior with a change in the limit to maximum working hours

The increased average energy level for an employee, when the maximum working hours are reduced has positive implications for safety reporting, as workers are less likely to commit unsafe acts as well as they are likely to observe more incidents and are more likely to report them as reporting does not cause high inconvenience at high energy level.

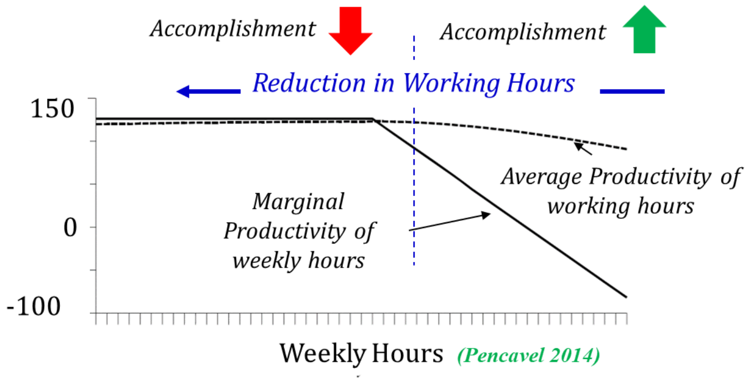


Figure 6-33 Productivity and Overwork

While the number of safety incidents becomes less and individual workers are more likely to report the observed incidents, the absolute number of incidents decreases and thereby the effect of organizational knowledge as well as pressure arising from an increase in accident rate on management's commitment to safety is slightly weakened. On the other hand, as the number of working hours become smaller, the decrease in a number of working hours is no longer compensated by the corresponding increase in the per hour accomplishment rate and thus beyond a critical limit, if the maximum number of working hours is further reduced, the performance pressure increases. Such an increase in performance pressure then leads to further pressure on reducing the management's commitment to safety, thereby decreasing the efforts put by the management in improving safety and the severity of the event increases. Hence, beyond the above-mentioned critical point (read inflection point), a further decrease in the maximum working-hours will have an adverse effect on both safety and production. Figure 6-29, demonstrates the effect of such a safety and production trade-off as the maximum number of working hours is reduced. In this particular case, the optimum safety and production results are obtained when the maximum limit on work is set at 8.5 hours/day. When maximum limit on working hours is further reduced (to 8 hours per day), the overall safety and production performance is worse than 8.5 hours case and may even become worse than the case when the limit is set at 9 hours/day.

The basis for the presence of such an inflection point was also confirmed originally by Homer (1985), by showcasing the non-linearity in the number of hours worked and the output produced. Up to a threshold point, the output increases linearly with the number of hours worked; however, beyond a threshold point, the output rises at a declining rate and may even decrease as the number of hours worked is increased. While Homer (1985) did not have the backup of such a model from the real-case, the similar non-linearity has since been observed through the real data (Pencavel, 2014), as shown in Figure 6-33.

Understanding such trade-off then has important implications for the organizations, and organizations should carefully examine the presence of burnout cycles for their employees. If the current work-stress is such that the burnout cycles exist, then policies related to reducing working hours can have profound effects on improving both safety and productivity. However, if such an effect of burnout is not present, a policy to reduce the working hours motivated by some general external trends may negatively affect both the production as well as the safety performance. Further, the impact of the reduction in the number of working hours is path-dependent and is affected by the current state of the burn-out effect. Depending upon the current stress level of the employees, any policy to reduce the number of working hours may have different responses (as shown in Figure 6-34).In some cases, the policy to reduce the working hours may not have any effect, as worker's average number of working hours may already be below (due to the fatigue and burnout) than the maximum number of hours even after a reduction. In other cases, a reduction in maximum working hours may even have a negative effect on productivity in the short-term (for the order of a few weeks). This happens due to the time required for the workers to replenish their energy levels after an episode of chronic fatigue. In this recovery period, workers will not be as productive, while the number of hours has been reduced, thereby contributing to reduced overall productivity. The results of such modeling have also been confirmed through real-life examples discussed in (Robinson, 2012). According to the article, increased working hours, even if not for a prolonged time, may have a negative impact on productivity. As per Robinson (2012), once a team working 60 hour-a-week team gets to go back to its regular 40, it can take several more weeks before the burnout begins to lift enough for them to resume their typical productivity level.

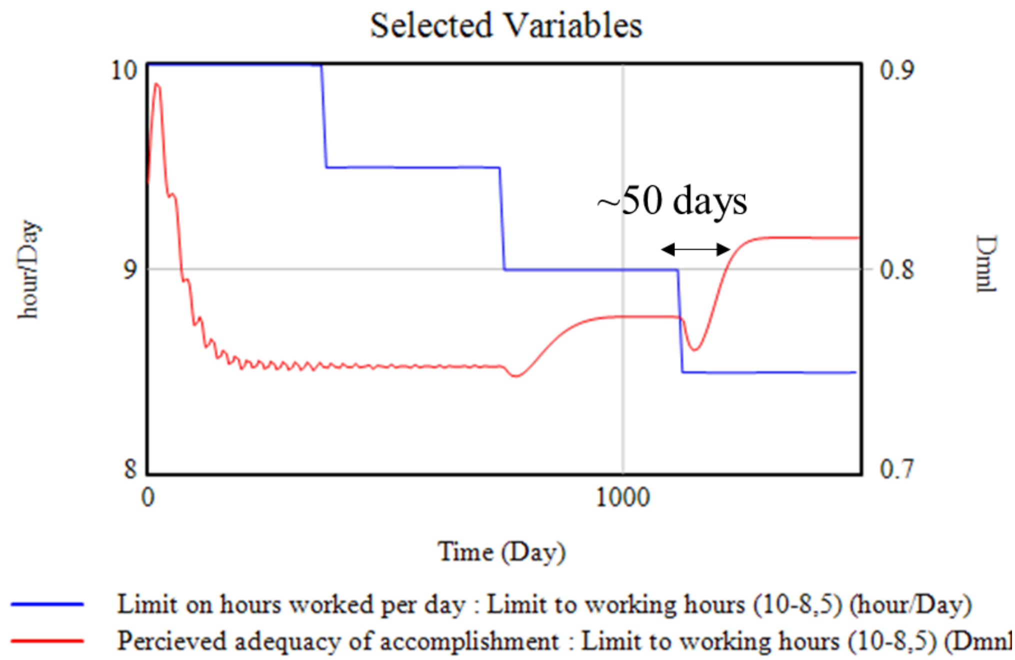


Figure 6-34 Path-dependent effect of the policy on limiting the working hours

The policy to reduce the number of working hours may not be readily acceptable by the managers as well as the workers in the context of the construction industry. For construction workers, generally, the compensation is directly associated with the number of hours worked. Hence, they have little incentive to support a policy for limiting the maximum number of working hours. Even from the management's perspective, a policy to limit the working hours is usually counter-intuitive, and in the short-term, it may be possible that the perceived productivity declines or does not change at all (shown in Figure 6-34).

Under this context, an alternative policy having a similar effect could also be envisaged. Given the availability of slack-time, for reducing the number of working hours without adversely affecting the production or safety, sometimes it could be devoted to stress-reducing activities such as physical exercise or sports activities. These activities, if linked with safety awareness programs in innovative ways, such as possibly through the opportunity to participate in sports competitions for the worker eligible for safety-related rewards, etc. could boost the safety awareness among employees and help reduce their work. The exact activities should definitely be planned in consultation with all stakeholders. However, it is evident that such activities could simultaneously target multiple aspects affecting overall safety and reporting behavior.

6.10.3 Effect of interpersonal Bonding

As highlighted previously, that one of the fundamental approaches to the behavior-based safety approach is to promote inter-personal bonding among colleagues. When this happens, the safety performance of an employee is likely to go up, as they receive immediate feedback from their workmates or the management. However, such an approach makes the reporting against the workmate very difficult. Less reporting is likely to affect the organizational knowledge and thus can have safety-related impacts. To test this, variation in the inter-personal bonding is introduced in the model as an exogenous policy variable. In the Base case, the parameter was kept at 1.0 and was reduced in the subsequent simulations.

Figure 6-35 summarizes the effect of reducing the interpersonal bonding parameter. When the parameter is high (1.0), the absolute number of the incident occurred on the site are reduced. However, as the reporting becomes more difficult, overall, a smaller number of incidents are brought to the management's notice. This is equivalent to a reduction in organizational knowledge, and thus management's commitment to safety achieves the oscillatory behavior at a lower value compared to the cases when this parameter is at a lower value (0.4, or 0.6). Hence the severity of the incidents is likely to go high, as the interpersonal bonding among the workmates' increases.

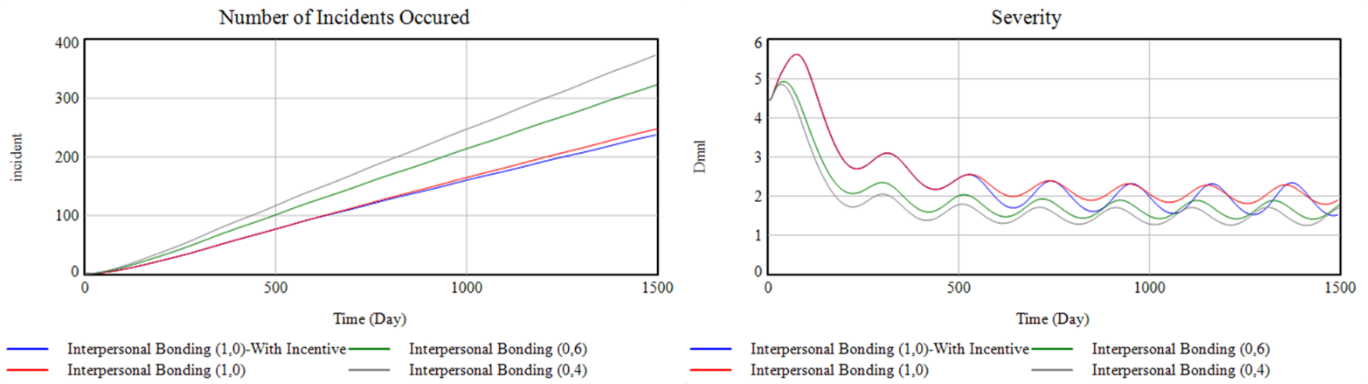


Figure 6-35 Variation in Safety Performance with the variation in the interpersonal bonding

To compensate for the negative effect on reporting, if the employees could be provided with more incentive to report (and reduce the negative consequences), both the fewer incidents as well as lower severity of the incidents could be achieved (Figure 6-35).

However, the assumption that the incidents have no effect on the production-loss does not hold true for a general organization. Hence, the suitability of such a policy should also be tested with the assumption that the incidents could also result in a production loss (proportional to their severity). Under such a scenario, the loss in production arising from the incidents will result in increased production pressure and can thus have a negative effect on the management's commitment to safety. Figure 6-36 summarizes the simulation results for three scenarios Low interpersonal bonding (0.4), Medium interpersonal bonding (0.6), and High Interpersonal Bonding (1.0). The results are significantly different from those shown in Figure 6-35. For low interpersonal bonding scenarios, many incidents with relatively low severity are reported to the management early in the project, thus raising the management's commitment to safety to a higher level early in the project. Thereafter the management's commitment is sustained, and therefore both high safety and high production performance are achieved.

For a high interpersonal bonding scenario, in the early stage, the number of reported incidents is very low. Thus, organizational knowledge is not sustained, leading to reduced management's commitment to safety and thus raising the severity of the incidents. However, as the severity becomes very high, management's commitment to safety increases (analogous to a situation of a very serious incident), thereafter improving the safety as well as the production performance. However, for the medium interpersonal scenario, the combination of severity and the incident frequency is such that management is locked in a constant battle to a commitment to safety and to production. This is a very dangerous situation, where both the safety and the production performances are drastically reduced compared to the previous two cases. However, such organizations were also described in (Cooke, 2003a; Cooke and Rohleder, 2006), which are perpetually locked into poor-safety and poor financial performance. The simulation here shows that the level of interpersonal bonding in an organization can also trigger such a locked-in effect. However, more cases must be reviewed in order to understand the impact of the level of interpersonal bonding and its effect on reporting behavior and is kept one of the themes for future research.

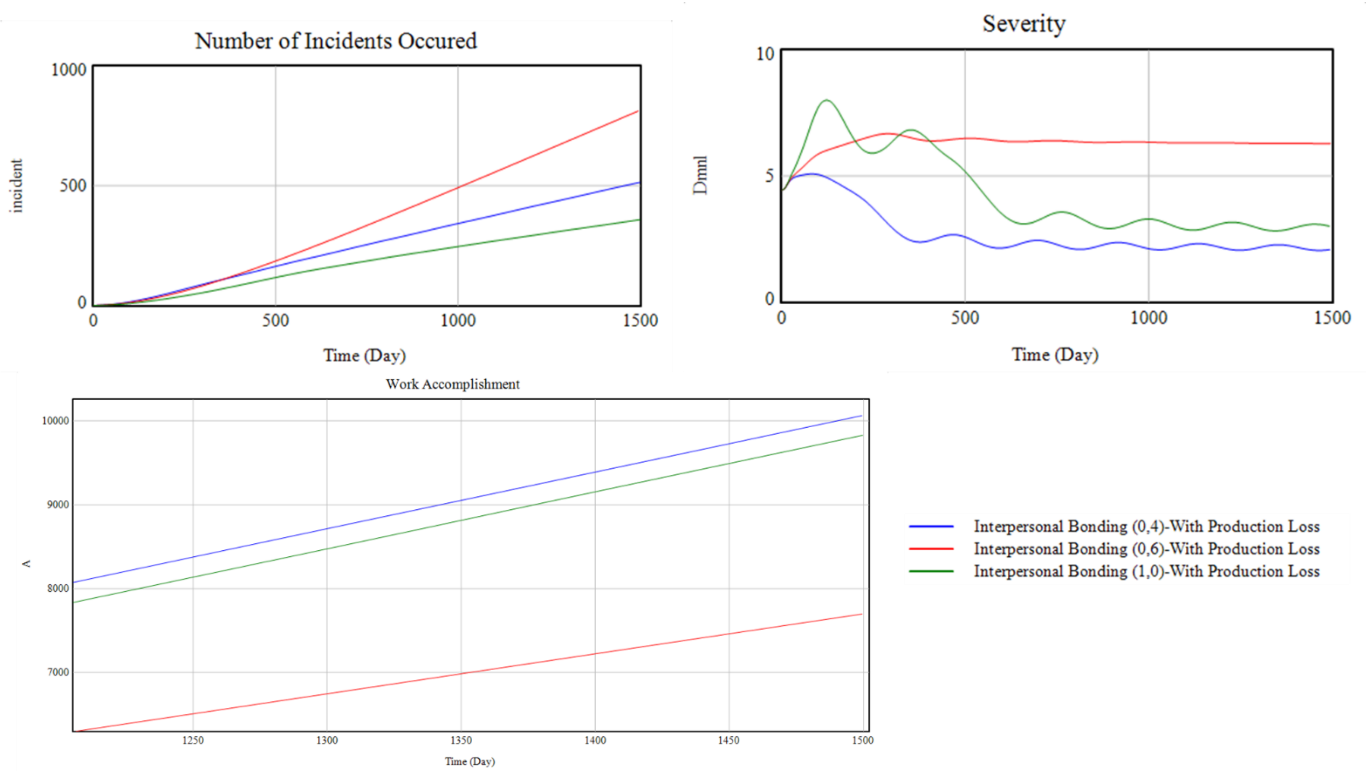


Figure 6-37 Effect of Interpersonal Bonding under Production Loss

Figure 6-37, then shows the results of the simulations, that can help break the cycle of locked-in effects. The simulation provides an expected result in this regard that the locked-in effect can be countered by either raising the level of incentives or by altering the interpersonal bonding of the workers, such that it does not form an obstruction for the employees reporting the behavior. Interpersonal bonding is often required for efficient operations in the work-place, and hence a policy to improve the incentives for reporting should be carefully planned.

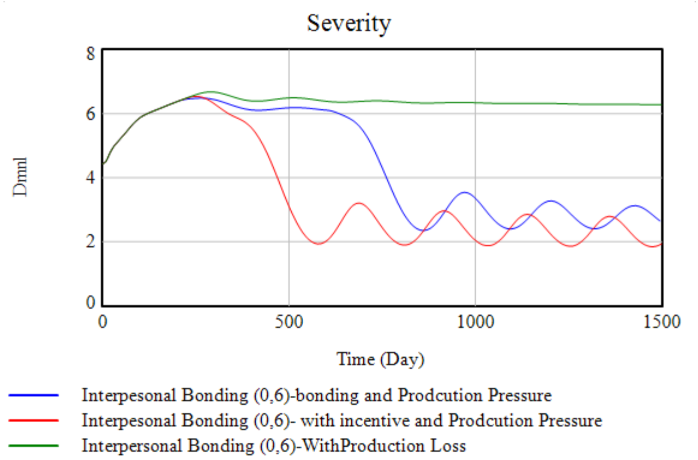


Figure 6-36 Breaking the locked-in effect

6.11. Policy Implications for HSR Organizations

While the parameters estimated for the construction industry, hold no meaning for the HSR organizations, the factors and the structure affecting the reporting behavior was similar in both the organizations. Hence, the simulations still can have some general implications for the HSR organizations as well. In this regard, the three scenarios are conceptualized and simulated. For the first scenario, the working hour and the associated conditions are kept at what is currently observed in the Japanese HSR organizations. For the second scenario, the time-effect parameters are increased (such as the order of the time-delay, etc.) so as to reflect an organization more hierarchical in nature and involving longer timeframes for information processing and decision-making processes. In the third simulation, long-term reporting behavior is analyzed, corresponding to variation in the level of reporting incentive in the organization. Such a scenario is consistent with the findings from the interview at JR officials, who had highlighted the importance of incentive structure in changing the overall reporting behavior in the organization. The results of the simulations are discussed in the next sub-section.

6.11.1 Effect of Fatigue in Japanese HSR Operators

Our interview had highlighted that the Japanese HSR TOCs are aware of the overwork on their employees. In this regard, by law, the Japanese HSR TOCs follow a practice of 160hr/month for all their personnel involved in important train operation related activities. Such a practice corresponds to a practice of 40hr/week, or 8hrs/ day considering a five day week. Hence, the average working hours in the Japanese HSR TOCs correspond to the level, which is considered as a universal norm for the maximum working limit.

However, for HSR TOCs employees, within a month, the number of working hours can vary for each week, such that the total is not more than 160hr/month. For example, in some weeks the working hour could go to 60 hrs, and on others may remain as low as 20 hrs. In addition, often, the employees at HSR TOCs spend extra time for participating in training and other meetings, etc., which is not counted in the regular working hours (石野沙織, 2012) .

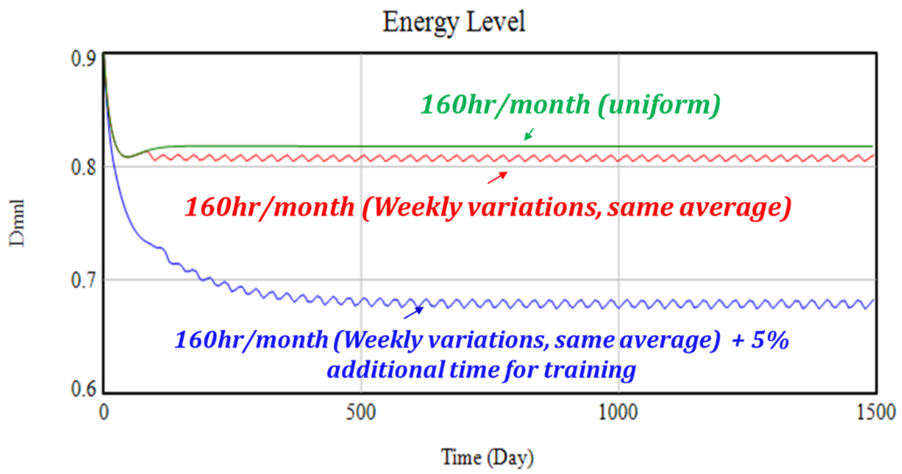


Figure 6-38 Simulation of fatigue effect for HSR TOCs in Japan

Figure 6-38 shows the results of the simulation relevant to the HSR TOCs in Japan. In this, the parameters of the base model remain unchanged (from the model prepared for the construction industry). In the base scenario, a uniform 40hr/week is workload is implemented. The simulation shows that workers are able to maintain a very high level of energy. In comparison, when a non-uniform week is simulated, the simulation results demonstrate that a certain reduction in energy-level can arise because of such non-uniform working hours across weeks. In another scenario, it is assumed that a worker spends 5% of his/her time in training or meetings, in addition to their regular working hours. For an 8hr working day, 5% corresponds to less than half an hour of additional work, which is normally expected within the HSR TOCs (石野沙織, 2012). The results of the simulation demonstrate a significant decline in the worker's energy level, corresponding to just 5% additional work. The results of the simulation thus suggest that even Japanese HSR TOCs are prone to suffer through the consequences of the overwork, as per their current practices. The validity of these scenarios could not be confirmed in this study; however, information gathered through certain informal channels such as the online blogs, etc. do suggest that TOCs employee, do feel the overwork because of the above-mentioned work practices.

Such evidence supports the necessity to conduct studies analyzing the employee's fatigue behavior in the HSR TOCs.

6.11.2 *Hierarchical Organizations*

The SD models, once developed, offer valuable opportunities to analyze the dynamic behavior. In this section, such dynamic behavior is explored. The parameter for the original model is suitable for the construction industry, where a number of decisions are taken local to the site. However, for the centralized organization, such as Railway, information processing may require a longer time, as the information has to be collected and summarized at multiple levels within the hierarchy. To simulate this behavior, some of the key model parameters regarding the average time taken for certain decisions are modified. First, a first-order information delay for the organizational knowledge to form is assumed to be 120 days (compared to no such delay in the construction industry model). Next, variation in two types of parameters is considered. First, is the time taken for averaging the incident rate, which affects the management's commitment to safety. In the original model, this time was kept at 7 days; however, for a centralized organization, this time is modified to be 120 days, which corresponds to a large number of layers in-between the top-management and front-end employees, leading to more time for management to notice the average number of incidents happening. Further, a variation in the external hazard level is considered. In the simulation, a sudden sustained increase in hazard is introduced at time = 500 days. The input is shown in Figure 6-39. The resulting simulations for four scenarios are shown in Figure 6-40.

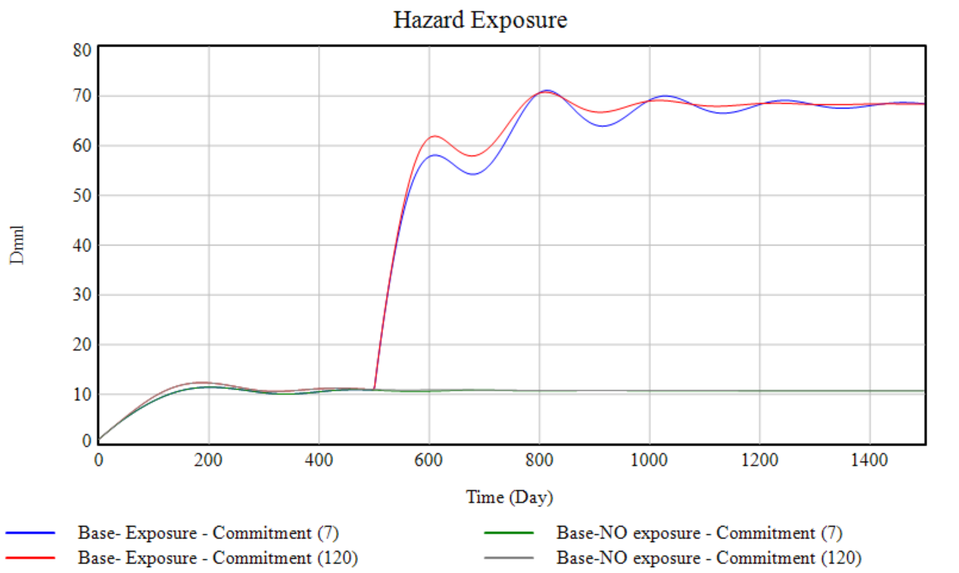


Figure 6-39 External increase in hazard exposure at time = 500 days

First, a comparison is made for the cases with external hazard increase as compared to no such external increase in hazard exposure. When the hazard exposure increases, correspondingly, there is an increase in the number of incidents being reported, leading to a rise in Risk-Perception and thus an increase in the number of reports being reported. Such an increase in the number of reports then leads to an increase in organizational knowledge, thereby leading to a sudden rise in management's commitment to safety. However, this increase in management's commitment to safety, coupled with increased organizational knowledge, leads to a decline in the severity of the incidents. Further, this decline in incident severity is such that it overpowers, the incident frequency-dependent components of both the individual's risk-perception as well as the management's commitment to safety, and as a result, there is a net decline in management's commitment to safety, compared to no external hazard exposure case.

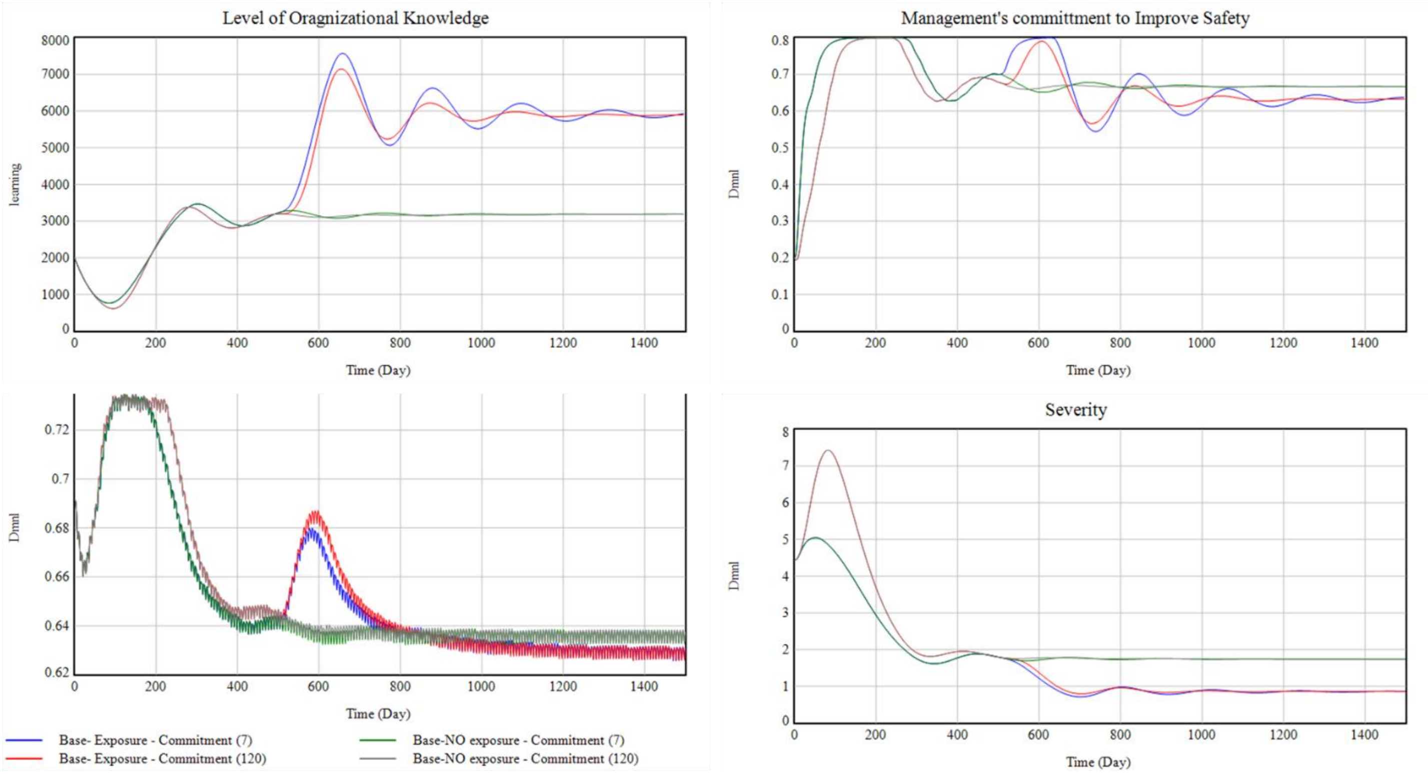


Figure 6-40 Effect of organizational hierarchy

The simulation thus suggests that even after a very high rise in exposure, the management's commitment to safety can actually decrease while the accident severity is also lower, compared to no hazard case. In this regard, the organizational knowledge has played an important role, such that the measures taken to reduce hazard exposure are comprehensive in nature and supported by extensive organizational knowledge. In this case, a particular organization is able to maintain a better safety state, while not having to compromise on production-related activities, as management have spare resources to spend on the process improvement.

Further, the simulation results highlight the differences in response to the external shock for two systems with a different average time to process the trend of an increase in a number of incidents. For a lean system, the management's commitment to safety rises quickly as the external shock is provided, thereby quickly limiting the severity of the incidents. However, the management's commitment to safety shows a rather stable trend for the centralized organization. For lean systems, in this case, the decision making becomes rather short-termed, where a fall in the number of incidents, immediately leads to a drop in management's commitment to safety. In this regard, the effect of the information processing time is similar to the effect of decision making time horizon adopted by the organizations. Where, in general, it is argued that the long-term trends safety trends should be monitored instead of the short-term ones (Cooke and Rohleder, 2006). Going by such logic, the longer the processing time, the better would be for the organization. However, on the other hand, such long-information processing chains are considered to be negatively affecting safety, and faster information processing is deemed necessary for the organizations to efficiently maintain the good safety performance (Hopkins, 2019). Such seemingly contradictory behavior can be explained by understanding the information processing that happens at each of the hierarchical levels of an organization. In reality, not all the information received by one hierarchical level is passed on to the level above for processing. Such a trend is also mimicked through the use of the SMOOTH function for modeling this delay in the SD model. However, often the information which is not passed on may then prove to be important as it might contribute to all improving certain systemic conditions. Hence for safety, long-term monitoring of systemic safety issues will prove to be effective. The current model in this regard is limited, as it does not differentiate in the type of information, and such an improvement should surely be considered as an important extension of the model.

6.11.3 Effect of incentives and perceived benefits of the reporting

Interviews with the JR officials had highlighted several important aspects of the level of incentives affecting the reporting culture in the Japanese HSR TOCs. Pre-privatization, a string punishment, was often associated with apparent human error, and hence a culture of hiding prevailed, where employees would not turn against each other. After the privatization, some of the HSR TOCs had adopted an alternative approach of rewarding safe behavior, so that more and more employees are motivated to report. Further, our interview with JR Kyushu allowed us to collect the data on near-miss reporting, as shown in Figure 6-41. JR Kyushu had started the near-miss collection program in 2006 and set-up an incentive program to promote reporting. The trend is shown in Figure 6-41, also is expected to be affected by an opening of a safety creation hall that opened in 2011.

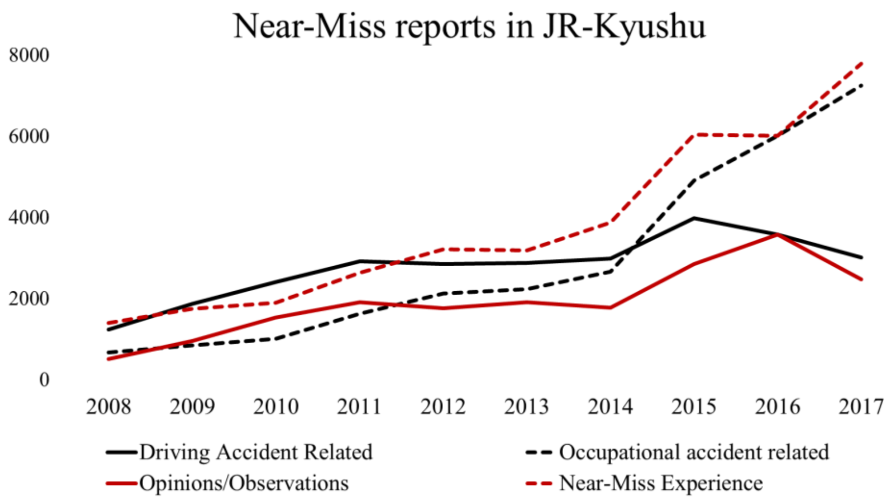


Figure 6-41 Trends in near-miss reporting obtained from JR Kyushu

JR Kyushu classifies the reports as per two different sets of classifications. The first classification relates to Driving Accident Related/ Occupational Accident Related. The second classification relates to Opinions/Observations and Near-miss experience. The total number of reports thus can be obtained by either summing Driving/ occupational-related accidents or Opinions/Experience reports.

6.11.3.1 Discussion on near-miss reporting trends with JR Kyushu

The long-term trend in the type of reports shows that, after an initial steady growth in the number of reports, the trend for reports that are difficult to identify (for employees in JR Kyushu) have become saturated (see performance of driving accident and actual observations in the year 2014, 2015, 2016). As per the JR Kyushu, such a trend is happening because employees report what is easy to perceive for them and report it for the incentives that are the same for each type of report. JR Kyushu expects that there are many more near-misses remaining in the system and that their employees are not able to observe these remaining near-miss observations. Hence, JR Kyushu managers are trying to improve the perception of their employees, so more of these near-misses can be identified by the employees.

6.11.3.2 Modified modeling approach

One of the limitations already identified for the current SD model is its inability to distinguish between various types of reports. In the previous section, a necessity to develop an integrated model that considers the difference between the several types of incidents has been highlighted. The previous discussions have also highlighted that the worker’s perception, the critical contribution of an incident to accidents, and management’s response could be different for each type of report, and hence, an integrated model was deemed important.

In order to improve the above-mentioned limitation of the current SD model, an attempt is made to develop an integrated model, which considers two types of incidents together. Further, the assumption has been taken in order to reduce the complicated model to a simplified causal structure, as shown in Figure 6-42. The revised model considers two types of reports (High Severity (H) and Low

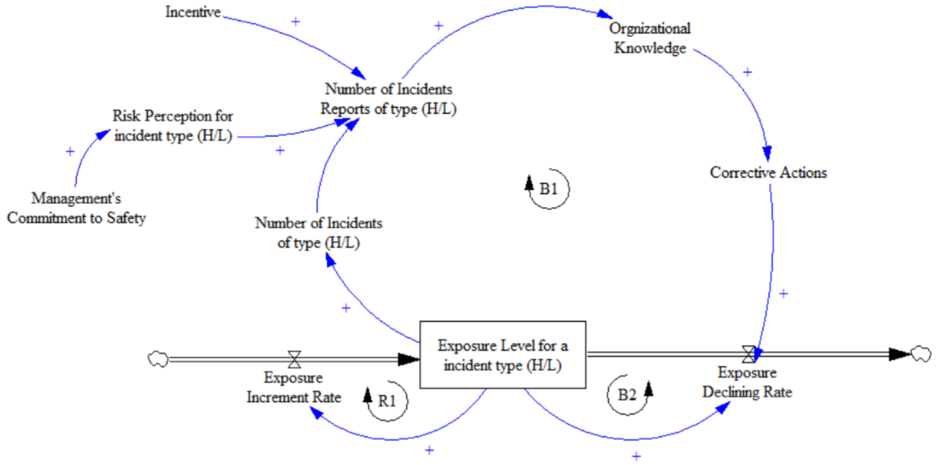


Figure 6-42 A simplified causal structure for the integrated reporting model

Severity (L)). Management's commitment to safety is assumed to be High and constant throughout the model simulations, as emphasized by the JR Kyushu officials during the interviews. Risk-Perception for H type events is also assumed to be constant; as commonly reported in the literature, the employees are willing to report high-severity events irrespective of their level of motivation, etc. Here, the Risk-Perception of employees can be improved through adequate training; however, the detailed modeling is currently omitted. Risk perception is part of the overall utility and intention to report. All other factors contributing to the utility of reporting are assumed to remain the same as of the previous model. Other effects, such as the effect of fatigue, etc. have been considered to be not effective.

The CLD (Figure 6-42) consists of three main feedback-loops. Balancing Loop (B1), captures the effect of safety improvement in an organization. As the level of exposure for a specific type of incident increases, a number of incidents of that type increase. The effect of Risk-perception and the number of incidents then determine the number of incidents being reported of a specific type. These reports then lead to an increase in organizational knowledge, which then leads to the corrective actions being implemented and thereby reducing the exposure level within the organization. This is a balancing loop, implying that any initial increase in a variable, will after some time, lead to a decline in that variable and vice versa. The loop B2, states that an increase in hazard exposure level causes to increase in exposure declining rate, which in turn decreases the hazard exposure level. Such a behavior is also acceptable, as the efficiency of exposure level reduction is dependent on the current level of exposure. Such a loop also explains how difficult it is to completely remove the exposure, as the exposure distributed throughout the organization will be difficult to find, as it's level drops. The loop R1, states that an increase in hazard exposure level causes an increase in exposure increment rate, thus forming a reinforcing loop. Such a behavior is also consistent with the idea that an exposure left unattended, leads to more exposure in an organization. Often, exposure, when left unattended, can affect the organizational processes, which may adapt in response to undetected exposure. These adaptions then make the system even more vulnerable, thus increasing system exposure. Depending upon the value of parameters and the non-linear relationship between the variables, several behaviors can originate from the CLD structure shown in Figure 6-42. For example,

1. When a new incentive program is implemented in an organization, in the most common scenario, the two balancing loops work in-phase with each other and are able to quickly absorb any increase in a number of incident reports. In such a case, the dynamic behavior quickly reaches a steady state without having a sustained increase or decrease in a number of incident reports.

2. However, in the case where the two-balancing loops can be brought out-of-sync, a behavior that is long-term increasing or declining after a period of time can be obtained. (As shown in trends in Figure 1). Such a trend can also happen if there is a delay in the effect of corrective actions to materialize. Such a delay in the corrective actions to take place is not unheard of in the organizations.

6.11.3.3 Results of the simulation

An exact simulation of the trends obtained from JR Kyushu is not possible, as we were unable to obtain full system information during our interviews with JR Kyushu, which would be useful for parameter estimation. Further, the trends in Figure 6-41 show the effects only when the incident reporting system was formally made. However, near-miss reporting practice in JR Kyushu was also present before 2006, and information on such trends was not available to us, to set us the adequate initial boundary conditions could not be sent. Here the results show that the ability of the model to simulate the main behavior discussed in JR Kyushu's case.

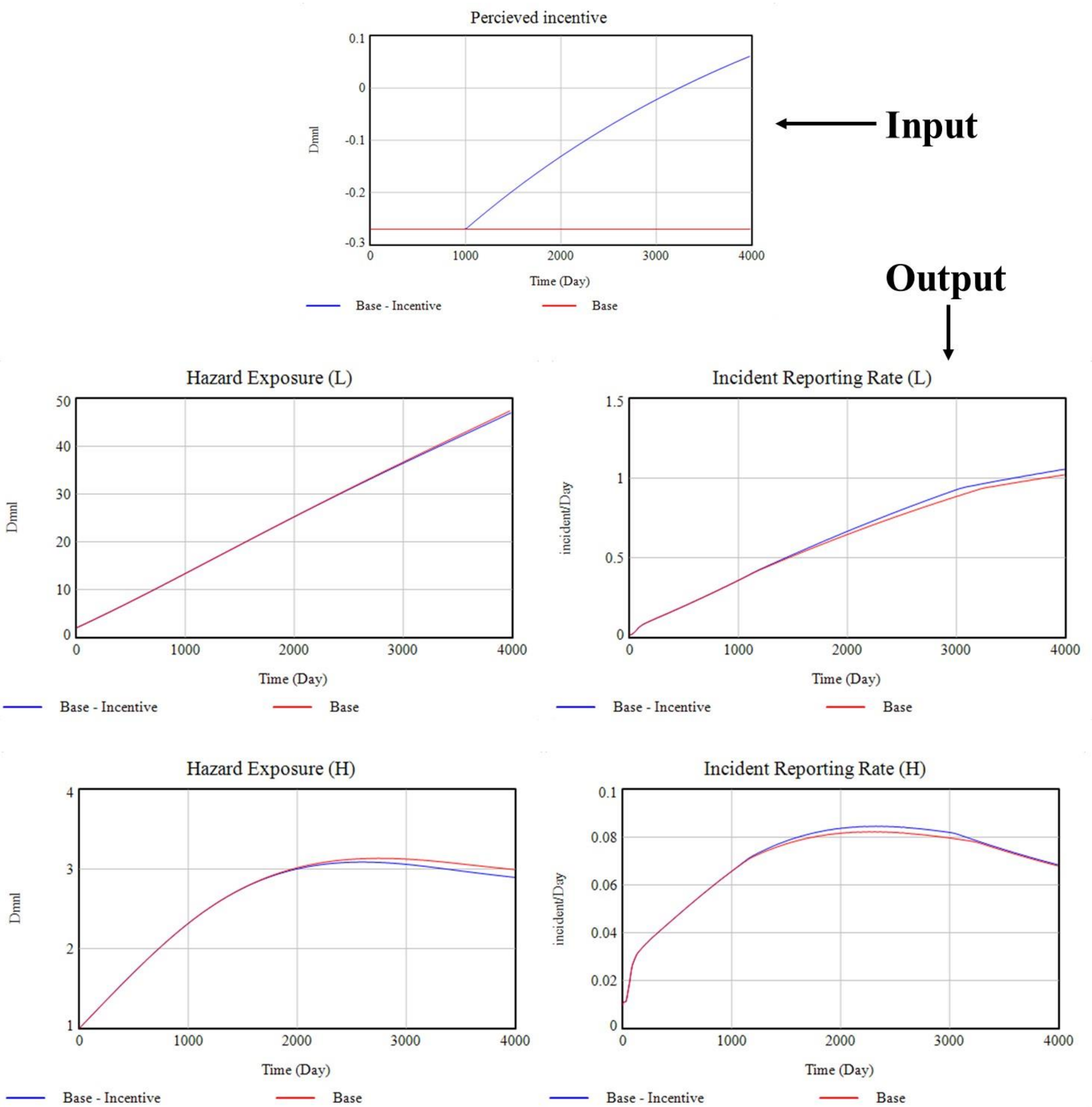


Figure 6-43 Exposure level and Incident Reporting Rate for L and H type incidents under the same incentive

Figure 6-43 shows the behavior of the model in predicting the trends of the two different types of incidents under the same incentive level. The incentive level is increased externally and serves as an input to the model. The output is summarized for the hazard exposure level, and incident reporting rate for two different types of incidents, i.e., H and L. In SD, a comparison against a meaningful is a comparison against the base case. For Low Severity events (L), there is a steady growth in the incident rate, compared to the base case, as long as the incentive is applied. For High Severity Events (H), there is an initial increase in the incident reporting rate; however, soon, the incident reporting rate falls to similar levels as that of the Base Case (Figure 6-43). The behavior is comparable to trends obtained by JR Kyushu, where the High Severity events became less and less reported as the time progressed. The difference in the reporting behavior for two different types of incidents under the same incentive level can thus be obtained by the SD model.

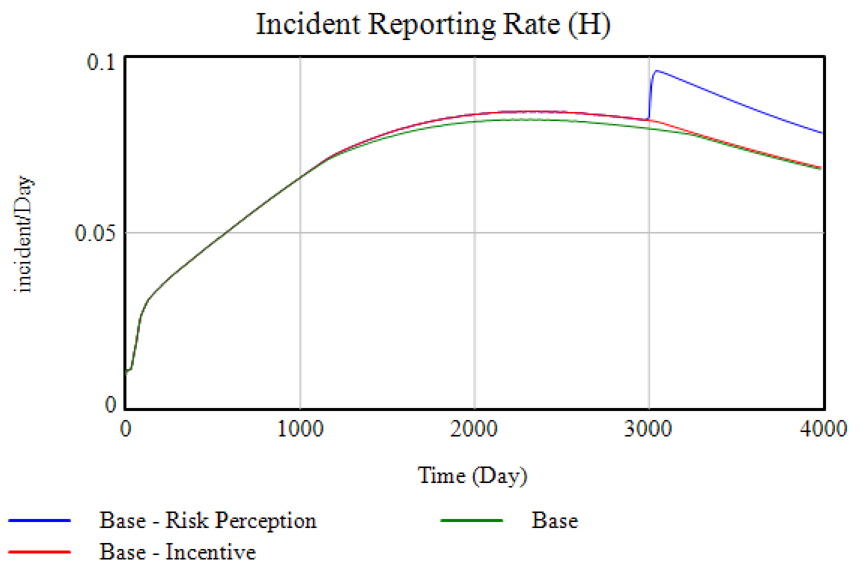


Figure 6-44 Effect of policy to increase the employee's risk perception

The behavior is also consistent, with the understanding of the JR Kyushu officials, who understood that the number of high severity incidents is becoming less, as they are getting difficult for the employees to observe. Which is an alternative way to describe that the number of observable incidents (for a given level of Risk-Perception) is decreasing. Hence, as per JR Kyushu, a further increase in employee training would enable them to identify several severe incidents. A new simulation implementing such a policy shows that (Figure 6-44), while the incident reporting rate may increase for some time, once the new training measures are put into place, the declining trend in reporting may still be irreversible. Whether or not such a trend is visible, is yet to be seen from the JR Kyushu data in 2020.

Table 6-6 provides an overview of the model parameters used in this simulation. The comment section in table 6-6 describes the suitability of the assumed model parameters.

Table 6-6 Model parameters for the integrated model

Parameter	High Severity – Hard to observe	Low Severity – Easy to observe	Comment
Exposure Rate	0.02*"Hazard Exposure (L)"/"Average time for Hazard accumulation (L)" + ***0.001***	0.02*"Hazard Exposure (L)"/"Average time for Hazard accumulation (L)" + ***0.01***	Low severity events are more frequent.
Exposure Mitigation	Corrective Actions *Hazard Exposure /10/Average Time for Hazard Mitigation	Corrective Actions *Hazard Exposure /100/Average Time for Hazard Mitigation	Corrective actions are more effective for the High Severity events
Average time for Exposure Mitigation	**180 days**	**60 days**	Mitigation of high Severity incidents takes a long time on average.

In conclusion, the SD model can simulate the differences in trends for different types of incidents under the same incentive structure. The model explanation is consistent with the practitioner's understanding of the trends in near-miss reporting. Further, studies are necessary to estimate the parameters and replicate the trends shown in Figure 1. Further, the reproducibility of the analysis can be explored using sensitivity analysis of the results; however, such an exercise is omitted here, as the choice of parametric variation has an uncertainty associated with it because such detailed information was not available from JR Kyushu. However, the SD model is successful in demonstrating the main behavior obtained in the JR Kyushu study.

However, the current SD model also has one important limitation in fully explaining the process of cultural change in an organization. As the interviews with JR Central official revealed, that it took many years for the top-management of the newly privatized HSR TOC to change the organizational culture through the use of incentives, where the reporting near-misses became acceptable, from being an act of punishment. The trends of the near-miss-reporting obtained from the JR Kyushu (as shown in chapter 3), also suggest that steady growth in near-miss reporting was achieved only after a few years. However, not all organizations are able to emulate the similar success of cultural changes (Hopkins, 2019). Such differences in the cultural change trajectories of various organizations aren't fully modeled as per the current SD model. The SD model on the reporting culture will then have to be integrated as part of the larger safety culture related dynamics. Numerous other trade-offs will have to be dealt with, for example, several studies have identified that factors such as the work-load, incentives, etc. all affect the reporting behavior of the "near-misses," but for incidents with tangible outcomes, employees are willing to report even when the conditions that generally support near-miss reports are not favorable (Halbesleben *et al.*, 2008; Williamsen, 2013). Hence, the same SD model should be extended to consider variations in the type of reports as per their severity. Further, the incidents with tangible outcomes will have certain implications on the production loss, thus affecting the dynamics of production pressure and the management's commitment to safety. Hence, a model dealing with the different types of reports will be able to better simulate the near-miss reporting behavior of the organizations, which invariantly is affected by the impacts from the other serious accidents. Such a model will then be better suitable to trace the trajectories of the different organizations on how they improve near-miss reporting by their employees.

6.12. Practitioner's Feedback

As a general good practice, research for social systems should be carried out in close cooperation with the practitioners as most likely; they are the end-users of the research. In this regard, the results obtained from several policy analyses shown in this study were shared with practitioners from respective fields so as to gather their understanding of the modeling approach, the trust in results, and obtain comments or scope of improvements. Once again, qualitative interviews were carried out to discuss the results at length; the summarized discussions are reported as follows.

6.12.1 Construction Industry

The results obtained from the analysis were shared with the HSE expert from the same construction site where the current study was implemented. The interview was used as an opportunity to re-discuss the key assumptions of the study, share the results of the analysis, get an expert's understanding of the results obtained from the analysis as well as discuss future possible improvements for the model.

The interview with HSE experts in the construction industry was instrumental in re-affirming the assumptions of the study, such as the effect of fatigue hampering the reporting behavior, etc. The step-by-step introduction of the whole SD methodology was also seen as welcoming from the experts. Further, the results of behavior prediction tests were confirmed to be satisfactory, such that indeed severity of the incident follows a similar path as rightly stimulated by the SD model.

The discussion had also focused on discussing the results of each of the three policy simulations conducted in this study, i.e., the effect of frequency of the tool-box meeting, the effect of limiting the burnout cycle, and the effect of burnout cycle. Our simulation had concluded that a half-an-hour toolbox meeting once a week is considered to be ideal for the worker's safety perception. The response from the HSE expert suggested that it is indeed a standard practice of the site, and it is a standard practice widely adopted in the construction industry across the world based. While the frequency of the toolbox meeting will certainly have an economic rationale, the simulation conducted in this study is also able to replicate the results from standard practice and provide a dynamic explanation of the tool-box meeting and its effect on safety perception of the workers.

The discussions on the simulation for limiting the effect of burnout cycles and the effect of interpersonal bonding was also discussed in detail. The HSE expert had supported the two of the several main ideas regarding these simulations; however, for remaining, the HSE expert was not able to immediately provide a comment. Firstly, even in the HSE expert's views, the effect of a policy to reduce the number of working hours is not uniform across the different organizations adopting these practices, thus providing certain supporting evidence for the simulation results shown in Figure 6-34. Nevertheless, more conclusive evidence supporting the analysis could easily be obtained from the reported similar experiences. However, the HSE expert did not have any personal experience to recall the effects of such policies. Similarly, the HSE expert had acknowledged the trade-off of the interpersonal bonding highlighted in the simulation. Indeed, the worker's interpersonal bonding plays an important role in improving their safe behavior; at the same time, it creates challenges in improving their reporting behavior. To overcome such challenges, several efforts are taken to improve the reporting behavior at the study-site. First of all, near-miss reporting is never used as a tool to punish any of the persons involved; rather, there are several awards created around reporting near-miss behaviors. Such positive sentiment associated with near-miss reporting, then destigmatize the reporting behavior, and even workers are not able to exploit the reporting as a tool to use revenge against members of other teams, etc. (Oswald, Sherratt and Smith, 2018). Thus, the success of the safety program at the designated site was largely attributed to being able to manage the trade-off by improving the worker's sense of belonging and thus improving their safety performance, as well as providing enough incentive so as to promote healthy reporting of safety issues. However, the HSE expert could not provide instances of different organizational behaviors, as depicted in Figure 6-36.

The discussions were also useful in highlighting several improvements in the model, and one of the factors is related to the complexity of the construction industry. At any construction site, there are multiple contractors working simultaneously, each of them having their own safety management related practices. Further, there are several practices that are enforced by the clients. Hence, as a result, at a given site, multiple types of safety management system co-exists. Each of these systems has its own reporting standards and formats etc. Such a situation often proves to be overwhelming not only for the workers at the site but also for the various HSE managers and the staff. Hence, a necessity to simplify and standardize the safety management practices at the construction site was identified. In the current study, the effects of the presence of multiple safety management systems are not considered in detail, as in principle, at the study site, safety management practices were made uniform by the lead contractor. However, more microscopic studies illustrating such effects should be carried out in future research.

Another important issue that was identified as related to the issue of the responsibilities of the HSE department. As per the experience of the HSE professionals interviewed in this study, a few years ago, his responsibility had primarily focused on safety and health aspects. However, over the years, additional responsibilities are introduced for HSE professionals. For example, the Environment is one of the responsibilities. Further, recently another "S" standing for sustainability has been added to their responsibilities. With such a trend, the HSE department is also overwhelmed with the work, and the analysis of safety-related reports gets marginalized. When the reports are not effectively utilized by the organizations, safety may worsen; at the same time, further reporting may also worsen. Hence, as an improvement to the model, such constraints faced by the HSE department could be included.

Overall, the SD methodology and several of the key ideas discussed in the SD model were very well received by the HSE experts, as reflected in their comments as follows.

"*This thesis provides the mechanisms and foundation for achieving our Vision. Our company has to approach constantly re-evaluating as we move through the different work fronts opening up. This thesis should assist our projects in reaching the highest levels of performance in coaching and advising our project staff at all levels [as] is seen as key for our project success. It is strongly recommended that [our company] immediately initiates a Cultural fact-finding study with this thesis found to assess the full context of Cultural behaviors that might positively or negatively influence a high performing safety* *culture. Then use the information gained to provide Cross-Cultural Learning to be an effective & successful Intercultural Company."*

Such an encouraging response from practitioners is encouraging that the SD method can be successfully deployed for future studies and can help practical organizational policy tools.

6.12.2 HSR Experts

For this study, an in-depth discussion was conducted with the 4 researchers from the Huma-Factor laboratory at the public railway research body of Japan, i.e., Railway Technical Research Institute (RTRI). A number of previous studies from RTRI have also focused on improving the reporting behavior of employees in the Japanese railway company. A brief overview of their activities is presented in Chapter 1, and a few selected academic studies are referred here (MIYACHI, 2008). A number of previous studies conducted at RTRI as well had conducted a survey-based study to identify factors that affect the near-miss reporting behavior of the railway drivers in Japan, particularly focusing on violations of the rule. Theirs and the previous studies had highlighted the importance of several factors affecting the reporting behavior of employees. Among this public self-consciousness of the employees arising due to social obligation of their work, private self-consciousness, emphatic concerns, and perspective-taking such as consideration of the impact of reporting on their colleagues from other departments, etc. were found to be important and critical. However, only a handful of these factors were statistically significant in explaining the reporting behavior, and the studies have thus emphasized the limitations of the statistical methods in understanding the reporting behavior. Further, the researchers had highlighted the limitations in accessing the true employee perception, as full-scale surveys were often denied due to the sensitivity of the safety aspects in the Japanese Railway.

Then the discussions had focused on introducing the system dynamics methodology, the results of the qualitative studies conducted as part of the current studies, the developed system dynamic model, and the steps undertaken to test the model using various behavior prediction tests. Key assumptions and limitations of the study were either highlighted upfront by the presenter or were discussed during the interactive discussions. Comments were then invited on the relevance of the methodology in the context of the Japanese Railway, reliability of the results obtained from the study, and the possible improvements.

Overall the response from the RTRI researchers was very supportive of the idea of using the SD modeling method. In their approach, RTRI researchers had been primarily focused on identifying individual factors affecting the behavior of the individuals but rarely examined the organizational factors affecting the reporting behavior, and hence they appreciated the focus of the model for highlighting the management's perspective. A number of factors identified in the model were also confirmed to be important as per their understanding and their previous researches. For example, factors such as the net perceived benefit of incentives in an organization in the SD model are closely related to the factors such as the public self-consciousness of the employees, private self-consciousness, and various emphatic concerns. The RTRI researchers also acknowledged the importance of the management's decisions in improving the reporting behavior of the employees in an organization. In their experiences, often, there exist gaps between the claimed efficiency of the management's actions such as the training and safety awareness campaigns, and their real implementation, which affect the overall reporting behavior of the employees. However, even their previous attempts have been limited in identifying such gaps as they faced limitations in accessing the employee's perspectives in such issues because of the sensitivities involved. This is also an important limitation for the current study, as several of the causal relationship described in the SD model should be carefully examined in the Japanese HSR TOCs context.

A detailed discussion of the key assumptions involved in analyzing the data obtained from the construction industry was also made. Given the limitation of available information, RTRI researchers supported the idea of utilizing Good Observations as an important source of analyzing trends. In their experiences, many railway companies in Japan are now promoting good observation behavior as a way to promote a habit of reporting among the employees. During the discussions, the importance of distinguishing between the type of reports also received attention. Even in the Japanese Railway company experiences, the reporting perception for near-misses, rule violations, or the incidents differs, depending upon the net incentives and the perceived benefits of reporting each event. The fear of more investigation upon reporting was also confirmed to be important. The issue of worker's fatigue affecting the reporting behavior was also supported by the researchers at RTRI, and they were quick to point out the interesting aspects of the simulation results obtained in Figure 6-38. The discussion had also focused on the change in culture as witnessed after the privatization in the Japanese railway and had agreed on the role of top-management in steering such cultures. At the same time, they acknowledged that the management's practice is not uniform across JR, and there have been significant time differences between various JRs adopting taking similar management initiatives. However, the reason why such differences remain was not clear even for RTRI researchers.

While in general, the researchers agreed on the relevance of the SD model in its current form, the discussions were also useful in identifying several potential improvements. For the generalizability of the model, certain industrial characteristics will have to be taken into consideration. As per the RTRI researchers, the employees in other industries such as aviation and medical, are more specialized in their work than the employees in railway companies. In Railway company, the front-end employees have to often rely on the higher authority to take necessary actions while in highly specialized job roles; often, the employees are expected to take actions by themselves. Under such varied roles, it can be expected that the workers are more likely to tackle the problems on their own and focus less on reporting. Hence, as a general extension of the model, it should be tested with respect to other systems as well. In this regard, it is expected that the model will be able to manage the highlighted complexities, as it is relying on reporting behavior in several complex organizations to build the generic model structure. However, more system specific validation is thought to be necessary.

6.13. Summary

Near-misses are considered an important source for learning and improving safety for accident-prone complex systems. Over the years, several types of research have taken issues and have identified several contributing factors. While a number of researches had focused on the specific elements promoting or acting as a barrier to the near-miss reporting. Several others have argued the behavior as an emerging property out of the organizational structure and its processes, in that the idea of centralized structures creating a better reporting behavior has been argued. The importance of near-miss reporting has also been understood by Japanese HSR operators. However, several Japanese HSR TOCs, despite having a fairly centralized structure, still face the issue of improving their reporting culture, and hence a necessity for an approach that could deal with the complex interactions among the several aspects affecting the reporting behavior within an organization was realized. The literature has also expressed the inability of a purely statistical approach or a cross-sectional study to identify the nuances of the employee's reporting behavior. To overcome the limitations described above, the current study developed a novel SD model explaining the near miss reporting behavior of employees in an organization.

In this study SD model representing the dynamics of people, structure, and the management policy within an organization is developed to identify factors and their impact upon the quality of the *Feedback*. The SD model development involves three main steps – a.) development of the causal structure, b.) validation of the model structure, parameter estimation, and behavior validation, and c.) Simulation and policy analysis. While model development and validation, is suitable in identifying the relevant factors, the simulation and policy analysis are suitable to assess their impact on reporting behavior. Cross-industry literature was first reviewed to develop a dynamic hypothesis explaining employee's near-miss reporting behavior. The dynamic hypothesis was then validated within the Japanese HSR context through semi-structured interviews involving senior experts from two different HSR operators in Japan using a disconfirmation approach. The key factors affecting the reporting behavior are workload and fatigue level of employees, incentive structure, and management's commitment to safety in providing feedback to reported incidents. An executable simulation model using the causal factors was then developed and was calibrated using 3 months of daily safety observation data for a construction company. The same causal structure was also validated through the simulation, revealing a level of generalizability for the proposed model. The simulation results developed resembled the trends observed in the data obtained from the construction company on a total of 5 aspects. Simulations were then carried out for testing several policies revealing the path-dependent nature of the results obtained from a policy to reduce the number of working hours, as well as variation in the effect of similar incentives on different types of incident reports, reports in an HSR operator. The numerically executable SD model thus provides an important policy analysis tool to analyze the organizational factors affecting the quality of the near-miss reports in an organization and are shown to be having implications for the Japanese HSR TOCs. The main conclusions from the study are summarized as below.

6.14. Main Conclusion

C6.1- The SD model developed in this study allows simulating the organizational policy scenarios affecting the reporting behavior of employees in a complex socio-technical system. The SD model developed in this study has been grounded in previous academic literature modeling the organizational culture using SD; however, it is novel in its acute focus on the reporting of near-misses, which are often ignored within an organization as they do not have immediate consequences attached to them. Further, only a few studies have comprehensively examined the near-miss behavior under the purview of the organizational factors, and the use of the SD approach to make the simulation model is a novel academic endeavor. ***(Section 6.10, 6.11, O3, R4)***

C6.2- Commonly reported factors affecting near-miss reporting behavior are the effect of work-load fatigue, incentives, and their perceived benefits, the habit of reporting, risk-perception, feedback from the management, and the management's commitment to safety. These factors were identified based on the literature review and expert interviews. ***(Section 6.8.3, Section 6.9.3, O3, R4).***

C6.3- Further, the SD model emphasize that for adequately understanding the trends of any particular indicator, the underlying interactions among the factors affecting the specific indicator must be understood. For example, if the number of the incident reported is an indicator, its trend must be understood in conjunction with the Risk Perception of the Employees as well as the safety improvement implemented by the organization. Without the proper monitoring of the two, it is almost impossible to assess whether an increase in a number of reported incidents is happening because of improvement in the risk perception of the employees or the poor safety improvements by the organization. ***(Section 6.5.8, O3, R4)***

C6.4- In addition, the SD model is **useful in demonstrating that because of the non-linear dynamic relationships, outcomes of the organizational policy in a specific context, are often path-dependent and requires periodic adjustment for a desired response**. Depending upon the state of the variable, the same input of policy may have a different outcome. For example, a policy to reduce the number of working hours by a fixed duration is shown to have a different effect on the level of perceived accomplishment, depending upon the state of the functions. In some cases, the policy may have no effect at all; in others, it may affect negatively the short-term but may create benefits in the long-term ***(Section 6.10.2, Section 6.11.1, O3, R4)***. The **results from the simulation also help gather support in the importance of organizational incentives and their effect on reporting behavior. However, the incentive structure itself can affect different types of reports diffidently and hence, should be adequately adjusted periodically**. ***(Section 6.11.3, O3, R4)***

In addition, several important limitations of the current model could also be identified. At present, the SD model treats all the incidents in a similar manner; and partially it considers variation in hazard exposure level for different types of incidents, however, a necessity to further differentiate between the incidents based on severity, such as near-misses with no-loss and events with the loss associated with them, was identified. Such a differentiation would then allow for a better prediction of reporting trajectories for the near-misses with no-loss associated with an event and for the incidents with the loss associated with them. Hence, an SD model that can integrate the employee reporting behavior for several types of events is considered as the scope for future studies.

Chapter 7. Discussions and Implications

This chapter focuses on several related discussions on the results obtained, as well as on the implications of these results. The discussions are as follows.

7.1. Summary of Conclusions

The summary of the research questions, the study objectives, and the main conclusions are summarized in Table 7-1. Based on these conclusions, several relevant discussions and implications are derived in subsequent sections of this chapter.

Table 7-1 Summary of the conclusions of the study

Research Questions *Q1. How do the organizational (Risk-Management, Reporting Behavior) and institutional level (Risk-Management) risks affect Shinkansen Safety? and* *Q2. How can Shinkansen Safety be improved?*			
Research Objectives *O1. Clarify challenges in the current safety management practices (Risk-management) at Organizational and Institutional levels in Japanese Shinkansen and identify strategies to improve the practices.* *O2. Develop methods necessary for implementing pro-active risk-management strategies at the organizational and institutional levels.* *O3. Clarify the factors affecting reporting behavior at the organizational level in Japanese Shinkansen.*			
Summary of main conclusions			
#	**Q**	**O**	**Conclusion**
1	Q1	O1	RM related issues are among the most prominent issues in past HSR accidents, while the current focus of the practitioners is on technical and human-error-related factors.
2	Q1	O1	RM practices in Japan at the organizational and institutional levels are comprehensive. However, the underlying tools and the understanding of the accident is old and not suitable to be applied for complex systems. Due to increased complexity in Japanese HSR, the system is more prone to systemic accidents in which multiple safety-defenses can be rendered ineffective by a few systemic factors. Such accidents cannot be analyzed by the current Japanese RM practices and need accident models such as STAMP. STAMP analysis is useful in identifying lessons that are often missed by the comprehensive accident analysis reports.
3	Q1	O1	The study identified a safety archetype describing the vulnerability of the operator-regulator relationship in providing adequate safety control. The archetype is also useful in identifying potential solutions to overcome the vulnerability, such as the to have an independent risk assessment for the regulator and the organization being regulated, and to develop leading-indicators at the organizational level, that can enable time-bound risk-assessment of the system.
4	Q2	O2	The proposed generalized leading indicator operationalization method is shown to be grounded in several theoretical and practical safety-related aspects, is found to be effective in identifying leading indicators that are more comprehensive than the

			indicators currently being monitored for two complex systems, i.e., Johkasou and for HSR.
5	Q1, Q2	O2	The proposed indicator operationalization scheme received a mixed response in the real-world verification. In reality, there are several contextual factors and trade-offs that affect the desired level of system monitoring and are not currently captured by the proposed method of leading indicators. These trade-offs include the capacity constraints for the regulator and the balance between control and operator's autonomy.
6	Q1, Q2	O3	The SD model developed in this study allows simulating the organizational policy scenarios affecting the reporting behavior of employees in a complex socio-technical system and thus can be used to improve the safety.
7	Q1	O3	Commonly reported factors affecting near-miss reporting behavior are the effect of work-load fatigue, incentives, and their perceived benefits, the habit of reporting, risk-perception, feedback from the management, and the management's commitment to safety. Our model showcases that the effect of a reduction in a working hour is path-dependent, and often in the short-term, the behavior could point out that the policy of reducing the work hours is not working. The results from the simulation also help gather support in the importance of organizational incentives and their effect on reporting behavior.

7.2.Safety vs. Other functional responsibilities of the HSR TOCs

Safety is an important functional requirement of railway operations; however, it is not the only requirement from the railway operations. In addition to being safe, railways are expected to perform their operations with high service reliability in a punctual manner. Further, in the age of information communication and technology, newer and newer services are expected from the railway in that the railways should be comfortable, frequent, etc. While the demands from the passengers are multi-fold, their willingness to pay for these functional requirements is only limited. Hence, often the numerous functional requirements from the railway business along with the expected profitability out of business may often lead to a conflicting situation. Even if these requirements are not in direct conflict from the resource sharing perspective, the systems designed to handle each of the functional requirements can interfere with each other and creating conflicts. The focus of the discussions in this section is to highlight how do the Japanese HSR operators ensure that the various functional requirements are not in conflict with each other, and thus, neither of the requirements is compromised.

In principle, safety is the highest priority area for Japanese HSR TOCs. A review of the safety policy documents from several JR companies, as well as the interviews with the top executives taken during the course of this study, all reiterate the principles of assigning the highest priority to safety. There are several real-world examples that also provide support for the said objectives of JRs. For example, a number of recent new technologies in railways are not primarily designed for safety improvement but could be useful for another functional improvement, nevertheless in the development of such a system; safety-related implications are carefully examined and accommodated during the product design stage (Sugai *et al.*, 2016). Further, often, efforts undertaken for one functional requirement prove to be complementary to the fulfillment of other requirements. For example, (Bugalia, Maemura, and Ozawa, 2019a) have discussed the efforts made by the HSR operators in Japan to improve the delay-performance of their operations. In their analysis, (Bugalia, Maemura, and Ozawa, 2019a) have highlighted the role of technical improvements such as adequate asset maintenance, constant system monitoring for external threats, human resource development, and integrated decision making across the organizations to improve the delay performance of the trains. The same factors are also shown to be effective for managing safety, as demonstrated in this thesis.

The perspective on whether the various functional requirements are in conflict with each other is also a matter of timescale. For example, in Japanese HSR, in the event of heavy rainfall in a certain area, the speed of the train is reduced to achieve the operational safety. Such speed restrictions, in short-term, may induce delays in preceding trains, but such a solution is thought as optimal as in case of an incident due to unsafe operations, the service delays and cancellations will much higher. Japanese HSR TOCs have made further efforts to minimize the impact of such external factors on the railway operations through the use of technology. Such is the level of system improvement, that often in many snow-ridden areas of Japan, the HSR technology is able to function without any speed restrictions whatsoever. Hence, here both the objectives of safety and punctuality could be simultaneously achieved.

However, technical systems are often not designed to function standalone, and they work with human controllers who operate the technology as per certain procedures, etc. While the technical design can be such that it can satisfy multiple functional requirements simultaneously, various operating procedures could be of the nature that they create conflict. For example, in the Kagoshima Mainline accident in February 2002, the operating procedure was such that the drivers could cross the red signal after a pre-designated time. Such a rule was clearly a violation of the fundamental safety constraint necessary for railway operations. Nevertheless, such a rule was put in place to compensate for delays and create additional capacity for trains. Here the priority was given to the on-time performance, although not with complete disregard for the safety, leading to accidents. Numerous such possibilities could exist in any railway system, where the shortcomings of technology are compensated by the appropriate human behavior, and conflicts in these procedures guided human behavior could lead to safety issues. For example, in Japanese HSR, the ATC system thought extremely important for applying brakes, does not function for speeds below 30 kmph. The operators have to manually apply brakes for such speeds, and the errors here could have detrimental effects on both the safety and punctuality performance of the overall system.

On the other hand, the issue of financial resource allocation to various functional requirements of the railway also warrants attention. In Japan, the HSR TOCs are privatized and often enjoy a variety of autonomies provided to them to sustain their railway business as much as possible. In this regard, a number of private TOCs have been able to achieve commercial success in their businesses, and by constantly re-investing in their business, they have been able to achieve a high level of safety and other functional performances. On the other hand, some railway companies are not able to sustain their businesses due to numerous factors, and in turn, achieve poor functional performances as the system starts dilapidating in the absence of investments. Hence a uniform level of regulatory arrangement aimed at reducing the regulator’s involvement would cater well to the positively performing TOCs but is ill-suited to capture the poor performance of the dilapidating TOCs.

The system-thinking based RM strategy (such as using STAMP) is shown to be effective in carefully analyzing the complete interactions between organizational and institutional factors with the physical and the human sub-systems. Thus, by adopting such a methodology, the decisions taken to achieve functional requirements other than safety could also be analyzed for their safety-related implications, such that the system-evolution necessary for achieving the other functional requirements of the system does not negatively affect the safety.

In summary, there is no single answer to the question of whether in the Japanese railway industry safety and other functional requirements are complementary or in contradiction with each other. An important implication of the research is thus following :

I.1- System-specific contexts determine the overall emerging behavior, and hence organizational and regulatory level decisions should utilize the system-thinking based RM approach to design solutions in such a way that they can manage system-specific variations to keep a healthy balance in the simultaneous achievement of multiple functions. (O1, Q2)

7.3. Organizational factors and implications for improving reporting culture in HSR TOCs

A major focus of the current study has been to highlight the organizational factors that could affect the near miss reporting behavior of employees in an HSR TOC. From the interviews with JR Kyushu and JR Central and the simulation of the SD model, the importance of organizational incentives for promoting reporting behavior has been highlighted. The discussions presented in this study is on the generalizability of the results to other systems. In this regard, an important question must also be addressed whether the lessons identified from this study can be applied to each of those HSR TOCs.

However, it is a difficult question to address. While all HSR TOCs in Japan share a common parent company called JNR, there are many similarities in their organizational process and structure, and hence many aspects of the organizational culture will also be similar. These similarities are also evident from the summary of various safety promotion activities across JR, as summarized in Chapter 3. For example, all HSR TOCs in Japan, acutely focus on continuous human resource development in their respective organizations, and many of the HSR operators have similar training practices. Further, the safety policy statements and expected role of top managers in them also share certain similarities. Considering these similarities, one could generalize the lessons from this study to other HSR TOCs.

Nonetheless, dissimilarities between various HSR TOCs are also expected. All HSR TOCs have been independently running their organizations for more than 30 years, and hence a number of different practices adopted post-privatization will have its own effect on the organizational culture aspects. Indeed, in this thesis, numerous accounts point to the possibility that the organizational culture varies from TOC to TOC. For example, the summary obtained in chapter 3 has been based on the review of official documents present for an organization; however, even the researchers in RTRI have faced the issue of reality being different from what being portrayed in official company documents. Nonetheless, such information is difficult to bring to notice, and to the best of the knowledge, no such academic study has been conducted for providing an inter-organizational comparison on culture, and rightly so due to inherent difficulties in obtaining information on the sensitive topics of safety management.

One rather rare example of highlighting the cultural differences between various JRs has been provided by the official accident report for the only "Serious accident" in the history of Japanese HSR. The accident-related to crack in the bogey frame occurred on the Sanyo Shinkansen line of JR West. The train here originates from the Hakata station and runs on the tracks of Sanyo Shinkansen to Osaka. From Osaka onwards, the same train is driven by the crews of JR Central on the tracks of the Tokaido Shinkansen without changing the train. In this incident, the crew of the JR West had difficulty in making a judgment to stop the train and take it for inspection once the crew had observed the abnormal noise, odor, and vibrations. In this regard, the official accident report conducted a survey to examine the response of the two JRs over their responses to the issue of abnormal noise (Figure 7-1) (Japan Transport Safety Board, 2019).

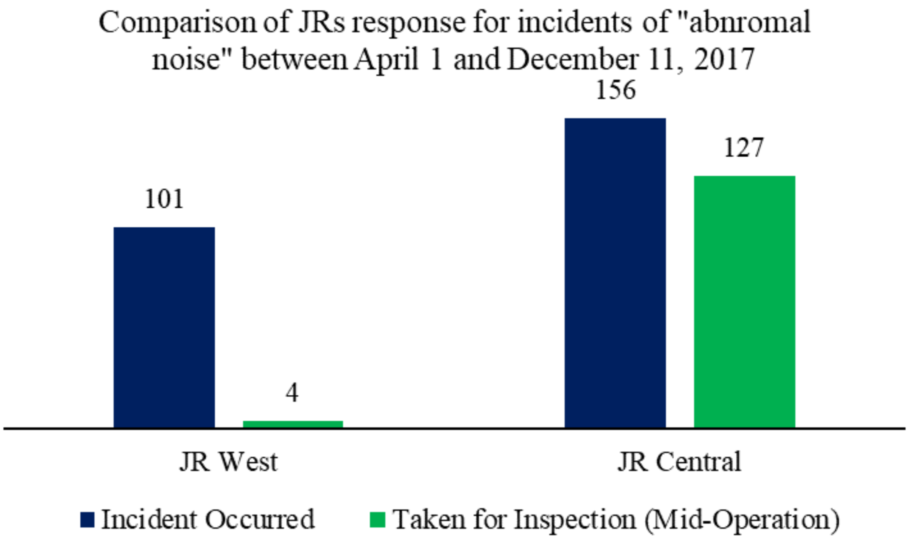


Figure 7-1 Comparison of JRs responses to abnormal noise

While the purpose of Figure 7-1 is not to present a one on one comparison, as each incident of the abnormal noise was of different severity; nonetheless, the official reports pointed out that it had become a norm for the JR West to not stop the train and check for abnormalities, thus suggesting the presence of certain underlying organizational factors responsible for the employees behavior.

Here, the SD model developed in this study could partly help provide a recommendation to further improve the reporting or the organizational culture for HSR TOCs in Japan.

For the context of Japanese HSR, the effect of organizational incentives, and the employees' net perceived benefits of such incentives had been identified to be one of the prominent factors. In several Japanese HSR operators, the importance of incentives in improving the reporting behavior of the organizations are well recognized and correspondingly several HSR TOCs have introduced award systems of various degree for employees taking safety incentives including the near-miss reporting. Although great variations exist in the introduction time for these incentives in the respective HSR TOCs. For example, immediately after the privatization, JR central had started to change its management practice. JR Kyushu is among the pioneer HSR group to having started a formal near-miss reporting channel in their organizations. JR Kyushu was followed by JR East in the suit.

In contrast, JR West, still haven't launched any incentive programs for promoting near-miss reporting. The SD simulations are shown in this study also suitably highlight the importance of putting incentives for improving the reporting behavior. However, not having an incentive mechanism in place is not sufficiently evident to conclude that the culture of JR West is different from that of the other JRs if at all cultures can be measured at all. As per the clarification sought for one of the senior JR West employees (over the e-mail), the importance of the organizational factors in improving the reporting attitudes on safety is well-understood even by JR West, as discussed in the quotation below-

"we [JR West] believe that it is important to create an environment and atmosphere that helps employees report on safety."

The specific practices for JR West to create a positive safety environment are different compared to the other JRs as highlighted as follows.

"*As a result of reviewing the past punishment of human errors, JR West made a decision not to deal with them as the scope of punishment or negative personnel evaluation; "Human error nonpunishment policy." [In that] Interview method in the case of events were improved as follows;*

- *Interviewer training which makes examinee's statement easier*
- *Publishing instruction manual which provides tips of interview*
- *Interview based on facts recorded in onboard video recorder, which helps examinee remember*
- *Subordinate companies of the railway industry also apply the same concept above.*
- *This reporting practice is not motivated by awards [and is] different from other companies.*

However, these different practices (mentioned-above) also are apparently working, as stated in the response from the JR West expert, as shown below –

"As a result, the number of reports on "events unknown to the company unless employees reported" has been increasing. Establishment of proper environment and atmosphere for making the report easy are meaningful."

Despite the fact the JR West's unique approach for improving the near-miss reporting is apparently effective, the importance of the organizational factors as stressed in the current study has important implications for further improving the reporting behavior at JR West. JR West's current practices seem to be focused on improving the quality of the information obtained during a formal discussion session between the managers and the employees. As previously highlighted, many JR Companies have such an organizational practice, where periodic meetings between the staff and the management are utilized to share the near-miss experiences faced by the employees. Such a practice is qualifying as an involuntary safety reporting enabled through a formalized process, as opposed to a voluntary reporting, where employees can report whenever they observe a safety issue. In all other JRs, such a voluntary reporting channel has been established, and the organizational incentive has been proven to be effective for promoting such voluntary reporting among employees. Hence, the lessons derived from this study could still be helpful for JR West to further improve the efficiency of its reporting programs. Even the JR West expert agree that the consideration of such organizational factors in their strategy has been rather limited, as reflected in the comments below –

"On the other hand, in my own opinion, our effort of improvement of practice in case of human errors is on the progress from the psychological perspective."

An important implication from the research thus can be summarized as follows :

I.2 - Lessons from the study here focusing on organizational factors, such as the effect of fatigue and the incentive to reporting, and their impact on near-miss reporting is surely important and could play an important role in improving the reporting culture, and thus safety, of HSR TOCs in Japan, such as JR West (O1, Q2)

7.4. Practical Implications for Risk-Management in Japanese HSR TOCs

Results from the various types of accident analyses presented in this have important academic and practical contributions to make. The thesis has utilized the previously unutilized accident reports for Japanese HSR in conjunction with the methodology from state-of-the-art safety theory to reveal new findings. Some of the potential implications are then discussed here.

I.3 - The results from ACAT analysis provide immediate food for thought for the Japanese HSR practitioners. A natural extension of the current study will be to obtain ACAT trends by analyzing the events of near-misses, etc., to further develop a thorough understanding of the risk factors in Japanese HSR. Unlike the common understanding from practitioners, the majority of accident causal factors in Japanese HSR are not related to the technical failures or human errors but point to the various organizational and institutional factors. Even the limited number of accidents, provide certain valuable trends that are often missed in an individual accident, for example, Japanese HSR TOCs do face issues in developing new information based on adequate risk-management principles as well as sensing the degradation in the current practices from that of approved ones. The trends from ACAT are obtained by taking adequate measures for ensuring the reliability of the analysis and are valid as far as the authentic, publicly available information for accidents in HSR is considered. A natural extension of the current study will be to obtain ACAT trends by analyzing the events of near-misses etc., to further develop a thorough understanding of the risk factors in Japanese HSR; however, obtaining such information would likely be very difficult, as HSR TOCs in Japan do not disclose the reports in public domain.

Nevertheless, the results of the ACAT analysis are limited to knowledge already presented in the official accident reports. Hence to further analyze the underlying organizational and institutional factors, more information from other authentic sources is used and combined using the state-of-the-art accident model called STAMP. The comprehensive STAMP analysis reveals several new areas to explore, which have not been explored even in the official accident reports. Further, the systematic analysis ensured by the STAMP has led to the development of a new accident archetype at the organizational and institutional level, a contribution that is a novel both from the academic perspective as well as from the practitioner's perspective. The archetype is shown to be generalizable in the context of the Japanese railway industry, as well as his abilities to explain certain characteristics of the accident in other complex systems, such as the recent accidents involving Boeing's 737 Max. The HSR professionals positive response has already been documented in the section above, highlighting the powerful capability of the SD causal loops in explaining the complex dynamics of various stakeholders.

The accident archetype also demonstrates that the seemingly proactive approach of Japanese HSR operators to analyze long-term trends using past issues is, in fact, reactive in nature. The current study demonstrates how mental models of various stakeholders relying heavily on past events can contribute significantly to the occurrence of accidents. Such an approach is not genuinely proactive as there will always be a relatively long-time delay in the risk perception of the operator and the real risk of accidents (close to 10 years in the case of a crack in bogey frame).

I.4 - In this regard, the development and effective monitoring of system-specific and assumption based leading indicators for process safety may be an effective approach for pro-active safety management (Dokas, Feehan and Imran, 2013; Leveson, 2015). These leading indicators must be developed for all types of system components, including the organizational and institutional components. Monitoring leading indicators can help reduce the time-lag in updating risk perceptions and thus can contribute to improving safety. Japanese HSR operators do develop leading indicators, and in fact, the JTSB report identified one such indicator. In a perfectly balanced bogey, the sum of the "Normal reactions forces" on wheels located at the diagonally opposite ends of the frame should be equal. The official accident report then prescribes the monitoring of these forces through the sensor system that issues a warning when the assumption that the sum of the forces at the diagonal ends is equal does not hold true. Such an indicator is indeed consistent with the idea of system-specific assumption-based leading indicators necessary for complex systems (Dokas, Feehan and Imran, 2013; Leveson, 2015). Further, such indicators should also be expanded to human, organizational, and institutional components of the system. One of the inherent assumptions in the current system is related to the dimensional accuracy of the manufactured bogey. The current indicator to assure the dimensional accuracy, such as the running tests, etc. has clearly shown to be ineffective in preventing the crack from being propagated. Hence, it is also necessary to revise the current testing procedures, an activity that needs to be initiated at the organizational and institutional levels. Several indirect leading indicators, such as adequate monitoring of the information on change-management at the manufacturer level, can also be derived from the system-specific requirements described in the STAMP analysis. Nevertheless, the current methodologies for leading-indicators have been largely focused on the physical components (Leveson, 2015), and further research on developing formal methods to identify leading indicators for non-physical system components is necessary. Leading indicators for the organizational components may prove to be suitable not only for MLIT's regulation on the operators but will also be useful for operators to monitor the safety management systems of their suppliers etc.

The study has also made an attempt to address the limitation of the current methods to identify and operationalize leading indicators for non-physical components for complex systems. The generalized leading indicator approach developed in this study was also implemented for other complex systems within Japan and was shown to be effective. Such a methodology, when implemented for HSR,

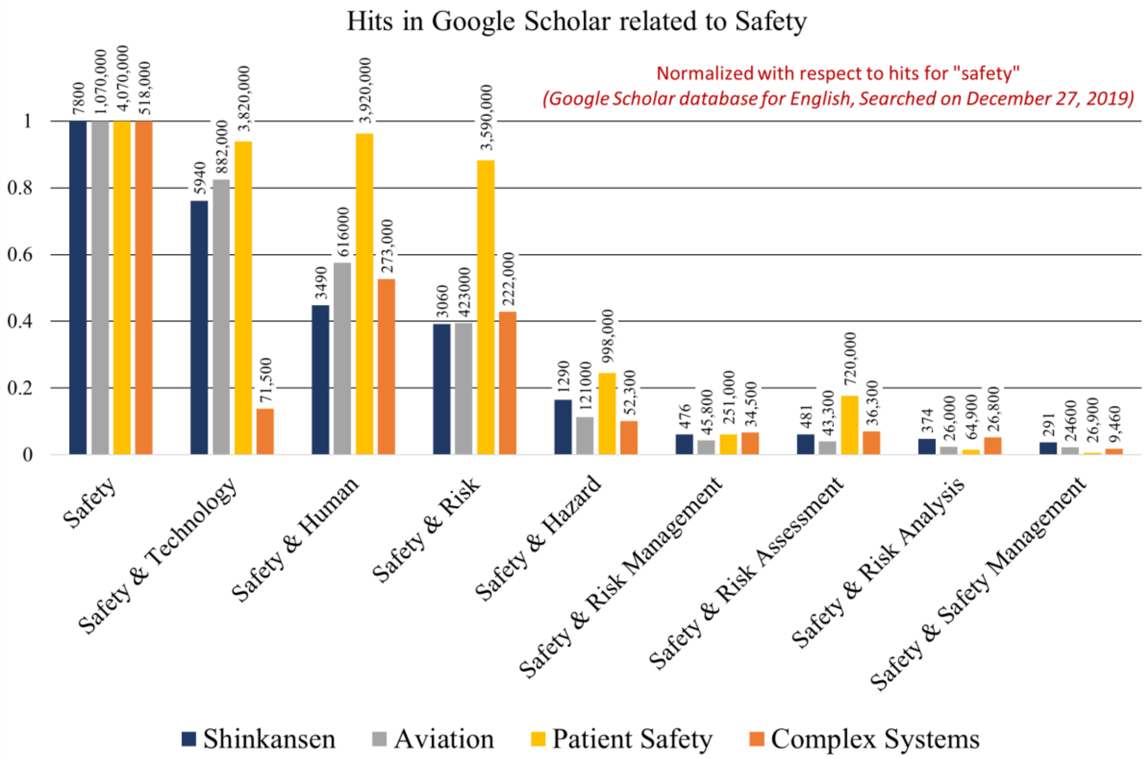


Figure 7-2 Focal themes for safety research for a variety of complex systems

can then allow to further improve the RM practices for Japanese HSR stakeholders at the organizational and institutional level.

7.4.1 Implications for other complex systems

The successful application of the ACAT on this study and its revelation of a surprising contrasting trend, compared to the practitioner's existing perspective than can be generalized for other complex systems. Figure 7-2 showcases that the lack of focus on the organizational and institutional level factors affecting safety is a trend common across several other complex systems, with a certain degree of variations. For aviation, the relative focus on human elements on safety is comparatively more prominent than the Shinkansen; however, both systems showcase a lack of focus on RM, Risk Analysis, and safety management related practices. Although the absolute number of studies focusing on issues of safety management and risk management are almost 100 times that of the Shinkansen, and there is a possibility that recent studies have focused more on the issue relating to organizational and institutional factors affecting safety. On the other hand, for patient safety, the importance is provided much more to Human factors, largely because of the highly specialized roles for humans in such a system, however, even there such systematic studies and accident taxonomies could prove to be useful.

7.5.System-level implications for Japanese HSR: Combined lessons

The current thesis has analyzed a range of safety of the Japanese HSR at several hierarchical levels. By combining the lessons from these multiple studies, various system-level implications can be generated for the Japanese HSR. This section discusses such implications.

Figure 7-3 shows the characteristics of the Japanese HSR system with respect to a generic hierarchical structure (SCS). In this figure, the length of the Box representing a system-components denotes the scope of (type of) activities that fall under the purview of the system component. Further, the height of the Box represents the power to influence the system performance. The specific characteristics of the Japanese HSR systems are also represented in Figure 7-3.

As highlighted in the introduction section of the thesis, the Japanese HSR industry has always been operator-driven, in that, the efforts to continuously improve the HSR system had lied on the operator itself (Rao and Tsai, 2007). Even after the privatization in 1987, the responsibility of the regulatory body has been limited to provide oversight, and the trend of deregulation is increasing (see

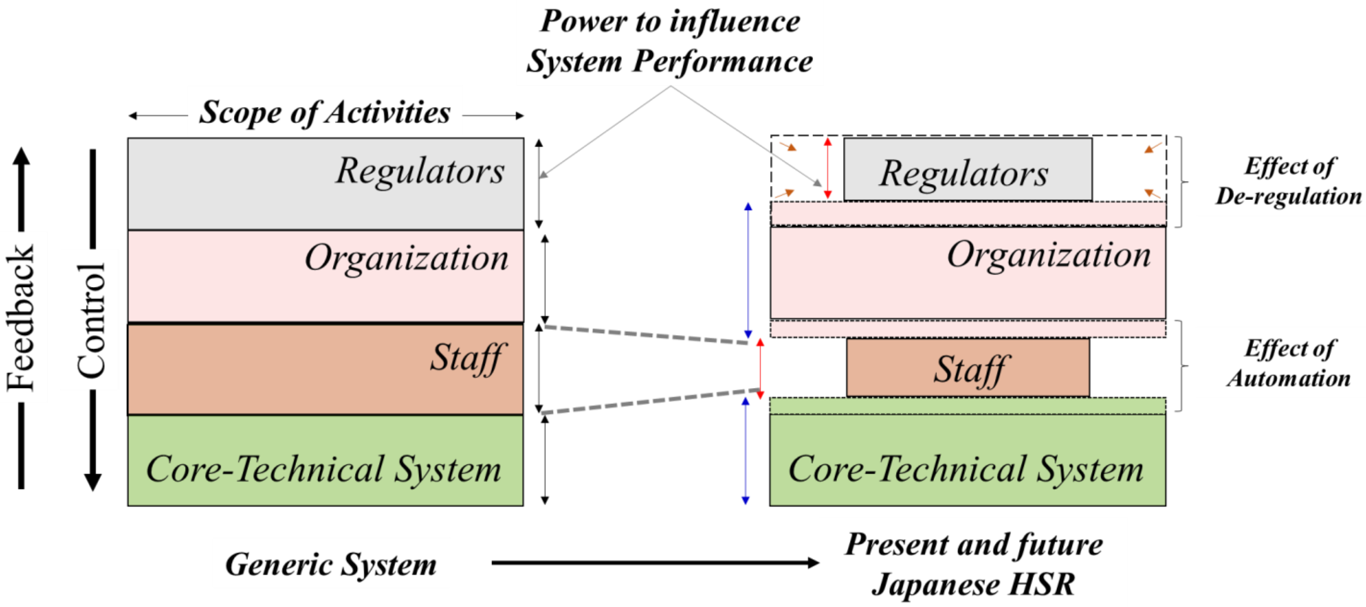


Figure 7-3 Expected system characteristics of the Japanese HSR

Source : Author

section 1.8.5). Due to such trends, the HSR TOCs have a larger scope and stronger power to influence the HSR system (as depicted in Figure 7-3). In addition, the trends in automation and its expected effect on the reduced roles of humans in Japanese HSR is also discussed in Chapter 1. Given the trends, the role of technology and the role of organizations is expected to grow further, and the role of humans is expected to reduce as an operator of the technology. Under such a context, several important implications can be derived from the various analysis conducted in this study. These implications are as follows.

7.5.1 Implications for safety management

Figure 7-4 summarizes the key implications for the safety management for the Japanese HSR that can be derived from the current research. The research conducted in this thesis can be broadly summarized to be focusing on the two interfaces between the system-components (as shown in Figure 7-4). The STAMP analysis and the case study on Johkasou, are broadly centered at the interface between the operator and the regulator. In addition, the System Dynamics model is centered at the interface between the operator and the staff, in its consideration of management decisions affecting the near miss reporting behavior of the employees.

Research	Key Findings	Implications
STAMP Analysis	▪ Ineffective redundancy vulnerable to safety issues ▪ Necessity of systematic and independent Risk-Assessment by the stakeholders	**Current Approach** ▪ Due to the expected trade-offs related to monitoring only generalized indicators based on unsystematic risk-assessment using past knowledge

Leading Indicator Analysis	▪ Indicators can enable system specific proactive safety management
	▪ Trade-offs with enhanced indicator monitoring
	  ▪ Capacity constraints of the regulator
	  ▪ Control vs Autonomy
		▪ System - specific risks can be missed
		Suggested Approach
		▪ First, system-specific indicators based on systematic and independent risk-assessment

SD Model	Trends for any indicator must be understood considering the underlying interactions among factors affecting it	▪ Second, monitoring level to be set with stakeholder coordination and considering the dynamics of the factors affecting the indicator

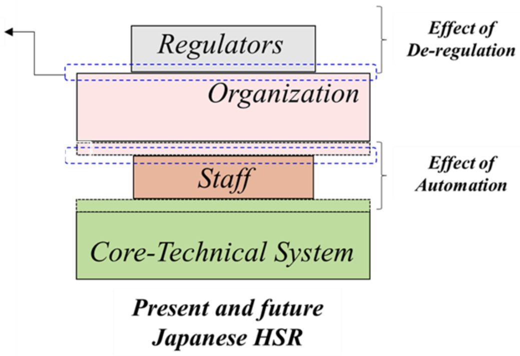


Figure 7-4 Summary of System-level implications for Japanese HSR

Source: Author

The results from the STAMP analysis revealed that in Japan, there is a redundancy between the operator and the regulator, such that the regulator is expected to provide oversight over the operator to ensure safety. However, the analysis presented in this thesis (Chapter 4) revealed that such a redundant structure is in-effective in Japan because both the operator and the regulator rely on the same source of information and analytical methods to base their decisions. Hence, in case of an issue with the information itself, the accident could still propagate. In order to compensate for this deficiency of the system, the necessity of an independent and systematic risk-assessment by each of the operators and the regulator was identified (see Chapter 4).

Further, the thesis had proposed utilizing the leading indicators as a way for pro-active safety management in the Japanese HSR. Monitoring of the leading indicators can provide an indication of whether or not a system is moving in a risk-state. A generalized leading indicator operationalization approach was developed in this study, which is shown to be grounded in the theoretical foundations of the system-theory. However, when such an approach was applied to another centralized system in Japan, i.e., the case of Johkasou in Japan, the method revealed a mixed result. In that, the leading indicators identified were surely shown to be effective; however, whether or not such indicators should be implemented and monitored was not immediately clear to the practitioners in Johkasou. In particular, the interview with the Johkasou expert revealed several trade-offs for implementing such a high number of indicators to be monitored. First, the capacity constraints at the level of the regulator to adequately monitor such a large number of indicators were highlighted. In HSR, technology is changing very rapidly, and the rate of introduction of new technology is increasing. In such a case, the capacity constraints at the regulator could prove the bottleneck for the growth. Further, the regulator may not even have an understanding of the increasingly complex systems. In addition, the large number of leading indicators could also serve as a tool to execute a high degree of control, has the potential to be exploited as well can hamper the industry growth and the safety itself. Hence, too much regulation is also not seen as advantageous for an industry like HSR.

Further, while the SD model is primarily focused on the organizational level factors, it has two important implications overall system monitoring. First of all, for adequately understanding the trends of any particular indicator, the underlying interactions among the factors affecting the specific indicator must be understood. For example, if the number of the incident reported is an indicator, its trend must be understood in conjunction with the Risk Perception of the Employees as well as the safety improvement implemented by the organization. Without the proper monitoring of the two, it is almost impossible to assess whether an increase in a number of reported incidents is happening because of improvement in the risk perception of the employees or the poor safety improvements by the organization. Hence, the interdependence of several factors on trends of indicators must be adequately understood.

Further, the SD model is useful in demonstrating that because of the non-linear dynamic relationships, outcomes of the organizational policy in a specific context, are often path-dependent. Depending upon the state of the variable, the same input of policy may have a different outcome. For example, a policy to reduce the number of working hours by a fixed duration is shown to have a different effect on the level of perceived accomplishment, depending upon the state of the functions. In some cases, the policy may have no effect at all; in others, it may affect negatively the short-term but may create benefits in the long-term. The two implications are visually depicted in Figure 7-5.

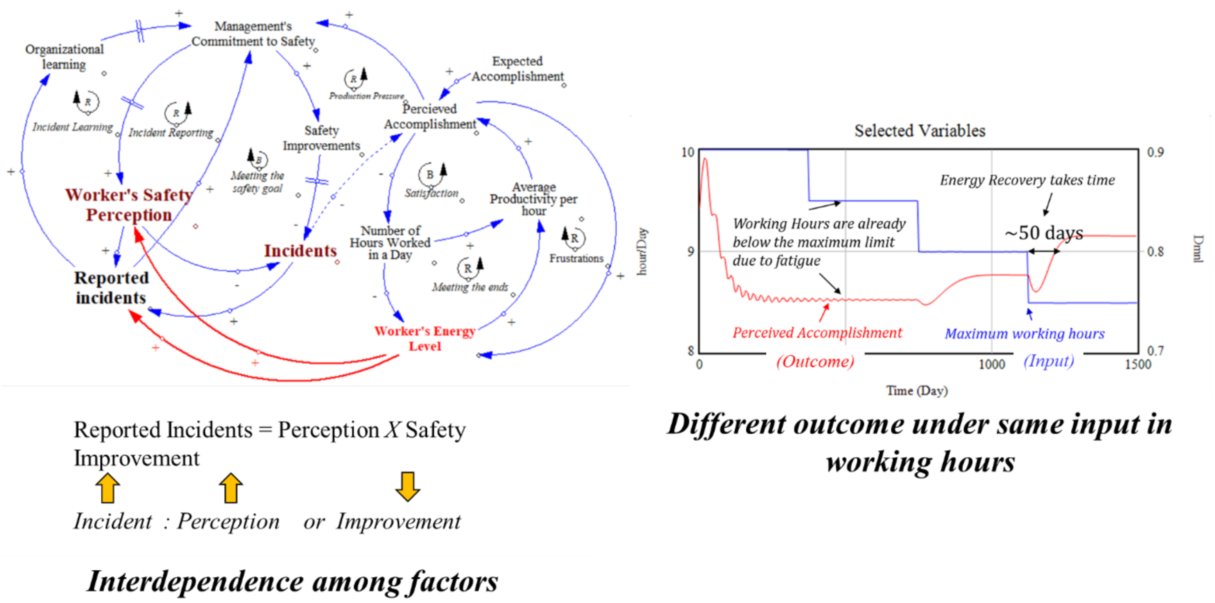


Figure 7-5 Implications of the SD model on risk monitoring

While the trade-offs in extensive system monitoring are known, the challenge that such trade-offs pose for safety, as visible from the current approaches to the risk-management, is as follows. In most cases, due to the recognition of trade-offs, a screening is put on the specific risks that need to be monitored. Hence, not all the risks that are identified are mentioned in the official documents and subsequently are never monitored, thereby reinforcing the belief that such risks do not exist at all. It is due to this consideration of potential trade-offs at the later stage; the regulator often ends up developing a generalized set of indicators that are applied across industries. For example, in Japan, since 2006, the MLIT has approved 14 general indicators for monitoring the SMS of various transport operators (MLIT, 2017b). However, even when such a set of indicators was put into monitoring in 2006, one of the prominent railway companies in Japan, i.e., JR Hokkaido, still faced a management crisis that revealed only in 2013, when a few accidents were observed. Clearly, the 2006 management indicators, from MLIT, were not enough to proactively measure the poor state of affairs at the JR Hokkaido.

Each system (comprising of technical, human, organizational, and institutional components) is unique, and hence, its hazards will also be unique. Risk monitoring, considering the potential-trade off in monitoring and thereby using a set of generalized indicators, can thus jeopardize certain safety when the unique risks materialize. Hence, an alternative arrangement should be to First identify the system-specific risk factors (irrespective of their consideration in the final monitoring plan) and then devise an appropriate monitoring plan with stakeholder consultation. Further, while coming up with a monitoring plan, due consideration must also be given to the dynamic interactions among a variety of factors affecting the trends of the specific indicator. In Japanese HSR, a common criterion to not pay attention to a specific issue in a system is that such risk factors have never played any role in the past. Even during the certification of a new system, the HSR regulators refer to cases where another HSR operator has already demonstrated the safety of a similar system. Under such an approach, the issues that have not occurred in the past will be masked from the monitoring gradually and could trigger accidents at a later stage, as we have seen in our analysis.

Hence, the results from the current study have important implications for improving the current RM approach in Japanese HSR.

I.5 – In the RM for a complex system, it is important to first identify as many risk factors as possible and then make a decision on an adequate level of monitoring. In doing so, a comprehensive repository of risks can still be available, out of which some can be monitored frequently, while others could be monitored at a pre-determined frequency suitable to both the regulator and the operator. Hence, a win-win solution can still be obtained by addressing the important trade-offs addressing the regulator's capacity, as well as the balance between the operator's autonomy and control. (Q2, O1)

7.5.1.1 Implementation scheme for suggested RM in Japanese HSR

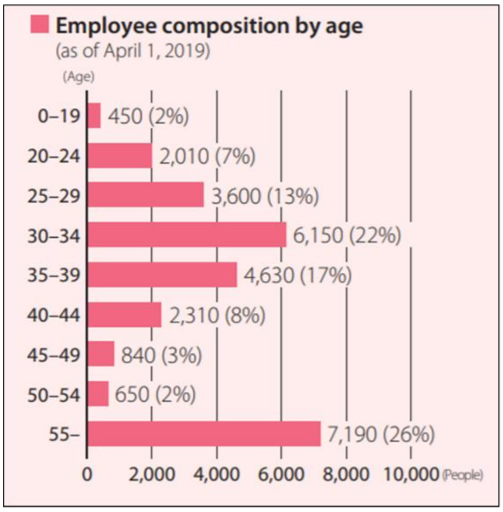
While the previous section suggests improvements in the RM practices for the current RM practices in Japanese HSR, the section here briefly discussed the potential implementation scheme suitable specifically for the Japanese HSR.

The suggested approach calls for the adoption of a more systematic approach to RM in Japanese HSR, such as through the use of the STAMP analysis and further recommends ensuring the independence of the risk-assessment at the operator and the regulator level. While, in principle, such independence could be achieved through the use of an independent source of information, for the decisions each by the operator and the regulator, however, gathering such independent information may not always be feasible. In fact, one of the strengths of the Japanese System is considered to be the accumulated knowledge of more than 5 decades, which is comprehensively put into practice in Japanese HSR system approval by the regulator through industry-wide circulation (Yanase, 2010). In fact, such extensive system-wide knowledge is often described to provide an advantage to the Japanese system over their counterparts in the European and the American railway sector, where the focus is on the reliability of the individual components and less on overall system performance (Ota, 2008; Yanase, 2010).

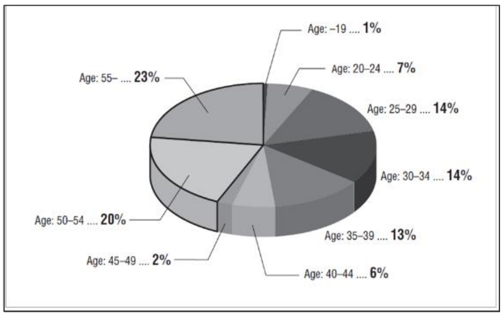
On the other hand, completely independent risk-assessment by the regulator and the operator may also be resource-intensive, and often the regulator may not even have such resources allocated to them through the provision of the public funds. Lack of human resources and the capacity of the regulators themselves is an issue across industries across the globe and is often the result of a general shift towards the self-regulation models (Le Coze, 2017). Hence, a suitable consideration of the human resource capacity at the regulatory level needs to be made for implementing an adequate RM strategy in the Japanese railway context.

In Japan, since the privatization of the HSR TOCs in 1987, and the subsequent deregulation in the railway industry in 2002, the railway specific knowledge has become decentralized and has become concentrated in the human resources in individual TOCs. Further, the regulatory standards have become "performance-based," and the overall model of the industry has become the "self-regulation" model, where all the TOCs themselves assume the safety responsibilities and conduct necessary system improvements.

However, it has been more than 30 years since the privatization, and the HSR TOCs in Japan, have since been undergoing a significant demographic change in their employees. At the time of the privatization, the organizations were filled with young employees; however, since then, the HSR TOCs in Japan have had somewhat limited hiring, gradually decreasing the numbers in their total workforce. However, now a majority of the employees, who joined the TOCs at the time of the privatization, are on the verge of retirement, as can be seen from the employee composition by age for JR West (JR West, 2019), and JR East (Takikawa, 2016), and others, as shown in Figure 7-6. Such a demographic change is also causing the issue for the HSR TOCs as they face challenges in sustaining the organizational knowledge. Even several of the HSR TOCs have started employment extension programs for these employees, by extending their retirement age and allow them to work as the safety trainers and take responsibility of human-resource development within each of the TOCs (Bugalia, Maemura, and Ozawa, 2019b).



JR West in 2019



JR East in 2016

Figure 7-6 Employees' age composition in Japanese HSR TOCs

Considering the lack of available human resources at the regulator level and the high proportion of experiences HSR professionals in Japan going out of the HSR system, the current study then proposed a win-win solution that could work for the Japanese Context. The system is very similar to the old system of certification employed by the FAA in the USA (Gates and Baker, 2019). The overview of the proposed system is shown in Figure 7-7. Under the new system, a new license to RM could be issued to the experienced HSR professionals of the retirements age in Japan. These experience HSR professionals could be given adequate training for conducting systematic risk-assessments using the approach prescribed in the current study, such as the STAMP. The performance evaluation of these licensed professionals should be monitored by the MLIT. However, as part of the self-regulation regime, the salary for these experienced professionals could be the responsibility of the HSR TOCs, which can still benefit from the experiences of these professionals to further sustain their organizational knowledge. However, the reporting by the Licenses RM professionals, should be directly managed to MLIT and not the HSR TOCs, to ensure the independence of the overall process as much as possible.

The MLIT can then use the system-specific Risk report generated by the licensed professionals to provide certification for the new system in Japanese HSR.

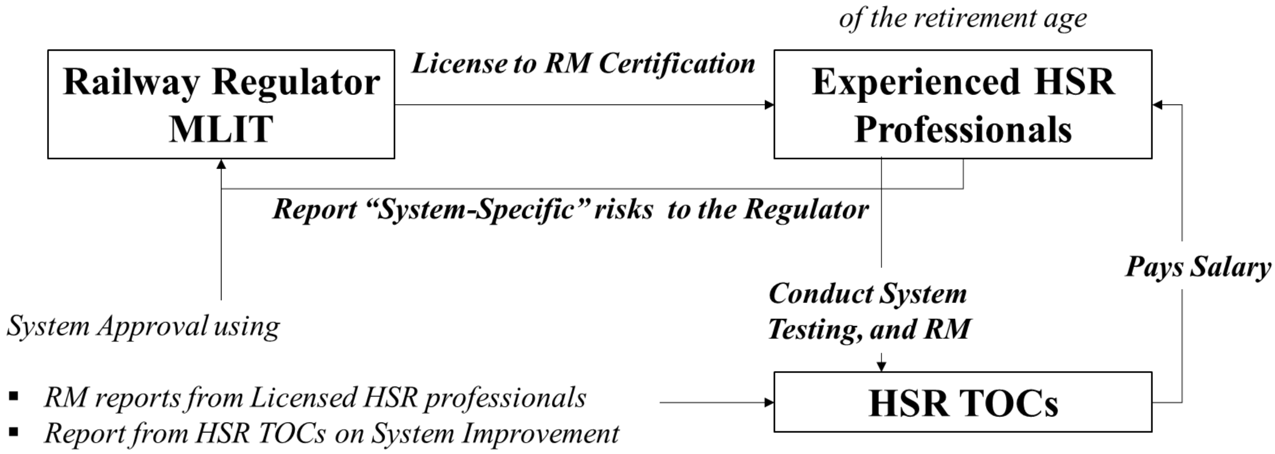


Figure 7-7 Proposed implementation plan for systematic RM in Japanese HSR

There are certain pitfalls for the proposed implementation plan, that should be paid attention to. For the case of FAA, over the years, the practice changed to become such that the licensed engineers started to report to the organization itself and no longer to the regulator. Under such a case, the independence of the risk-management process could not be ensured as the operator's management has the incentives to miscommunicate under the hanging business context. Other pitfalls could be related to the establishment of a well-developed license process of RM. Since the current RM practices of the Japanese HSR professionals are very different from what is prescribed by safety theory, such as STAMP, hence, significant resources for license and training would be required in the initial stage. Further training of experienced professionals could be difficult as their experience may hinder their learning. Further, it would be necessary to form a panel of experienced professionals from different TOCs to be designated for working in a specific TOC. While all the licensed professionals should not be from a different HSR TOC, as they may not fully understand the system, a balanced mix of employees from different TOCs should be made.

I.6 - In summary, the current study recommends establishing an RM License for experiences HSR Professionals in Japan, under which, the licensed professional can perform systematic RM for the Japanese HSR, on behalf of the regulator (Q2, O1). Thus, various methodologies utilized, and developed in the course of this study, can all be suitable in identifying a win-win strategy for proactive safety management at all system levels, such that the various trade-offs arising at the component boundaries can be adequately mitigated.

7.5.2 Implications for Choice of an appropriate accident model

The analysis in the current study revealed that the system of safety management in Japanese HSR, is very close to the desired requirements for the safety management of complex systems (see Chapter 4), except in its use of utilizing event-chain accident models for analyzing all accidents. The current thesis warrants usage of the accident models such as STAMP for systematic risk-analysis at the organizational and institutional levels. The thesis has repeatedly demonstrated the merits of the STAMP accident models against the event-chain models in providing a systematic, unbiased, and blame-free analysis of the organizational and institutional factors. However, whether STAMP will be utilized in the HSR TOCs in Japan, is dependent upon several factors.

(Underwood and Waterson, 2014) have discussed relative merits and demerits of various accident models suitable for complex systems. In that, STAMP is suitable for analysis for complex systems for its Explicit description of System Structure, Modelling the component relationship, the system behavior. However, STAMP fares poorly on several other dimensions, such as the reliability of the analysis, longer application times, and less effective graphical communication. Further, they have discussed the different factors deemed important for practitioners as well as industry experts in selecting a suitable accident method. In that, practitioners prefer an accident method that is thorough, cost, and time-efficient, usable in the given constraints, and are proven to be applicable in several other cases. Practitioners also require a taxonomy to identify the accident causal factors.

The feedback from the HSR practitioners in this study also reveals several other requirements of the accident models. In their experience, using an event-chain model provides a clear direction for each system component on what should be further improved. Hence, the accident analysis is seen as a way to attribute responsibility, which is an alternative manner is a way to attribute accident blame. STAMP also has the possibility to generate detailed system-improvement recommendations at all levels, while saving the blame from being attributed.

From the philosophy perspective, there is a strong similarity between the key messages supported by STAMP and that of the current Japanese HSR RM practices (as shown in Table 4-5). Hence, a transition to STAMP could really be possible for the Japanese HSR stakeholders. In addition, STAMP has been extensively used for conducting hazard analysis for the future systems, for a variety of complex systems, including for railway systems (Ota, 2008; Kawakami, 2014a). Hence, several arguments favor the adoption of STAMP. On the other hand, STAMP is not suitable for all the applications in complex systems. For systems where elaborate modeling of the process is necessary, academic applications have also used FRAM, and hence, depending upon the requirements of the analysis, a variety of accident models should be considered. Nonetheless, an improvement from the current event-chain models is necessary.

However, in addition to the discussions above, various studies conducted in this thesis, are also useful in revealing the system-wide impact that the choice of accident model may have. Such implication is summarized in Figure 7-8.

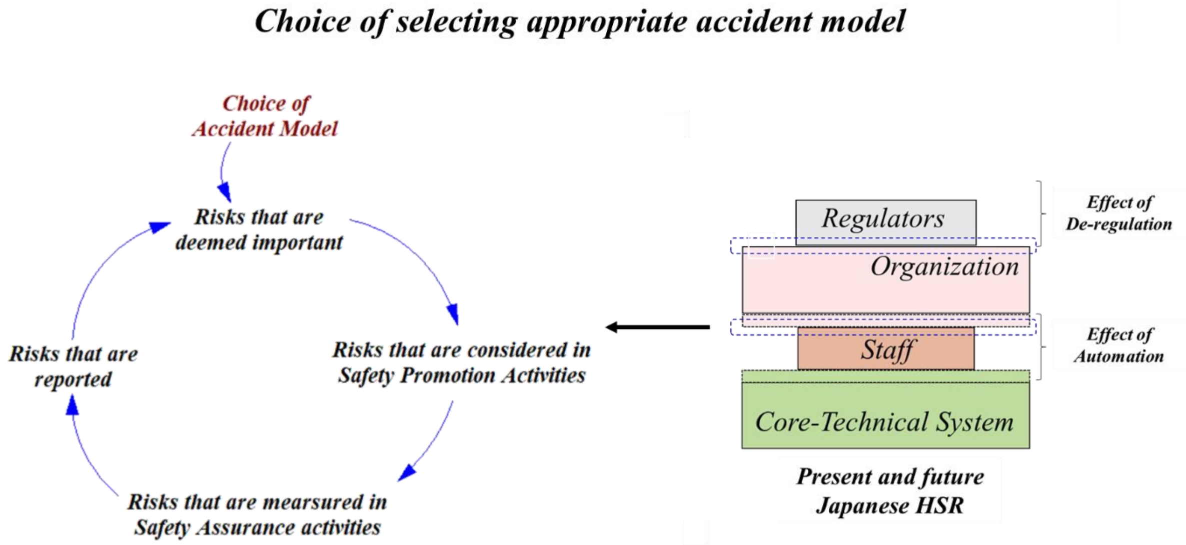


Figure 7-8 Implications for selecting the accident model

In any system, the Choice of Accident Model affects the Risks that are deemed important. Then, only those risks that are deemed important are considered in safety promotion activities. For example, in Japanese HSR, the human training related recommendations are given in almost all the official accident reports, however, seldom recommendations are made about improving the existing standards at the organizational level (while their vulnerability is demonstrated in STAMP analysis of this thesis). Then, the risks that are included in safety promotion activities are also measured in safety assurance activities. Even during near-miss reporting, employees tend to report the same risks that are discussed during the training or safety campaigns, in-short are risks that are already known to the management. The reported risks than form the management’s perception of the risks that are deemed important.

Hence, the risk-perception of the management gets reinforced over time, and they may end up feeling that new learnings are difficult to come by. A similar situation was also faced by the construction industry, as identified in our review in Chapter 6. In this regard, the selection of the Accident Model can enhance management's understanding of the potential risks, and thus enable them to identify the new risks present in their system. The discussions presented above then have the following implications for the selection of appropriate accident models to be used in Japanese HSR.

I.7 - In a situation where the choice of accident model is usually constrained by the practical requirements of the practitioners, for a learning organization, it is always important to try and adopt newer methods of risk analysis. Here, STAMP could serve as an important tool, where the in-depth analysis of organizational and institutional factors under the expected increase in the degree of complexity and system centralization could reveal new accident mechanisms and provide guidance on future improvement. (O1, Q2). Other accident models suitable for complex systems such as the FRAM, should also be considered for their advantages.

Further, from Figure 7-8, it can be inferred that the choice of the Accident Model could also serve as an important tool for preserving the organizational knowledge. Sustaining the organizational knowledge is already shown to be crucial for many HSR TOCs in Japan, as many of the experienced HSR professionals have begun to retire. However, whether or not STAMP could also serve as an important tool for sustaining the organizational knowledge is a research theme for the future that must surely be explored. (O1, Q2)

7.6.Implications for the enhanced Operator-manufacturer relationship

In STAMP analysis, the necessity for the enhanced safety-coordination between the operator and the manufacturer (or the supplier) is deemed necessary. Such a requirement is also suitable to analyze from the perspective of inter-organizational complexity and the associated trade-offs and is briefly discussed in this section.

Depending upon the distribution of safety-related responsibility among the operator and the manufacturer, three possible scenarios are possible, each posing their own set of challenges.

In the first scenario, more safety-related responsibility is deemed suitable to be assigned to the manufacturer itself. The MLIT working committee, set up to investigate large-scale transport disruptions in Japan, recommended that it is often too difficult for the HSR operator to timely detect the issues in the quality of the manufactured products, and hence, more responsibility of the quality control should be assigned to the manufacturer itself (MLIT, 2018). Over the years, the supply-chain of the manufacturer has also grown to become long, and hence, the number of parts has been increasing, with the average size of the parts becoming smaller and smaller. Due to such changes, the manufacturing process has grown to become complex, which requires the joining of many parts together to form the final product. The MLIT working committee recommends the simplification of the design and the manufacturing process, so as to keep the number of joins to a minimum, and the simple designs which can be easily maintained. However, under such an arrangement, the manufacturer will have to restructure its own supply-chain. Whether or not manufacturers have the right incentives to do so is a question that is discussed here. Under the tepid growth in the domestic market, the Japanese rolling-stock manufacturers are already eying for more international market access[18] but face fierce competition from their European and Chinese counterparts (Mizoguchi, 2005). Japanese systems are priced higher, where the demand for such high-quality systems around the globe is questionable in price-sensitive markets. Hence, an overhaul in the manufacturing process to address safety issues may not be desirable from the perspective of international competition and the cost-saving benefits that are borne through outsourcing.

In the second scenario, and also identified by the current study, enhanced monitoring of the manufacturer's activity by the operator is recommended. The same has also been implemented by the JR West for their suppliers (JR West, 2019), where JR West started to assume greater roles in quality

[18] https://www.tetsushako.or.jp/english/english01.html

management of the suppliers such as throughout advance checks of documentation, including materials regarding inspection systems (including certification management), work processes, drawings, molds, the management of contractors and others, and education and training. While theoretically, such enhanced monitoring will likely result in enhanced quality of the goods produced by the manufacturer, the academic literature has also identified several challenges with such safety-coordination (summarized in Table 7-2). While all the factors listed in Table 7-2 may not necessarily be important for the current context, the issues with the breakdown in the communication flow, enhanced complexity of the safety-management system, fragmented decision-making process, etc. all can be crucial for the operator-manufacturer relationship in the Japanese HSR and will require further consideration, when such a scenario is established.

Table 7-2 Interorganizational Complexity and Organizational accident risk (Source : (Milch and Laumann, 2016))

Themes	Sub-Themes	Examples
Economic Pressures	Lack of shared responsibility	Depending upon the organizational size, smaller organizations may face economic pressure for implementing safety. While the lack of accountability may lead to hiding information.
	Safety/production trade-offs	Safety vs. production efficiency. Unequal distribution of safety costs and benefits among multiple stakeholders
Disorganization	Breakdown in the communication flow	Uncertainty about who should be reported, different communication practices among organizations, slow information flow, and distrust between the workers from different organizations
	Complex safety-management system	Excessive paperwork, Written procedures become too complicated to manage, and a growing volume of paperwork.
Dilution of Competence	Lack of industry-specific knowledge and experiences	The suppliers can often become distant from the railway industry and may not understand the common risks and hazards.
Organizational Differences	Fragmented decision-making processes	Lack of superior authority to make final decisions, creating difficulties for safety optimal decisions when facing local conflicts.

In the third scenario, the responsibility of the quality-control for both the manufacturer and the operator can be allocated to another authority, that can provide adequate regulation to both the operator and the manufacturer. However, in doing so, all the discussions related to the associated trade-off (discussed in the previous section) will become relevant and should be adequately considered.

I.8 -In summary, each of the option to distribute the safety-related responsibility among the operator and the manufacturer is associated with corresponding trade-offs, and a detailed stakeholder analysis must be carried out in order to identify the best suitable solutions relevant to the Japanese HSR.

7.7.Implications for other HSR Systems (India)

The first HSR project from Mumbai to Ahmedabad (MAHSR) is ongoing. The MAHSR project is going to utilize the renowned Japanese HSR technology or *Shinkansen* as known in Japanese. Also, HSR is expected to see significant growth in India, as a few HSR projects are currently under various planning stages. A review of various HSR projects in India, under various stages of planning, is shown in (Ravi, 2019). For the Indian plans of HSR to materialize the operational sustainability of the first project, i.e., the MAHSR project is going to pivotal. Similar was also seen in the experience of Japan and France, where the operational success of the first project, had led to significant demand for future projects(Hancock, 2015). Some of the key ideas discussed in this thesis will also have important implications for the upcoming MAHSR project.

7.7.1 Potential effects affecting MAHSR

The governments of both India and Japan agreed on a technology and "know-how" transfer agreement, and since then, numerous activities related to the transfer of technical standards and capacity building and training are ongoing (Ravi, 2019). Based on the information available, two broad categories of influencing factors affecting MAHSR can be identified.

7.7.2 Potential influence at the Technical and Human-level for MAHSR

The core-technical system of Shinkansen is going to adapted "as is" for the MAHSR project. A few minor adjustments have to be made for the local climatic and demographic conditions. However, none of these adjustments are likely to have an impact on safety-critical components (IIT Gandhinagar, 2018). For the Indian context, the Shinkansen system is a new leap forward in technology, as currently, India has no experience of operating a High-Speed service. The most recent efforts for developing high-speed trains in India have resulted in new trains, capable of achieving a maximum commercial operating speed of 180 km/hr[19], which is sub-par from the UIC standards of HSR for existing tracks. Naturally, the introduction of Shinkansen is going to cause new stress on the system, and the capacity of all staff members will have to be improved through the training efforts.

Having realized the significant need for the capacity building for the future staff of MAHSR, a "know-how" transfer agreement was also reached between the Indian and the Japanese side. In this regard, the Japanese private TOC responsible for the MAHSR project has been promoting its own methods and experiences of Human-Resource development (HRD).

Technical failure and Human-errors are among the most common causes of accidents in railway systems across the world (Kyriakidis, Majumdar and Ochieng, 2018) and the same hold true for railways in Japan (Saito, 2002) and India (Aher and Tiwari, 2018). Figure 7-6 demonstrates the trends in accident causes for India's national railway system, i.e., Indian Railway (IR) using the data from the year 2000-01 to 2015-16. More than 80% of the accidents in IR are primarily caused by Human-errors, and about 5% of the accidents are caused by equipment failure. In that, for a period from 2000-01 to 2005-06, 53.9% of the total accident was caused by the failure of the IR staff (calculated using the data shown in (Agarwal, 2006)).

In addition, a detailed taxonomy of human-errors in IR is reported in (Nayak and Tripathy, 2018). The study utilizes data from more than 1200 accidents reported between the years 1980 and 2010 and classifies human error in IR by staff type, e.g., Crew member, Stationmaster, Signal maintainer, etc. The most common human-error types are shown in Figure 7-7. Many human-errors in IR are related to signals being overlooked, failure in following the speed-limits, poor braking performance, or errors in local traffic management by the station master.

At this stage, a brief overview of the related technologies in IR is also necessary. On a large proportion of its tracks, IR utilizes Fixed-block auto-signal technology, in which the location of the train is automatically detected using the track circuits, and consequently, speed restrictions are shown for the following trains. On a few locations, there are no signals in-between the stations, and hence, the station master has to take over the responsibility of providing clearance to train movement. Further, the braking system on the IR network is not automatic, and hence, train drivers are expected to apply the brakes.

On the other hand, characteristics of the Shinkansen system, being adopted from Japan, are significantly different. Shinkansen system in Japan and the one being adopted for MAHSR does not rely on track-side signals. All related speed-limits are directly shown to the driver inside the cabin. Japan uses the Automatic Train Control (ATC) system for signaling and automatic braking actions. For

[19] https://en.wikipedia.org/wiki/Vande_Bharat_Express

this system, the trackside ATC circuits, detect the accurate positions of the two trains. The onboard ATC system at the preceding train then calculates the *Braking Curve* for that specific train. The driver is accordingly shown speed limits inside the cab, and if the driver fails to apply brakes, the onboard ATC system automatically applies brakes.

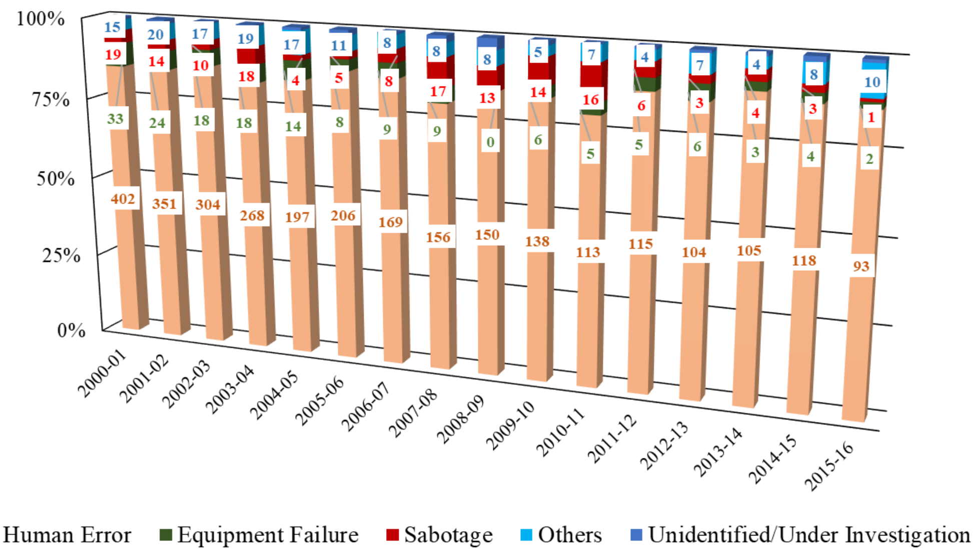


Figure 7-9 Trends of accident causes in Indian Railway

Created by author using the data obtained from (Aher and Tiwari, 2018)

With the introduction of the Japanese system to MAHSR, it is expected that a majority of the human-errors (as shown in Figure 7-6) will be eliminated. Further, the MAHSR is also taking necessary measures to reduce the possible causes of equipment failures in the Indian context (IIT Gandhinagar, 2018). The ATC system is designed to apply automatic brakes in normal, and many of the emergency situations, and hence, the errors such as signals passed at dangers, excessive speed, signaling-speed being overlooked, poor knowledge of brake system, signal blanking, and errors from station masters are all expected to be eliminated. In fact, the Japanese system is designed as a fail-safe system, such as using system-redundancy, so that safety will not be compromised even when the human-errors occur (Hancock, 2015).

On the other hand, no system is fail-proof, and human errors and technology failure still occur, even in the Shinkansen system. It is thus sure that the new type of human errors will emerge in the context of MAHSR. The level of education of the current Indian engineers compared to the desired level for the Japanese system will also prove challenging. Further, the technology that was developed suitable to the Japanese climatic and operational environment may function differently in MAHSR. The rather uncommon equipment failure in Japanese shinkansen now, are also dependent on a number of factors such as the quality of products supplied, and their effective maintenance. However, given the current experience of Indian engineers, such issues are likely to prevail in MAHSR, especially in the early years of operations (similar to the early-years technical failure related to welding of the tracks even in Japan (Hancock, 2015)), and India specific research for safety of HSR is necessary to be carried out to understand these factors in detail.

7.7.3 Potential influence at the Organizational and Institutional level for MAHSR

The current thesis has well established the importance of organizational and institutional factors for the safety of HSR. In this regard, the use of the proven Japanese technology may sure reduce the technical failure and human-errors at the front-end, but paradoxically, such shift to new technology puts more responsibility on the mid- and top- management within an organization (Bainbridge, 1983). Hence, the study of institutional, organizational factors affecting safety becomes even more important in the new Indian system.

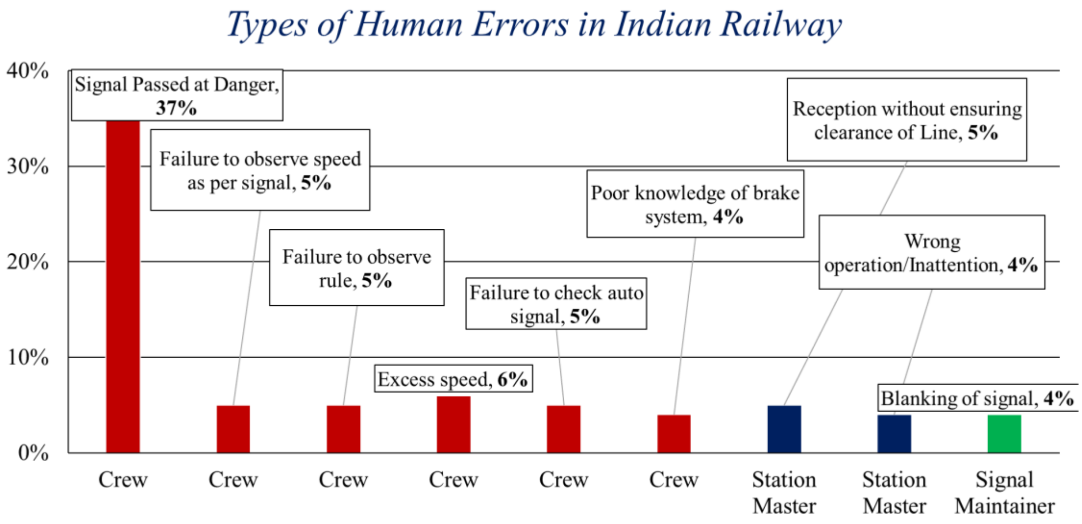


Figure 7-10 Human error classification for Indian Railways

Created by author using data reported in (Nayak and Tripathy, 2018)

At present, National High-Speed Railway Corporation Ltd. (NHSRCL) has been appointed to oversee the implementation of the MAHSR project. Currently, the implementation is limited to the construction of the fixed infrastructure and procurement of the rolling stock, and the status of the HSR operation related responsibility is still unclear (National High-Speed Railway Corporation Limited, 2018). NHSRCL is a special purpose vehicle, jointly formed by the Central Government of India and the Governments of states of Maharashtra and Gujarat. Under the Railways act of 1989 in India, the NHSRCL has been defined as a non-governmental railway, which is effectively governed by its board of directors, who are appointed by the central government of India. At present, no further information about the potential organizational and institutional structure during HSR operation is known, and hence, only the general estimate of the potential influences relating to MAHSR is possible.

At the organizational level, a mix of Japanese and Indian factors are likely affecting the safety at MAHSR. From a *Macro* perspective, the MAHSR market conditions and financial pressures will be significantly different from that of HSR in Japan. Further, the relationship with the regulator and the local laws will be specific to the Indian context and is expected to be significantly different from that of the Japanese context. From the *Meso* perspective, the effects will depend on the future organizational structure, Risk-management methods, and type of safety promotion and assurance activities carried out at the future MAHSR. However, it is highlight likely that the future MAHSR system will likely be influenced by the Japanese system. The feasibility study reports prepared for the project, have made a strong recommendation for adopting the similar management structures, that has been proven to be effective in prioritizing safety and effectively coordinate the complex interactions that are necessary to manage the safety of HSR (Japan International Corporation Agency and Ministry of Railways India, 2015). Form the *Micro* perspective of organization, the safe behavior, and safety culture, etc. is expected to be influenced by the psychological factors local to Indian human resources, at the same time, a great contribution on these *Micro* phenomenon comes from the organizational structure and policies at the *Meso* and *Macro* level, and thus the influence of Japanese system can also be expected. Further, at the level of the regulator and the government, the most significant influence is expected from the context-specific to India. Table 7-4 provides a summary of the type of studies that will be necessary for the safety of Indian HSR, and how the lessons obtained from the current studies can be applied to the Indian context.

Table 7-3 Summary of the potentially beneficial studies for MAHSR Safety

Analysis level	***Necessary important studies***	***Context of MAHSR***	***Transferability of lessons from Japan***
Machine- Level	Study of technical failures upon introduction of Shinkansen technology in India	Currently under construction, no operation experience	Indian specific research is necessary
Human- Level	Study of new types of Human-errors upon introduction of Shinkansen technology in India		
Organization (Micro)	Organizational factors in Japanese Shinkansen and their impact on HSR Safety	Structure and management practices are likely influenced by the Japanese system	Lessons from Japan are of direct relevance
Organization (Meso)			
Organization (Macro)	Impact of market conditions local to MAHSR and their effect on HSR safety	The exact market conditions of Indian HSR are yet to be determined	Lessons from Japan and other countries could be of relevance
Organization-Regulator relationship	Impact of Organization-Regulator relationship local to MAHSR and their impact on Safety	Such a relationship is yet to be determined	
The institutional structure of the Regulator	Factors related to regulators in Indian HSR and its impact on safety		
Government	Effect of Indian laws governing HSR and its impact on safety		

I.9 - Based on the observations summarized in Table 7-4, it is evident that the lessons from the **accident analysis at the organizational and institutional levels in this study are of direct relevance to India**. From the beginning, the Indian system can be designed to compensate for some of the weaknesses of the Japanese systems. In addition, **the operator-regulator relationship and organizational factors have been identified as crucial causal factors for many HSR systems around the world, such as China** (Dong, 2012; Kawakami, 2014b; Fan *et al.*, 2015)**, USA** (Kawakami, 2014b; Hidema, 2017)**, and others (Rao and Tsai, 2007; Ota, 2008), and safety implications from several of the above studies will be of direct relevance to India.**

Chapter 8. Conclusions

This chapter summarizes the important contributions, limitations, future work, and conclusions of the research.

8.1. Important Contributions

The study had identified several research gaps from the practical and academic perspectives in Chapter 1. For the sake of discussions, these gaps are listed here one more time, while their detailed explanation is available in Chapter 1. These gaps are –

R1. Due to changes in the system characteristics of the Japanese HSR, the role of organizational-level factors is expected to change; however, such relative importance of the variety of organizational factors has not been examined in the Japanese HSR.

R2. At the organizational level, the RM practices of the Japanese HSR operators have not been critically examined and face challenges in considering important potential accident causal factors. Further, At the Institutional level, the risks associated with the current practices of operator-regulator relationship, and its impact on RM of the operator, and the overall safety-related implications have not been examined.

R3. There is a necessity to develop a pro-active RM strategy for Japanese HSR operators and the general complex systems.

R4. At the organizational level, some of the HSR operators in Japan are facing the issues related to the near miss reporting behavior of their employees; however, only a handful of the studies comprehensively explore the organizational factors affecting the reporting behavior of employees in Japanese HSR TOCs or otherwise in general systems

In addressing the above-mentioned academic and practical gaps, the study makes the following contributions. The contributions are also coded with the gaps that they fulfill.

1. An in-depth review of the current RM practices in Japanese HSR at the organizational and institutional levels. (R1, R2, R3)

2. A comparative analysis between the state-of-the-art system-control safety theory-based RM practices and the current Japanese practices to reveal the important differences between the two. The Risk Analysis tools utilized by the current Japanese HSR TOCs are based on event-chain accident models, whose usage often masks the organizational and institutional level factors as well as creates ambiguity in the analysis at the organizational and institutional level. (R2, R3)

3. An accident taxonomy analysis (ACAT analysis) for obtaining the trends using the lessons from official accident reports for all 6 reported accidents since 2004, that were previously unanalyzed. The trends form the ACAT analysis highlight that a majority of accident causal factors in Japanese HSR are not related to technical failure or human-errors but have underlying organizational-level factors. The results from the ACAT analysis were shown to be instrumental in bridging the gap between the practitioner's understanding of accident causal factors compared to the safety theories for the complex systems. (R1)

4. An in-depth accident analysis for the first “serious accident” in the history of Japanese HSR, using STAMP based accident analysis technique, allowing to systematically analyze the accidents at the organizational and institutional level. The result revealed that the accident was a systemic accident, where a few systemic factors such as excessive reliance on past information, rendered the multiple safety defenses ineffective. The results from the STAMP are comprehensive compared to the official accident report and identify several important factors previously unidentified such as the necessity for enhanced safety coordination between the operator and the regulator, or the necessity to change the

standards in order to better control the dimensional accuracy of the manufactured rolling stock. (R1, R2, R3)

5. **A novel safety archetype at the organizational and institutional level, showing the ineffectiveness of the apparent redundancy in the safety control at the operator and regulator level**. The archetype is generalizable to the context of the Japanese railway as well as to other systems and provides theoretical improvements in safety management for complex systems, such as the necessity to develop the leading indicators for system components other than the physical systems. The STAMP analysis was instrumental in identifying the archetype. (R2, R3)

6. **A novel generalized leading indicator operationalization approach** that can be implemented for all types of system components. The proposed approach is an improvement from the existing approaches, which have mostly focused on the physical system components. (R3)

7. **A novel System Dynamic model is describing the near-miss reporting behavior of employees in an organization**. The model takes careful consideration of the variety of factors affecting the reporting behavior, individually studied in previous studies, and simulates the emergent behavior out of interactions among numerous factors. The causal structure is seemed generalizable for two different types of complex systems, i.e., the construction industry, as well as the HSR operators in Japan. The simulation results are effective in demonstrating the effect of worker's fatigue, and level on incentives on near-miss reporting in an organization. (R4)

8.2. Limitations

All models and methodologies utilized or developed in this study were tested for their ability to explain the behaviors observed in the real-world. Based on that, several important limitations have been identified as follows.

8.2.1 Implementing STAMP within Japanese HSR Organizations

The HSR practitioners consulted for this study showed an acute understanding of the principles as well as the potential of utilizing the STAMP for accident analysis at the organizational and institutional levels. However, the experience from Japanese HSR suggests that organizational and institutional level factors have been systematically masked and not focused. Hence, even though STAMP can provide a successful methodology to be applied, its implementation and application in HSR TOCs will still depend on several other factors such as the industry-wide promotion and awareness of STAMP and organizational factors contributing to safety, or the future of operator-regulator relationship in Japan, or the selection criterion of the Japanese HSR TOCs in selecting an accident model. A variety of these factors have not been considered in detail in this study, and specific advantages of the STAMP against the factors masking the study at the organizational and institutional causal factors need to be highlighted. For example, the current study does not examine the question whether or not use of STAMP could prove to be beneficial for sustaining the organizational knowledge in Japanese HSR, which are facing the challenge of sustaining their knowledge as they have not experienced many accidents as well as the early engineers who pioneered the system are gradually going out of the organization.

8.2.2 Non-exhaustiveness of the current suitability criteria for a generalized leading indicator approach

One of the important limitations of the current study on the generalized leading indicator operationalization approach is related to the exhaustiveness of the identified suitability criterion. The current study had considered only one generalizable mechanism of system evolution, and correspondingly could identify two new suitability criteria. However, when the methodology was tested in the field by taking a case for Johkasou system in Japan, the reporting channels identified as crucial by the method were not necessarily considered to be crucial by the practitioners in the field. Such testing then highlights the importance of considering several other contextual factors that could affect the selection of the leading indicators to be monitored. Further, many more mechanisms of system evolution are possible, especially for non-technical systems. Hence further efforts are necessary to test the methodology proposed in this study for other complex systems as well as more mechanisms of system evolution that should be considered.

8.2.3 Integration among reporting systems for reports with varying degree of severity

Form the application of the generalized SD model to the HSR organizations, few limitations of the model were highlighted. Firstly, the model encountered seemingly contrary behaviors. In our model, it was found that the organizations which base their decision making on slightly long term trends of the number of reports are much suitable to have a stable commitment to safety and take safety measures. Hence, the organizations with more hierarchical structures that longer time to process the information on the number of reports performed more stably compared to lean organizations having a very quick response to the trends. However, as per the safety theory from (Hopkins 2019), organizations with hierarchical structures are likely are poorly versed to manage the safety issues in time. Our model is not able to explain such a trend partially due to its inability to consider the difference in the type of reports based on their severity. While the employee's reporting behavior for each severity will be different, the management's factor determining affecting the reporting behavior is determined based on the combined information obtained through several reporting channels. Hence, there is a necessity to consider the integration in the dynamics affecting the reporting of various types of reports for the SD model to be generalized. Such variation in the type of reports is not considered even in the previous SD studies focusing on the overall safety behavior of employees in an organization. Such an integrated model will then also help in simulating the reporting behavior in organizations with varying degrees of complexity.

8.3. Future Work

8.3.1 Extension of the study to other systems

The ACAT method, combined with STAMP, is proven to be an effective method to highlight the importance of the organizational and institutional factors contributing to the safety of complex systems. Even with the limited information of just 6 accident cases, significant supporting evidence could be gathered. When this evidence was presented to the practitioners, it was readily acceptable. The combination of the methodologies could then be further extended to the regular railway accidents in Japan, revealing more patterns for accidents at the organizational and institutional levels. In addition, the trends obtained for the relative focus on various accident causal factors are similar across the different types of complex systems (Figure 7-1). Hence, the methods should be extended to other complex systems. The research is also necessary to improve the limitation of the study highlighted in the previous section, i.e., factors focusing on the selection criterion of accident models and theories in the context of Japanese HSR should be identified, and the STAMP's merit specifically for those factors needs to be established.

8.3.2 Improvement in the study on leading indicators

As mentioned above, more generalized mechanisms of system evolution need to be identified in order to further develop the leading indicator methodologies for non-technical systems.

8.3.3 Testing the SD model for more systems

To the best of the author's knowledge, the current study was a first attempt to develop a comprehensive SD model explaining the near-miss reporting behavior in a general organization. In that, the model was successful in explaining several of the system-behaviors observed in real life. However, the model is also limited in explaining a number of behaviors. Such a limitation is thought to be improved by the use of an integrated model simultaneously considering the reporting behavior for reports with different severity. Hence, future studies should focus on developing an integrated model and calibrating it with long-term trends in the reporting behavior of various organizations.

8.4. Conclusions

The summary of the research questions, the study objectives, and the main conclusions are summarized in Table 8-1.

Table 8-1 Summary of the conclusions and implications of study

Research Questions *Q1. How do the organizational (Risk-Management, Reporting Behavior) and institutional level (Risk-Management) risks affect Shinkansen Safety? and* *Q2. How can Shinkansen Safety be improved?*			
Research Objectives *O1. Clarify challenges in the current safety management practices (Risk-management) at Organizational and Institutional levels in Japanese Shinkansen and identify strategies to improve the practices.* *O2. Develop methods necessary for implementing pro-active risk-management strategies at the organizational and institutional levels.* *O3. Clarify the factors affecting reporting behavior at the organizational level in Japanese Shinkansen.*			
Summary of main conclusions			
#	**Q**	**O**	**Conclusion**
1	Q1	O1	RM related issues are among the most prominent issues in past HSR accidents, while the current focus of the practitioners is on technical and human-error-related factors.
2	Q1	O1	RM practices in Japan at the organizational and institutional levels are comprehensive. However, the underlying tools and the understanding of the accident is old and not suitable to be applied for complex systems. Due to increased complexity in Japanese HSR, the system is more prone to systemic accidents in which multiple safety-defenses can be rendered ineffective by a few systemic factors. Such accidents cannot be analyzed by the current Japanese RM practices and need accident models such as STAMP. STAMP analysis is useful in identifying lessons that are often missed by the comprehensive accident analysis reports.
3	Q1	O1	The study identified a safety archetype describing the vulnerability of the operator-regulator relationship in providing adequate safety control. The archetype is also useful in identifying potential solutions to overcome the vulnerability, such as the to have an independent risk assessment for the regulator and the organization being regulated, and to develop leading-indicators at the organizational level, that can enable time-bound risk-assessment of the system.
4	Q2	O2	The proposed generalized leading indicator operationalization method is shown to be grounded in several theoretical and practical safety-related aspects, is found to be effective in identifying leading indicators that are more comprehensive than the indicators currently being monitored for two complex systems, i.e., Johkasou and for HSR.
5	Q1, Q2	O2	The proposed indicator operationalization scheme received a mixed response in the real-world verification. In reality, there are several contextual factors and trade-offs that affect the desired level of system monitoring and are not currently captured by the proposed method of leading indicators. These trade-offs include the capacity constraints for the regulator and the balance between control and operator's autonomy.
6	Q1, Q2	O3	The SD model developed in this study allows simulating the organizational policy scenarios affecting the reporting behavior of employees in a complex socio-technical system and thus can be used to improve the safety.
7	Q1	O3	Commonly reported factors affecting near-miss reporting behavior are the effect of work-load fatigue, incentives, and their perceived benefits, the habit of reporting,

			risk-perception, feedback from the management, and the management's commitment to safety. Our model showcases that the effect of a reduction in a working hour is path-dependent, and often in the short-term, the behavior could point out that the policy of reducing the work hours is not working. The results from the simulation also help gather support in the importance of organizational incentives and their effect on reporting behavior.
Implications			
1	Q1, Q2	O1	System-specific contexts determine the overall emerging behavior, and hence organizational and regulatory level decisions should utilize the system-thinking based RM approach to design solutions in such a way that they can manage system-specific variations to keep a healthy balance in the simultaneous achievement of multiple functions.
2	Q1, Q2	O1	Lessons from the study here focusing on organizational factors, such as the effect of fatigue and the incentive to reporting, and their impact on near-miss reporting is surely important and could play an important role in improving the reporting culture, and thus safety, of HSR TOCs in Japan, such as JR West.
3	Q1, Q2	O1	The results from ACAT analysis provide immediate food for thought for the Japanese HSR practitioners. A natural extension of the current study will be to obtain ACAT trends by analyzing the events of near-misses, etc., to further develop a thorough understanding of the risk factors in Japanese HSR.
4	Q2	O1	The development and effective monitoring of system-specific and assumption based leading indicators for process safety may be an effective approach for pro-active safety management. These leading indicators must be developed for all types of system components, including the organizational and institutional components.
5	Q2	O1	In the RM for a complex system, it is important to first identify as many risk factors as possible and then make a decision on an adequate level of monitoring. In doing so, a comprehensive repository of risks can still be available, out of which some can be monitored frequently, while others could be monitored at a pre-determined frequency suitable to both the regulator and the operator. Hence, a win-win solution can still be obtained by addressing the important trade-offs addressing the regulator's capacity, as well as the balance between the operator's autonomy and control.
6	Q2	O1	The current study recommends establishing an RM License for experiences HSR Professionals in Japan, under which, the licensed professional can perform systematic RM for the Japanese HSR, on behalf of the regulator
7	Q2	O1	In a situation where the choice of accident model is usually constrained by the practical requirements of the practitioners, for a learning organization, it is always important to try and adopt newer methods of risk analysis. Here, STAMP could serve as an important tool, where the in-depth analysis of organizational and institutional factors under the expected increase in the degree of complexity and system centralization could reveal new accident mechanisms and provide guidance on future improvement. Other accident models suitable for complex systems such as the FRAM, should also be considered for their advantages.
8	Q2	O1	Each of the option to distribute the safety-related responsibility among the operator and the manufacturer is associated with corresponding trade-offs, and a detailed stakeholder analysis must be carried out in order to identify the best suitable solutions relevant to the Japanese HSR.
9			The operator-regulator relationship and organizational factors have been identified as crucial causal factors for many HSR systems around the world, and safety implications from several of the above studies will be of direct relevance to India.

The study has examined organizational and institutional factors affecting HSR safety performance and makes a case for utilizing the system-control-safety theory for pro-active safety management in Japanese Shinkansen. The study thus identifies the necessity for developing leading indicators at the organizational level as a pro-active safety management strategy. The study has also developed practical approaches to implementing leading indicators within HSR organizations. The study developed and validated an SD model describing the factors affecting and assessing their impact on the quality of feedback. The SD model can serve as an important policy tool to assess and improve the effectiveness of the leading indicator programs while considering the underlying organizational dynamics.

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Appendix A: Equations of the System Dynamics Model

(001) Accomplishments per day= Accomplishments per Hour*Hours worked per Day
Units: A/Day

(002) Accomplishments per Hour = WITH LOOKUP (Energy Level,([(0,0.4)-(1,1)],(0,0.5),(0.2,0.6),(0.4,0.7),(0.6,0.8),(0.8,0.9),(1,1)))
Units: A/hour

(003) Additional hours by accident investigation= Average Time for an investigation*Level of Investigation*Report Investigation Rate/Number of workers
Units: hour/Day

(004) Attention effect on incident observation= (Effect of Energy level)^2
Units: Dmnl

(005) Average delay for PC decrease= 14 Units: Day

(006) Average Incident Rate= SMOOTH(Total Incident Reporting Rate, Time to form Average)
Units: incident/Day

(007) "Average report follow-up time"= 15 Units: Day

(008) Average Report Investigation time= 7 Units: Day

(009) Average Risk Perception among colleagues= 0.8 Units: Dmnl

(010) Average Time for an investigation= 2 Units: hour/incident

(011) Average time for awareness increment= 2 Units: Day

(012) Average time for Hazard accumulation= 60 Units: Day

(013) Average Time for Hazard Mitigation= 60 Units: Day

(014) Average Time for knowledge depletion= 66 Units: Day

(015) Average time for Risk Recovery= 30 Units: Day

(016) Average time to decay Hazard Mitigation= 120 Units: Day

(017) Average time to Decay Reporting Channel= 1825 Units: Day

(018) Average time to Decay Risk Communucation= 60 Units: Day

(019) Average time to Decay Training= 60 Units: Day

(020) Average time to decrase follow up perception= 14 Units: Day

(021) Average Time to decrease management Commitment= 60 Units: Day

(022) Average time to form Management's Commitment= 30 Units: Day

(023) Average Time to Improve Hazard Mitigation= 30 Units: Day

(024) Average Time to improve Risk Communication= 10 Units: Day

(025) Average Time to Improve Training= 60 Units: Day

(026) Average Time to Incentive perception= 15 Units: Day

(027) Average Time to modify Reporting Channel= 60 Units: Day

(028) Averge Time to forming perception= 14 Units: Day

(029) Awareness Increment= IF THEN ELSE("Safety Awareness (Level 1)"<1, DELAY1(Management's committment to Improve Safety , 28)*"Input of Tool-box meeting", 0) Units: Dmnl/Day

(030) Awareness Level 1 to 2= "Safety Awareness (Level 1)"/Average time for awareness increment/2 Units: Dmnl/Day

(031) Bias for fractional changes in expectations= 0.1/7 Units: 1/Day

(032) Burden of INvestigation= Additional hours by accident investigation/Reference Additional Hours Units: Dmnl

(033) Commitment Decrease rate= IF THEN ELSE(Management's committment to Improve Safety>0, Management's committment to Improve Safety /Average Time to decrease management Commitment , 0) Units: Dmnl/Day

(034) Commitment improvement Rate= IF THEN ELSE((Target Management Commitment to Safety-Management's committment to Improve Safety)>0, (Target Management Commitment to Safety-Management's committment to Improve Safety)/Average time to form Management's Commitment , 0) Units: Dmnl/Day

(035) Convinience for Reporting= (IF THEN ELSE(Switch to Inertia=0, 1 , Inertia of Reporting habit)*Initial Convinience of Reporting)*IF THEN ELSE("Switch to time-pressure"=0, 1 , (Weekly Energy/MAX(1, Burden of INvestigation))^1)
Units: Dmnl

(036) Corrective Actions= (Hazard Mitigation+Risk Communication Effectiveness+Safety Training+Relative Organizational Knowledge)/4 Units: Dmnl

(037) Day of the Week= IF THEN ELSE((Time/7-INTEGER(Time/7))*7<1 , 1 , IF THEN ELSE((Time/7-INTEGER (Time/7))*7<2, 2 , IF THEN ELSE((Time/7-INTEGER(Time/7))*7<3, 3 , IF THEN ELSE ((Time/7-INTEGER(Time/7))*7<4, 4 , IF THEN ELSE((Time/7-INTEGER(Time/7))*7 <5, 5 , IF THEN ELSE((Time/7-INTEGER(Time/7))*7<6, 6 , IF THEN ELSE((Time/ 7-INTEGER(Time/7))*7<7, 7 , 0))))))) Units: Dmnl

(038) Delay in incident perception=10 Units: Day

(039) Depletion Rate= (Number of incidents in a Week-4)*(PULSE TRAIN(7, TIME STEP , 7 , 4000)) /TIME STEP Units: incident/Day

(040) Effect of Energy level= Weekly Energy Units: Dmnl

(041) Effect of Energy level on hours worked = WITH LOOKUP (Energy Level,([(0,0)-(1,1)],(0,0),(0.2,0.4),(0.400612,0.697368),(0.614679,0.881579),(0.889908,0.964912),(1,1))) Units: Dmnl

(042) Effect of high ernegy on further recovery = WITH LOOKUP (Energy Level,([(0.8,0)-(1,1)],(0.8,1),(0.85,0.9),(0.9,0.7),(0.95,0.4),(1,0))) Units: Dmnl

(043) Effect of hour worked on energy recovery = WITH LOOKUP (Total working hours per day,([(0,0)-(24,2)],(0,1.3),(4,1.2),(8,1),(12,0.7),(16,0.5),(20,0.35),(24,0.25))) Units: Dmnl

(044) Effect of hours worked on energy depletion = WITH LOOKUP (Total working hours per day,([(0,0)-(24,3)],(0,0.3),(4,0.6),(8,1),(12,1.5),(16,2),(20,2.5),(24,3))) Units: Dmnl

(045) Effect of Incident Rate on Management'c ommitment to Safety=(Relative Incident Rate^Incident learning exponent)*Severity effect on PC Units: Dmnl

(046) Effect of low energy on further depletion = WITH LOOKUP (Energy Level,([(0,0)-(0.2,1)],(0,0),(0.05,0.4),(0.1,0.7),(0.15,0.9),(0.2,1))) Units: Dmnl

(047) Effect of Manger's descisions on Risk Perception= (Risk Communication Effectiveness+Safety Training)/2 Units: Dmnl

(048) Effect of percieved adequacy on energy depletion= Percieved adequacy of accomplishment*2 Units: Dmnl

(049) Effect of percieved adequacy on hour worked = WITH LOOKUP (Percieved adequacy of accomplishment,([(0,0)-(1.6,3)],(0,2.3),(0.2,1.9),(0.4,1.6),(0.6,1.35),(0.8,1.15),(1,1) ,(1.2,0.9),(1.4,0.8),(1.6,0.75))) Units: Dmnl

(050) Effect of Production pressure on Management's commitment to Safety= (Percieved adequacy of accomplishment/Reference adequacy of accomplishment)^Performance pressure exponent Units: Dmnl

(051) Effect of the Day of the Week = WITH LOOKUP (Day of the Week,([(1,0.7)-(7,2)],(1,1.2859),(2,1.1781),(3,1.078),(4,0.97),(5,0.87),(6,0.77),(7,0.77))) Units: Dmnl

(052) Effect on the Unsafe Acts= (1.3-Effect of Energy level)^1/EXP(Number of incidents in a Week*Level of Interpersonal Bonding /4) Units: Dmnl

(053) Energey Depletion=Energy depletion normal*Effect of low energy on further depletion*Effect of hours worked on energy depletion *Effect of percieved adequacy on energy depletion Units: 1/Day

(054) Energy depletion normal= 0.09/7 Units: 1/Day

(055) Energy Level= INTEG (Energy Recovery-Energey Depletion,0.9) Units: Dmnl

(056) Energy Recovery= Energy Recovery Normal*Effect of hour worked on energy recovery*Effect of high ernegy on further recovery Units: 1/Day

(057) Energy Recovery Normal= 0.17/7 Units: 1/Day
to convert into days

(058) Expected Accomplishment increment rate= IF THEN ELSE(Expected Accomplishment Per Day<Maximum Accomplishment Per Day , Expected Accomplishment Per Day*(Fractional change in expectations from percieved adequacy) , 0) Units: A/Day/Day

(059) Expected Accomplishment Per Day= INTEG (Expected Accomplishment increment rate, 9.5) Units: A/Day

(060) Exponent of Orgaizational Knowledge effect on management comimitment to Safety = 0.1 Units: Dmnl

(061) Exposure Mitigation= IF THEN ELSE(Hazard Exposure>0, Hazard Exposure*Corrective Actions/Average Time for Hazard Mitigation , 0) Units: Dmnl/Day

(062) Exposure Rate= 0.2*Hazard Exposure/Average time for Hazard accumulation +0.1 Units: Dmnl/Day

(063) External Descision to Improve Commitment=IF THEN ELSE(Switch to External Commitment Improvement=0, 0 , 1)*PULSE(Start Time for management's Commitment , TIME STEP)*IF THEN ELSE(Management's committment to Improve Safety<1, (1-Management's committment to Improve Safety)/TIME STEP , 0) Units: Dmnl/Day

(064) FINAL TIME = 1500 Units: Day

(065) Follow up perception decrease rate=IF THEN ELSE(Individual perception on report followup>0, IF THEN ELSE("Gap in follow-up perception" <0, -"Gap in follow-up perception"/Average time to decrase follow up perception , 0), 0) Units: Dmnl/Day

(066) Follow up perception formation rate=IF THEN ELSE(Individual perception on report followup<1, IF THEN ELSE("Gap in follow-up perception" >0 , "Gap in follow-up perception"/Averge Time to forming perception , 0) , 0) Units: Dmnl/Day

(067) "Follow-up Consideration Rate"=Management's committment to Improve Safety*Incident Reporting Rate*Number of workers Units: incident/Day

(068) Fraction of Incidents Reported=Number of Incidents Reported/Number of Incidents Occured Units: Dmnl

(069) Fraction of Reports Investigated= Number of Reports investigated/Number of Incidents Reported/Number of workers Units: Dmnl

(070) Fractional change in expectations from percieved adequacy = WITH LOOKUP (Percieved adequacy of accomplishment,([(0,-0.2)-(1.6,0.2)],(0,0),(0.2,0),(0.4,0),(0.6,0),(0.8,0),(1,0),(1.2,0.014),(1.4,0.036),(1.6,0.058))) Units: 1/Day

(071) Fractional Loss = WITH LOOKUP (Severity,([(0,0)-(6,1)],(0,0.14),(0.0550459,0.140351),(0.972477,0.157895),(2.05505 ,0.188596),(2.89908,0.27193),(3.48624,0.346491),(3.96636,0.416667),(4.48624,0.530702),(5.06728,0.666667),(5.57187,0.789474),(5.81651,0.881579),(6,1))) Units: Day/incident

(072) "Gap in follow-up perception"= "Real follow-up fraction"-Individual perception on report followup Units: Dmnl

(073) Gap in Hazard Mitigation= Management's committment to Improve Safety-Hazard Mitigation Units: Dmnl

(074) Gap in Reporting Channel Conditions= Management's committment to Improve Safety-Reporting Channel effectiveness Units: Dmnl

(075) Gap in Risk Communucation= Management's committment to Improve Safety-Risk Communication Effectiveness Units: Dmnl

(076) Gap in Safety Training= Management's committment to Improve Safety-Safety Training Units: Dmnl

(077) Habituation time= 120 Units: Day

(078) Hazard Exposure= INTEG (Exposure Rate-Exposure Mitigation,1) Units: Dmnl

(079) Hazard Mitigation= INTEG (Hazard Mitigation Imporvement Rate-Hazarrd Mitigation Decay Rate,0.3) Units: Dmnl

(080) Hazard Mitigation Imporvement Rate=IF THEN ELSE(Hazard Mitigation<1 , IF THEN ELSE(Gap in Hazard Mitigation >0, (Gap in Hazard Mitigation/Average Time to Improve Hazard Mitigation) , 0) , 0) Units: Dmnl/Day

(081) Hazarrd Mitigation Decay Rate=IF THEN ELSE(Hazard Mitigation>0 , (Hazard Mitigation/Average time to decay Hazard Mitigation), 0)Units: Dmnl/Day

(082) Hours worked per Day= INTEG ("hours/day increment rate",9) Units: hour/Day

(083) "hours/day increment rate"= (Indicated hours worked per week-Hours worked per Day)/Time to adjust HWW Units: hour/Day/Day

(084) I decrease Rate=IF THEN ELSE(Inertia of Reporting habit>0, IF THEN ELSE((Individual reporting fration -Inertia of Reporting habit)<0,-(Individual reporting fration-Inertia of Reporting habit)/Habituation time , 0) , 0) Units: Dmnl/Day

(085) I Improvement Rate=IF THEN ELSE(Inertia of Reporting habit<1, IF THEN ELSE((Individual reporting fration -Inertia of Reporting habit)>0, (Individual reporting fration -Inertia of Reporting habit)/Habituation time , 0) , 0) Units: Dmnl/Day

(086) Incentives for reporting= 0*STEP(1, 200) Units: Dmnl

(087) Incident learning exponent= 0.4 Units: Dmnl

(088) Incident observation effect on PC= (Perceived Incident observation rate/Reference Percieved Incident Observation rate)^Observation rate exponent for effect on PC Units: Dmnl

(089) Incident Observation Rate= Incident Occurance Rate*IF THEN ELSE(Switch to Safety Awareness=0, 1 , Safety Awareness)*IF THEN ELSE("Switch to time-pressure"=0, 1 , Attention effect on incident observation) Units: incident/Day

(090) Incident Occurance Rate= Nominal Risk of Accident*IF THEN ELSE(Switch of Hazard Mitigation=0, 1 , Hazard Exposure)*Effect on the Unsafe Acts Units: incident/Day

(091) Incident report intention rate=IF THEN ELSE(Intention to report>0, Incident Observation Rate*Intention to report, 0) Units: incident/Day

(092) Incident Reporting Rate=Incident report intention rate*IF THEN ELSE(Switch to reporting Motivation =0, 1, Reporting Motivation)*IF THEN ELSE(Switch to Inertia=0, 1 , Inertia of Reporting habit)*IF THEN ELSE(Switch to facilitating conditions=0, 1 , Reporting Channel effectiveness) Units: incident/Day

(093) Incidents rate for a week= DELAY FIXED(Incident Occurance Rate , 2 , Incident Occurance Rate) Units: incident/Day

(094) Indicated hours worked per week= MAX(MIN(Limit on hours worked per day, Hours worked per Day*Effect of Energy level on hours worked *Effect of percieved adequacy on hour worked) , Minimum Hours worked per day) Units: hour/Day

(095) Individual perception on report followup= INTEG (Follow up perception formation rate-Follow up perception decrease rate,0.5) Units: Dmnl

(096) Individual reporting fration= Number of Incidents Reported/Number of Incidents Observed Units: Dmnl

(097) Inertia of Reporting habit= INTEG (I Improvement Rate-I decrease Rate, 1) Units: Dmnl

(098) Initial Convinience of Reporting= 0.8 Units: Dmnl

(099) INITIAL TIME = 0 Units: Day

(100) "Input of Tool-box meeting"=IF THEN ELSE(Time>=490, PULSE TRAIN(490, 0.042 , 14 , 4000)*0.5/0.021,PULSE TRAIN (7, 0.021 , 7 ,4000)*0.5/0.021) Units: Dmnl/Day

(101) Intention to report= MIN(1, DELAY1(Utility of Reporting, Time to intent formation)) Units: Dmnl

(102) Investigation consideration Rate=Management's committment to Improve Safety*Incident Reporting Rate*Number of workers Units: incident/Day

(103) Knowledge Depletion Rate= Level of Oragnizational Knowledge/Average Time for knowledge depletion Units: learning/Day

(104) Learning from Incidents= Level of Investigation*Quality of learning*Report Investigation Rate*Severity Units: learning/Day

(105) Level of Interpersonal Bonding= 1 Units: Dmnl

(106) Level of Investigation= IF THEN ELSE(Management's committment to Improve Safety>1, 1 , Management's committment to Improve Safety) Units: Dmnl

(107) Level of Oragnizational Knowledge= INTEG (Learning from Incidents-Knowledge Depletion Rate, 2000) Units: learning

(108) Limit on hours worked per day=IF THEN ELSE(Time>=500, 11.993-Additional hours by accident investigation ,12-Additional hours by accident investigation) Units: hour/Day

(109) Management's committment to Improve Safety= INTEG (Commitment improvement Rate+External Descision to Improve Commitment-Commitment Decrease rate ,0.2) Units: Dmnl

(110) Maximum Accomplishment Per Day= 12 Units: A/Day

(111) Maximum Management's commitment to Safety= 1.2 Units: Dmnl

(112) Maximum PC= 1 Units: Dmnl

(113) Minimum Hours worked per day= 8 Units: hour/Day

(114) Monthly Incident= INTEG (monthly incident coming rate-Monthly incident reporting rate,0) Units: incident

(115) monthly incident coming rate=Incident Reporting Rate*Number of workers Units: incident/Day

(116) Monthly incident reporting rate=(Monthly Incident/TIME STEP)*PULSE TRAIN(30 , TIME STEP , 30 , 4000) Units: incident/Day

(117) Monthly Rate=Monthly incident reporting rate*TIME STEP Units: Dmnl/Day

(118) Nominal Risk of Accident= 0.06 Units: incident/Day

(119) Normal accomplishment per hour= 1 Units: A/hour

(120) Number of incidents in a Week= INTEG (Incidents rate for a week-Depletion Rate, 4) Units: incident

(121) Number of Incidents Observed= INTEG (Incident Observation Rate, 1) Units: incident

(122) Number of Incidents Occured= INTEG (Incident Occurance Rate, 1) Units: incident

(123) Number of Incidents Reported= INTEG (Incident Reporting Rate, 0.35) Units: incident

(124) Number of incidents to be reported= INTEG (Incident report intention rate,1) Units: incident

(125) Number of Reports followed up= INTEG (Report Following Rate,0.6) Units: incident

(126) Number of Reports investigated= INTEG (Report Investigation Rate,0) Units: incident

(127) Number of Reports to be Followed Up= INTEG ("Follow-up Consideration Rate"-Report Following Rate,1) Units: incident

(128) Number of Reports to be Investigated= INTEG (Investigation consideration Rate-Report Investigation Rate,0) Units: incident

(129) Number of workers=16000 Units: Dmnl

(130) Observation rate exponent for effect on PC= 0.4 Units: Dmnl

(131) PC Decreasing Rate=IF THEN ELSE("Risk Percieving Coefficient (PC)">0, DELAY3(Risk Recovery/ Average time for Risk Recovery , Average delay for PC decrease) , 0) Units: Dmnl/Day

(132) PC increment Rate= IF THEN ELSE("Risk Percieving Coefficient (PC)"<1, 0*Risk perception compared to collegues /Risk Percieving time +Risk perception compared to Management's descision/Risk Percieving time +IF THEN ELSE(Target PC>"Risk Percieving Coefficient (PC)", (Target PC-"Risk Percieving Coefficient (PC)")/Risk Percieving time , 0),0) Units: Dmnl/Day

(133) Perceived Incident observation rate= SMOOTH(Incident Observation Rate , Time to form perception for incidents) Units: incident/Day

(134) Percieved accomplish increment rate= (Accomplishments per day-Percieved accomplishment per day)/Time to percieve accomplishments per day
Units: A/Day/Day

(135) Percieved accomplishment per day= INTEG (Percieved accomplish increment rate, 8)
Units: A/Day

(136) Percieved adequacy of accomplishment= Percieved accomplishment per day/(Expected Accomplishment Per Day*(1+0*Fractional Loss *Incident Occurance Rate)) Units: Dmnl

(137) Percieved incentive= SMOOTH(Management's committment to Improve Safety*Incentives for reporting , Average Time to Incentive perception) Units: Dmnl

(138) Percieved incident Severity= SMOOTH(Severity , Time to form perception for incidents) Units: Dmnl

(139) Performance pressure exponent= 2 Units: Dmnl

(140) Pressure to change management's commitment to Safety= Effect of Incident Rate on Management'c ommitment to Safety*(Relative Organizational Knowledge)^Exponent of Orgaizational Knowledge effect on management comimitment to Safety*Effect of Production pressure on Management's commitment to Safety
Units: Dmnl

(141) Quality of learning=IF THEN ELSE(Management's committment to Improve Safety>1, 1, Management's committment to Improve Safety*Unit Quality of Learning) Units: learning/incident

(142) "Real follow-up fraction"= Number of Reports followed up/Number of workers/Number of Incidents Reported Units: Dmnl

(143) Reference Additional Hours= 0.004 Units: hour/Day

(144) Reference adequacy of accomplishment= 1 Units: Dmnl

(145) Reference Incident Rate= 160 Units: incident/Day

(146) Reference Organizational Knowledge= 2000 Units: learning

(147) Reference Percieved Incident Observation rate= 0.3 Units: incident/Day

(148) Reference Severity= 1 Units: Dmnl

(149) Relative Incident Rate= Average Incident Rate/Reference Incident Rate Units: Dmnl

(150) Relative Organizational Knowledge= Level of Oragnizational Knowledge/Reference Organizational Knowledge Units: Dmnl

(151) "Relative Strength of Awareness/Exposure"= Safety Awareness/Hazard Exposure Units: Dmnl

(152) Report Following Rate= IF THEN ELSE(Number of Reports to be Followed Up>0, Number of Reports to be Followed Up/"Average report follow-up time" , 0) Units: incident/Day

(153) Report Investigation Rate= IF THEN ELSE(Number of Reports to be Investigated>0, Number of Reports to be Investigated/Average Report Investigation time , 0) Units: incident/Day

(154) Reporting Channel Decay Rate= IF THEN ELSE(Reporting Channel effectiveness>0 , (Reporting Channel effectiveness/Average time to Decay Reporting Channel), 0) Units: Dmnl/Day

(155) Reporting Channel effectiveness= INTEG (Reporting Channel Improvement Rate-Reporting Channel Decay Rate, 0.3) Units: Dmnl

(156) Reporting Channel Improvement Rate= IF THEN ELSE(Reporting Channel effectiveness<1 , IF THEN ELSE(Gap in Reporting Channel Conditions >0, (Gap in Reporting Channel Conditions/Average Time to modify Reporting Channel) , 0) , 0) Units: Dmnl/Day

(157) Reporting Motivation = WITH LOOKUP (Individual perception on report followup,([(0,0)-(1,1)],(0,0.2),(0.174312,0.22807),(0.281346,0.315789),(0.388379, 0.403509),(0.525994,0.631579),(0.605505,0.842105),(0.697248,0.938596),(0.804281,0.973684),(0.902141,0.991228),(1,1)))
Units: Dmnl

(158) Risk Communication decrease Rate=IF THEN ELSE(Risk Communication Effectiveness>0 , (Risk Communication Effectiveness

/Average time to Decay Risk Communucation), 0) Units: Dmnl/Day

(159) Risk Communication Effectiveness= INTEG (-Risk Communication decrease Rate+Risk Communication Increase rate, 0.3) Units: Dmnl

(160) Risk Communication Increase rate=IF THEN ELSE(Risk Communication Effectiveness<1 , IF THEN ELSE(Gap in Risk Communucation >0, (Gap in Risk Communucation/Average Time to improve Risk Communication) , 0) , 0) Units: Dmnl/Day

(161) Risk perception compared to collegues=Average Risk Perception among colleagues-"Risk Percieving Coefficient (PC)" Units: Dmnl

(162) Risk perception compared to Management's descision=IF THEN ELSE((Effect of Manger's descisions on Risk Perception-"Risk Percieving Coefficient (PC)")>0, (Effect of Manger's descisions on Risk Perception-"Risk Percieving Coefficient (PC)") , 0) Units: Dmnl

(163) "Risk Percieving Coefficient (PC)"= INTEG (PC increment Rate-PC Decreasing Rate, 0.2) Units: Dmnl

(164) Risk Percieving time= 10 Units: Day

(165) Risk Recovery= 1/(10)^"Risk Percieving Coefficient (PC)" Units: Dmnl

(166) Safety Awareness= INTEG (Awareness Level 1 to 2-Safety Awarness Depriciation, 0.5) Units: Dmnl

(167) "Safety Awareness (Level 1)"= INTEG (Awareness Increment-Awareness Level 1 to 2, 0.5) Units: Dmnl

(168) Safety Awarness Depriciation=Safety Awareness/Average time for awareness increment/2 Units: Dmnl/Day

(169) Safety Training= INTEG (Training Improvement rate-Training Decay Rate,0.3) Units: Dmnl

(170) SAVEPER = TIME STEP Units: Day [0,?] The frequency with which output is stored.

(171) Severity= SMOOTH((1/Corrective Actions)^2, Average Time for Hazard Mitigation) Units: Dmnl

(172) Severity effect on PC= (Percieved incident Severity/Reference Severity)^Severity exponent for effect on PC Units: Dmnl

(173) Severity exponent for effect on PC= 1 Units: Dmnl

(174) Social Importance on Reporting= 0.2+(1-Level of Interpersonal Bonding) Units: Dmnl

(175) Start Time for management's Commitment= 600 Units: Day

(176) Switch of Hazard Mitigation= 1 Units: Dmnl

(177) Switch to External Commitment Improvement= 0 Units: Dmnl
(178) Switch to facilitating conditions= 0 Units: Dmnl

(179) Switch to Inertia= 0 Units: Dmnl

(180) Switch to reporting Motivation= 1 Units: Dmnl
(181) Switch to Safety Awareness= 1 Units: Dmnl

(182) "Switch to time-pressure"= 1 Units: Dmnl

(183) Target Management Commitment to Safety=IF THEN ELSE(Pressure to change management's commitment to Safety>1, 1, Pressure to change management's commitment to Safety)*Maximum Management's commitment to Safety Units: Dmnl

(184) Target PC= IF THEN ELSE(Incident observation effect on PC*Severity effect on PC>1 , 1 , Incident observation effect on PC*Severity effect on PC)*Maximum PC Units: Dmnl

(185) TIME STEP = 0.0078125 Units: Day

(186) Time to adjust HWW= 1 Units: Day
(187) Time to form Average= 7 Units: Day

(188) Time to form perception for incidents= 7 Units: Day

(189) Time to intent formation= 10 Units: Day

(190) Time to percieve accomplishments per day= 28 Units: Day

(191) Total Incident Reporting Rate=SMOOTHI(Incident Reporting Rate*Number of workers , Delay in incident perception , 0.1) Units: incident/Day

(192) Total working hours per day=Additional hours by accident investigation+Hours worked per Day Units: hour/Day

(193) Training Decay Rate=IF THEN ELSE(Safety Training>0 , (Safety Training/Average time to Decay Training), 0) Units: Dmnl/Day

(194) Training Improvement rate= IF THEN ELSE(Safety Training<1 , IF THEN ELSE(Gap in Safety Training>0, (Gap in Safety Training/Average Time to Improve Training) , 0) , 0) Units: Dmnl/Day

(195) Unit Quality of Learning= 1 Units: learning/incident

(196) Utility of Reporting= ("Risk Percieving Coefficient (PC)"+Convinience for Reporting+Social Importance on Reporting+(1+Percieved incentive)/1.5)/4 Units: Dmnl

(197) Weekly Energy= Effect of the Day of the Week*Energy Level Units: Dmnl

(198) Work Accomplishment= INTEG (Work Accomplishment Rate,0) Units: A

(199) Work Accomplishment Rate=Expected Accomplishment Per Day*Percieved adequacy of accomplishment Units: A/Day

Appendix B : List of Interviews

#	Interviewee	Date and Place	Main Discussion Theme
1	1. Mr. Masahiro OTANI, Former Senior Railway Official, JR Central and Former Senior Adviser to Taiwan HSR Corporation, 2. Mr. Toru FUKUSHIMA, Senior Engineering Advisor, Japan International Consultants for Transportation, and Former Senior Railway Official, JR Central	Apr 5, 2019. JIC office, Tokyo	Discussion on the crack in bogey frame in Japanese HSR, and the coordination between the operator and the manufacturer to manage the cracks
2	1. Mr. Masahiro OTANI, Former Senior Railway Official, JR Central and Former Senior Adviser to Taiwan HSR Corporation, 2. Mr. Toru FUKUSHIMA, Senior Engineering Advisor, Japan International Consultants for Transportation, and Former Senior Railway Official, JR Central	June 6, 2019. JIC office, Tokyo	Discussion on near-miss reporting behavior of employees in JR, and the verification of the causal structure using a disconfirmation approach
3	1. Mr. Masahiro OTANI, Former Senior Railway Official, JR Central and Former Senior Adviser to Taiwan HSR Corporation, 2. Mr. Toru FUKUSHIMA, Senior Engineering Advisor, Japan International Consultants for Transportation, and Former Senior Railway Official, JR Central	July 26, 2019. Through Email	Seeking confirmation for acknowledging the contribution of the two interviewees in our work
4	1. Mr. Masahiro OTANI, Former Senior Railway Official, JR Central and Former Senior Adviser to Taiwan HSR Corporation, 2. Mr. Toru FUKUSHIMA, Senior Engineering Advisor,	December 20th, 2019. JIC office, Tokyo	Discussion on the findings of the STAMP analysis and the Safety Archetype. Comments on the value-of the overall approach.

	Japan International Consultants for Transportation, and Former Senior Railway Official, JR Central		
5	Dr. Shinhi Kumokawa, Director, Center for International Cooperation of Johkasou System, Japan Education Center of Environmental Sanitation	September 17th, 2019. JECES Office	Discussion on risks related to the Johkasou inspection agency and the leading indicator monitoring
6	1. Mr. Yoshitaka Ishii, Former President, and Group Chairman, JR Kyushu 2. 1 official of JR Kyushu responsible for managing the near-miss reporting in JR Kyushu 3. 1 official of JR Kyushu responsible for the railway safety museum, an employee training center on safety	October 29, 2019. Field visit to JR Kyushu in Kitakyushu	Discussion on near-miss reporting as well as a visit to the railway safety museum
7	1. Dr. Yasushi Ujita, Deputy General Director, International Division, JR Railway Technical Research Institute 2. Dr. Koji Omino, Director, Human Science Division, JR Railway Technical Research Institute	December 23, 2019. Visit RTRI Office, in Tokyo	Discussion on the findings of the System-Dynamic model formation and results
8	Hiroyuki Kanaoka General Manager of Track and Structures Department Railway Operations Headquarters West Japan Railway Company	January 15, 2020. Through email	Confirmation about the use of incentives as a means to promote near-miss reporting at JR West.
9	Mr. Toru Sugimoto, Corporate Manager, HSE, JGC Corporation	August 16, 2019. Head office of JGC Corporation, Yokohama	Discussion on the concept of the System Dynamic Model development and setting up questionnaires.
10	Mr. Mark Germain, HSE Director Overseas, JGC Corporation	September 13, 2019 Through Skype	Discussion on Corporate programs for promoting HSE at the JGC Corporation

11	Mr. Marcos Morales, HSSE Manager, at the Construction Site	September 4th, 2019. Through Skype	Information gathering on HSE management at the designated site.
12	Mr. Marcos Morales, HSSE Manager, at the Construction Site	September 29th, 2019. Through Email	Data collection on the near-miss reports for 3 months.
13	Mr. Marcos Morales, HSSE Manager, at the Construction Site	October 10th, 2019. Through Skype	Initial discussion, data analysis, result sharing, hypothesis testing. Additional information seeking.
14	Mr. Marcos Morales, HSSE Manager, at the Construction Site	November 20th, 2019. Through Skype	System Dynamic result sharing.
15	Mr. Marcos Morales, HSSE Manager, at the Construction Site	December 29th, 2019. Through Email	Feedback and evaluation of the work progress.