博士論文（要約）

Studies on Harvesting and Supply Chain Management of Wood Chip for Energy
(木質バイオマスの収集集荷作業システムとサプライチェーンマネジメントに関する研究)

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論文の内容の要旨

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The ultimate objective of this article is to illustrate an economical chip supply chain using mobile chippers at landings in forest based on the analysis of harvesting, comminution and transportation processes.

The topic of section 2 was the productivity of winch harvesting on flat and steep terrains. With the increase of importance of bioenergy, the whole tree harvesting system was reconsidered. As a simple way of a whole tree harvesting system, this study analyzed two winching procedures in terms of productivity and influence from terrain conditions. One of the winching procedures was observed on flat terrain, where the felled trees were scattered and then, one-by-one, attached to the winch rope. The other was observed on a steep terrain, where the felled trees were concentrated in a line and then attached, at one time, to the winch rope. A significant difference caused by slope conditions appeared only in the reeling velocity. When increasing the harvested volume in a cycle, the productivity increased. The difference in productivity between two sites was slight with the same harvested volume. By the one-by-one procedure, the full volume harvested in a cycle was only skidded from the nearest felling points, while the bundled procedure skidded the full volume from various points including the farthest point. The one-by-one procedure will save the winch rope tension and reduce engine acceleration. Fuel consumption, therefore, will be decreased by applying the one-by-one procedure instead of the bundled procedure. Additionally, reducing the weight of felled trees by natural drying in a forest is effective for reducing fuel consumption not only in transportation but also in winching operation, and for enhancing the calorific value of bioenergy.

The topic of section 3 was the evaluation of chipping productivity. Chipping productivity is unstable across chipping observations at the process of timber to chip product at forest roadside over time. A variation in production is the major concern of stakeholders for sustainable forest operation, as it varies unexpectedly the ability to establish certain attainable production schedules on many operational levels. The aim of this study is to estimate the variance of chipping productivity by using a stochastic simulation model to achieve the objective evaluation of chipper performances. Chipping operations of five different kinds of mobile chippers, i.e. three smaller and two larger ones, were investigated. Probability distributions of material size and feeding time in a log-normal distribution including the machine chipping time were estimated. The estimations were from chipping operations reproduced for 2,000 or 4,000 times by mechanical repetitions that established a chipping productivity distribution. Except for the largest chipper whose observed productivity was 338 loose m^3/hr, all of the observed productivities varied from 18 to 68 loose m^3/hr were located within a two-sided confidential interval whose difference between both ends was less than 10 loose m^3. The estimations were generally reliable with small variances around the median productivity values in the model. This stochastic model enabled the representation of a chipper productivity to be evaluated objectively, while the accuracy would be improved more by increasing sample size and accurate material size measurement. It was elucidated that the operations followed by chipping should encompass enough volume capacity to allow for chipping productivities to keep itself, as a system, stable.

The topic of section 4 was the choice of a proper chipper in relation to the size of chipper and entrepreneur’s business scale. The productivity of chippers had a strong relationship with its engine power. However, more productive chippers require larger collection area, which increasing the transportation distance and cost. Such trade-off relationship between chipping and transportation costs should be taken into account when choosing chippers for a supply system. Transportation costs were calculated including the influence of the interaction between chipping and transportation processes by GIS network analysis and linear optimization for five alternative mobile chippers whose engine powers were widely ranged from 53 to 571 kW. It was clarified that the total supply cost could be theoretically minimized when using chippers with an engine power of 461 kW which yielded a total cost of about 1,150 JPY/loose m^3. Therefore chippers with middle or large engine were the most economical to use among the five studied chippers. This minimum point would go toward to lower points if the efficiency of truck unloading was improved. The chippers with small engine power (<150 kW) could be useful for establishing smaller supply chain with the annual business scale of 8,300-12,700 solid m^3 at the cost of about 1,780 JPY/loose m^3. By finding the best combination and allocation of the small and larger chippers, a well-balanced chip supply chain would be realized in the region.

The topic of section 5 was the chipping and transportation costs in relation to the allocation of mobile chippers comparing with a timber collection system. As a lot of projects on biomass power plants launched, timbers were mainly used as their energy resource in spite of the first intention to use logging residues effectively. To promote the energy use of logging residues, one of the inevitable issues to be clarified was the cost-efficiency of chip from logging residues produced at a landing in forest by using mobile chippers. Indeed mobile chippers with high productivity would be the most economical solution, it was often difficult to introduce because of the limited budget and its business scale to depreciate. The chip supply cost of mobile chipping system using both several small chippers and one large chipper were, therefore, analyzed as a model by using geographic information system and linear optimization. The chip supply costs were the same between the conventional system using a fixed chipper and the mobile chipping system using smaller ones close to the power plant. Moreover, the total supply cost of larger mobile chippers which had high potential of reducing chipping cost will be superior to that of conventional system. This result encourages the stakeholders to start to use logging residue even they cannot introduce the larger chipper, and benefits the society by the wise use of woody materials.

The topic of section 6 was the role of stake holders in relation to the ownerships of land and materials. It is one of the biggest issues to establish an efficient chip supply chain at low cost reflecting on the local and global forestry conditions. The aim of this study is to point out keys to establish chip supply chains successfully by satisfying the benefit of each stakeholder. An actual model supply chain in Denmark as an advanced model was analyzed by using cost and benefit rate. This model involved four stakeholders: Danish national forest, as a material collector; a local farmer, as a chipping operator; a third party logistics company, as a transporter; and a district heating plant, as a customer. Even though the cost and benefit rate between the chipping operator and the national forest was not high of 1.2 at the even point when the chipping contract price was 2.8 EUR/GJ, the net profit of the chipping operator, although the contract was temporary, and the national forest were 984 EUR/day and 1,671 EUR/day, respectively. This income of the chipping operator would bring positive effects in local economy and the model supply chain had an important role as a buffer to react the seasonal fluctuation of chip demand. From the point of commercial distribution, it was clarified that the model supply chain benefited to both chipping operator and chip supplier and that a key for successful establishment existed in the stakeholder who had material ownership that related to the timber/material sales systems.

This whole study analyzed the establishment of supply chain from different perspectives such as forestry operation, commercial distribution and stakeholder benefit. Indeed costs composing the total supply cost could be obtained by the analysis of forestry operation but it was also shown that the tactical decisions such as chipper allocation or timber/material sales systems would also influence on the total cost. It indicated that involving all stakeholders was indispensable to optimize a supply chain as well as improving cost efficiency of each process in the supply chain. The geographic and social structures of forestry in Japan have several weaknesses for efficient operations as mentioned through this study. This study suggested the necessity of overcoming such difficulties and showed the possibility of economical success by integrating the stakeholders in a supply chain. This point of view will be useful to support the promotion of bioenergy use not only in Japan but also other countries where suffered to establish economical bioenergy supply chains. The specific ways to integrate stakeholders should be discussed on local basis and the results of this study could contribute to encourage such practical movements.