博士論文（要約）

論文題目 Establishment of biomass supply chain of residue from rubber plantation regeneration

(ゴムプランテーション更新における廃材のバイオマスサプライチェーン構築)

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Dissertation

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January, 2014

Acknowledgements

Acknowledgements

This research has been completed with advice and encouragement of many people. First of all, I would like to express my sincere gratitude and appreciation to the principal advisor, Prof. Hideo Sakai for his kind supervision, suggestions, and generous comments to improve this study. Greatly thanks to Assoc. Prof. Toshio Nitami who is one of committee members for his valuable comments during my progress presentation. Special thanks also to Assist. Prof. Rin Sakurai for his cooperation and valuable help for my data investigation in Japan. I would also like to thank all members of forest utilization laboratory for many suggestions on my research including Japanese translation. Additional thanks to all committee member, Prof. Kenji Imou, Assoc. Prof. Owari Toshiaki, and Prof. Imatomi Yuki.

I would like to greatly thank to Khun Sarachai who is manager of MagaWood company and his colleagues for their kind permission allowing me for data investigation in rubber plantation. I also would like to thanks Dr. Krissada Sangsing for suggestions and allowing me for data investigation of rubber stump removal. Thanks to all members of forest engineering department, Kasetsart University for advice and helping me during the field work in Thailand. Special thanks are given to Dr. Apichon Witayangkurn for his suggestions on programming.

Furthermore, I would like to express greatly thanks to my family and my husband for their love, encouragement and support me during living out of my home country.

Lastly, I would like to deepest my gratitude to Anandamahidol Foundation. This research could not success without financially support from Anandamahidol Foundation. It is an honor to receive this great opportunity.

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Chapter 1

Introduction

Introduction

1.1 Background

Rubber tree (*Hevea brasiliensis*) has been cultivated in Thailand since around 1900 (Monge 2007) and become important commercial crop. The main product of rubber tree is latex, while rubber wood is considered as a by-product. The production period of latex was from seven years old to around twenty-five years old (Albarracin *et al.* 2006). The average annual income from latex was USD2,000/hectare while the stumpage price of rubber wood at the end of rotation period was USD1,000-1,500/hectare (FAO 2009). In the past, when latex yield tend to decrease, approximately 25-30 years interval, rubber trees were felled and burnt in the plantation areas (FAO 2001). After the logging ban in 1989 in Thailand, rubber wood has become one of the most popular timbers for making furniture, furniture components, wood panel, and other wood-based products (Hong 1996, Rantala 2006). The demand of rubber wood products has been increasing every year from that time (FAO 2001).

The rubber plantation area in Thailand is largest area of forest plantations in the country (Rantala 2006). Smallholder is main source of rubber product (Monge 2007). There were three million hectares in 2010; the second largest rubber planted area in the world. The distribution of rubber plantation were 1.9 million ha (64%) in south, 0.6 million ha (20%) in northeast, 0.4 million ha (13%) in east and central, and 0.1 million ha (3%) in north of country (Rubber Research Institute of Thailand 2012). There were averaged 33,914 ha/year of replanting area of rubber tree (Rubber Research Institute of Thailand 2012). Plantation owners will gain subsidy from the Office of the Rubber Replanting Aid Fund (ORRAF) for replanting with more developed rubber tree clones as well as with high value economic tree species (Kainulainen 2007). Although the main reason to fell the rubber tree is replanting, the value of rubber wood increased considerably (Bank of Thailand's Southern Region Office 2006). Nowadays, there are various products from rubber wood. Figure 1.1 shows the utilization of whole rubber tree according to the size of logs. Rubber logs more than 8 inches in diameter are usually for a raw material of veneer while logs in diameter between 6-8 inches are useful for lumber, particle board and medium-density fibreboard (MDF) (Sinthurahut 1996). Logs with less than 6 inches in diameter with lengths near to 1.8 meters are also for MDF, otherwise they will use for charcoal and fuelwood. Small branches have been left and burnt at the plantation. Generally, stump and root are used as firewood or burnt at the site (Albarracin *et al.* 2006, Kainulainen 2007). Rubber stumps have recently become an interesting source of wood chip for electric power generation.

Table 0.1 Physical and mechanical properties of rubber wood and teak

Property	Rubber wood (at 15% moisture content)	Teak (at 12% moisture content)
Density	460-650 kg/m^3	480-850 kg/m^3
Modulus of rupture (MOR)	66 N/mm^2	86-170 N/mm^2
Modulus of elasticity(MOE)	9240 N/mm^2	10500 - 15600 N/mm^2
Compression parallel to grain	32 N/mm^2	55 N/mm^2
Compression perpendicular to grain	5 N/mm^2	6.5 N/mm^2
Shear	11 N/mm^2	11 N/mm^2
Hardness (Janka)	4350 N	4500 N

Source: Killmann and Hong (2000), Lee *et al*. (1982), and Soerianegara and Lehmmens (1993).

Rubber wood is soft to moderately hard with an average density between 460-650 kg/m^3 at 15% moisture content (Killmann and Hong 2000). Intermediate weights and strengths properties are found in rubber wood which is likely teak, *Tectona Grandis* (Forest Management and Forest Products Research Office 2005). Table 1.1 shows the comparison of physical and mechanical properties between rubber wood and teak. Kainulainen (2007) pointed that there were three main reasons why rubber wood was famous use in several wood industries i.e. its whitish color, good machining and working qualities for sawing operations, and environmentally friendly.

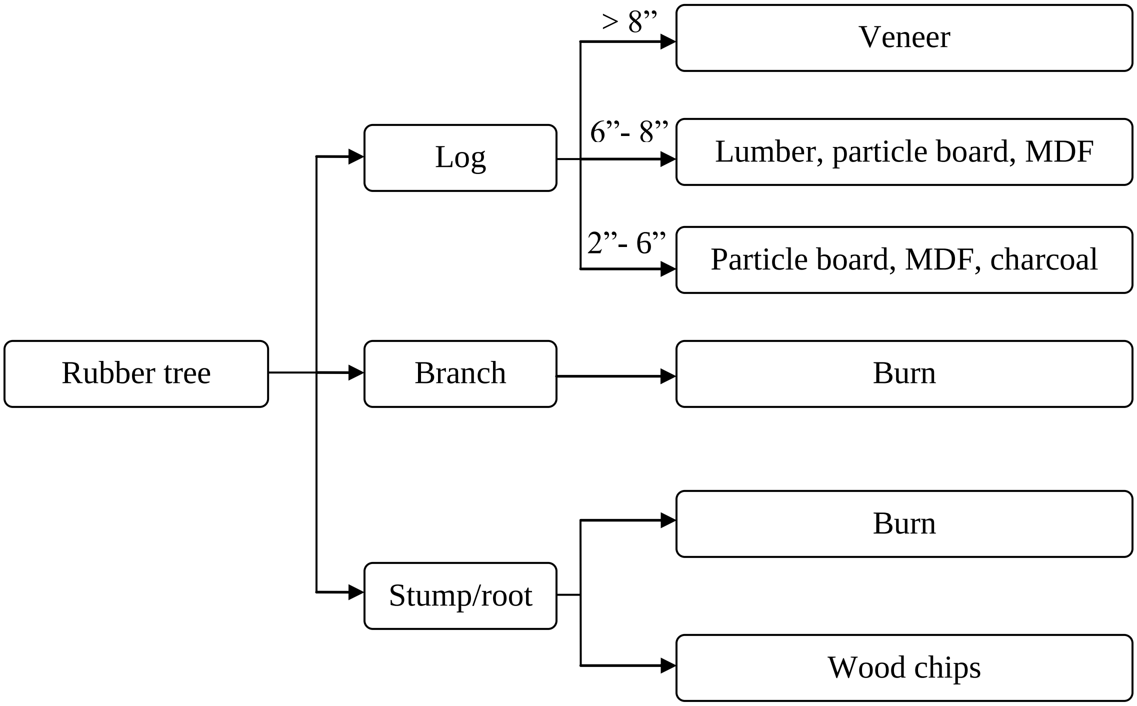

Figure 0.1 Rubber wood utilization

Rubber wood harvesting system is clear cutting to clear the site for replanting. Short wood method, that is rubber trees are felled, delimbed, and cut to desired length directly at the stump, is a normal harvesting method for rubber trees utilization in Thailand. The harvesting systems are divided into three operations; felling, processing, and transportation. There are two felling methods for felling rubber trees in Thailand i.e. chainsaw and bulldozer (Kainulainen 2007). The felled rubber trees are delimbed and scaled by manual with a big knife and a measuring stake. Then logs are cut to lengths between 1.0-1.3 meters (Albarracin *et al.* 2006). The dimension of rubber logs for sawlogs is larger than 6 inches in diameter (Kainulainen 2007). After the processing, the bucked logs are delivered to the sawmills by various kinds of trucks such as 10-wheel dump truck, 10-wheel stake body truck, 6-wheel dump truck, pickup truck, and motorcycle with sidecar. Manual loading is still majority method to load logs onto the cargo. Short transportation distance is usually executed. Long transport distances have to be avoided because of high possibility of insect and fungal attacks (Balsiger *et al*. 2000).

1.2 Purposes

To manage the supply chain of timber harvesting, time study and productivity of harvesting systems are necessary to establish the models for increasing the efficiency of forest supply chain (Kent *et al.* 2011, Motsa 2011). There was lack of information on biomass of residue from rubber plantation regeneration. Conventional and worker experienced operations were used to harvest rubber wood for long time. Recently, biomass of rubber wood has become a significant wood product of Thailand's economy (Ketsaraporn and Tian 2012). To enhance efficiency of rubber wood supply chain, the harvesting systems should be researched.

There are three main parts of this study covering rubber wood harvesting system, rubber stump harvesting techniques, and rubber wood transportation.

Chapter 2 is "Rubber wood harvesting and transportation". The harvesting operation on short wood system was considered. Investigations in work cycle and productivity as well as the significant variables that affected operation time were described. Time prediction models and cost analysis were also explained.

Chapter 3 is “Stump harvesting techniques and its utilization”. Techniques in stump harvesting were described both in forest road construction and in rubber plantation. Moreover, the trends of stump utilization in the study area were explained.

Chapter 4 is “Finding the most appropriate transportation routes using Google Maps API”. Establishment of cost estimation based on transportation route decision was developed. The shortest route for rubber wood transportation could be obtained from the result of Google Maps API process. Cost estimation data was obtained from Chapter 2 and used to estimate harvesting and transportation cost.

The overall conclusions were summarized in Chapter 5. In this chapter, the future research need was also outlined.

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Chapter 2

Rubber wood harvesting and transportation

Rubber wood harvesting and transportation

2.1 Introduction

Rubber wood harvesting has become one of the most important procedures in rubber wood industry. In Thailand, short wood system is the most common method for rubber wood harvesting when regeneration of rubber plantation. Clear cutting are conducted in rubber stand when decreasing of latex production. In long history of rubber wood utilization, many different types of equipment are applied to harvest rubber wood. However, information was lacking, a few common descriptions exited on what equipment was available for rubber wood harvesting. Generally, rubber wood harvesting system consists of felling and processing in stump area, and transportation from plantation to sawmill.

Firstly, felling method, to cut down a rubber tree, is based on manual and mechanized methods. Manual felling method is using chainsaw while mechanized felling method utilizes bulldozer. There have been many studies on short wood system's productivity, operation cost, and time study for chainsaw felling. Behjou *et al*. (2009) studied productivity and cost of manual felling using chainsaw in uneven-aged beech (*Fagus orientalis* Lipsky) stand in Caspian forests. They found that the net productivity and cost of manual felling were 26.1 m^3 per hour and USD0.81 per m^3, respectively. Mousavi *et al*. (2011) showed that the productivity of felling trees and average cost were 35 m^3 per effective hour and USD0.22 per m^3 with chainsaw processing. Ghaffarian and Sobhani (2007) described that the felling cost by chainsaw was approximately USD5.81 per hour for the team work of three persons. On the other hand, there were a few researchers that studied felling trees by bulldozer. William (1968) explained his invention that adapted bulldozer for use in pushing over trees. He attached the tree pusher over the blade to make a higher point of force application to provide better leverage when felling a tree, but there was no explanation for felling efficiency. Bulldozers have been used to fell rubber trees in southern part of Thailand for long time; the beginning year was not recorded. Rubber trees were felled with stump extraction by this felling method.

Secondly, the felled rubber trees are cut to length between 1.0-1.3 meters (Albarracin *et al*. 2006). Log processing in rubber wood is usually conducted in the plantation area before delimbing, scaling, and bucking. An operator, who was a marker, marked the felled tree from the bottom to the top by a stick of desired length and also removed small limbs. Manual processing by chainsaw is common method. The study of Mousavi (2009) showed that the productivity increased with increased tree size and that the best independent variables were tree height and volume in the time consumption model for chainsaw bucking process. The log volume and log length were important variables in the time prediction model for manual processing (Ghaffarian and Sobhani 2007).

Lastly, all required length logs of rubber wood are transported from plantation to sawmill directly. Various kinds of trucks are used in rubber wood transportation such as 10-wheel dump truck, 10-wheel stake body truck, 6-wheel dump truck, pickup truck, and motorcycle with sidecar. The scope of this research refers to a pickup truck carries in log transportation. Pickup trucks modify rear cargo part to increase the capacity of payload, and can easily access plantation areas but with small payload. Transportation distance and load volume were the major effective variables according to the time consumption model in timber transportation (Ghaffariyan *et al*. 2012, Mousavi 2009).

The objective of this chapter is to analyze the productivity, prediction model, and cost analysis of felling methods, processing, and transportation using pickup truck.

2.2 Materials and Methods

2.2.1 Study areas

Field studies were conducted in January- February 2012 and January 2013 in southern region in Thailand. Felling method with chainsaw was investigated in Surat Thani province (8° 52' 50.8''N 98° 54' 4.3''E) while felling method with bulldozer was investigated in Trang province (7° 29' 3.8''N 99° 36' 24.5''E and 7°27' 29.9''N 99°35' 10.4''E) during dry weather season. Processing and transportation data were obtained from both sites. The diameters of tree at breast height (DBH) were during 13-35 cm in Surat Thani and 15-52 cm in Trang. The log volumes per tree were approximately 0.3 and 0.7 m3, respectively. These areas were flat land with less than 10% slope. Average day temperature was 35 °C and the average relative humidity was approximately 46%. Clones were different each other i.e. BPM24 in Surat Thani, RRIM600 and PB235 in Trang. Tree spacing was 3x6 m or 3x7 m, respectively. Figure 0.1 shows the characteristics of rubber plantations. Rubber plantations are normally adjacent to a public road or a small private road for easy access.

Figure 0.1 Rubber plantation

2.2.2 Machineries and equipments

Chainsaws used were the Stihl MS381 model with 25 inches saw bar and 5.3 hp motor. The bulldozer was Komatsu D50A with 90 hp (67kW) which was modified by attaching the tree pusher over the blade as shown in Figure 0.2. The tree pusher provides better leverage and permits to fall large trees with the same engine power (William 1968). Dimension of tree pusher normally was 50 cm wide, 180 cm long, and 100 cm height from ground. The maximum height from the ground of tree pusher was approximately 210 cm.

Figure 0.2 The modified bulldozer attached with tree pusher

A big knife and a measuring stake of 1.13 m in length were used to remove small limbs and scale, respectively. In this study, transportation rubber logs from plantation to sawmill investigated pickup truck transportation. The type of pickup truck used was 2500 cc diesel. Rear cargo dimension of pickup truck normally was 2.3 m in length, 1.5 m in width, and 0.4 m in height and a ton of payload capacity. Modified rear cargo of pickup trucks has been accepted to carry more loads up to 1.5-2 tons (Figure 2.3).

Figure 0.3 Modified rear cargo of pickup truck

2.2.3 Data collection and analysis

In order to analyze the efficiency of all operations, work elements for each operation cycle were observed using stopwatches and video recorders. The elemental time for each cycle was defined as follows:

Felling with chainsaw

(1) *walking*: worker started to walk from previous felled tree to the next target tree, and reached at the tree,

(2) *clearing*: worker started to clear the brush around the tree, and finished when ready to cut,

(3) *undercut*: worker started to cut horizontally, and finished a pie-shaped piece of wood in the falling direction,

(4) *back cut*: worker cut~~s~~ above undercut in the opposite direction, removed the saw, and felled the tree on the ground,

(5) *post cutting*: worker cut the cross section area of the stump after felling to make smooth surface, and withdrew the saw from the timber,

(6) *delay*: time was spent for discussion or others which was non-productive time.

This operation was performed by one man. After felling the first tree, worker cut the next tree at the same row. Because of the short tree spacing system and flat area, walking distance was not measured as influence factor.

Felling with bulldozer

(1) *backward moving*: bulldozer moved backward away from the previous felled tree, and was on the turning position,

(2) *forward moving*: bulldozer moved forward to the target tree, and put~~s~~ the tree pusher at the tree,

(3) *pushing*: tree pusher pushed the tree, and felled the tree on the ground,

(4) *uprooting*: bulldozer moved forward to uproot the felled tree, and finished when the rubber root released from the ground,

(5) *sorting*: using blade of bulldozer sort the felled trees by making a row to prepare for bucking process.

Felling tree ranged from two to three trees, and sorting process was operated to rearrange the felled trees in the row.

Bucking

(1) *walking*: bucker walked during the bucking operation,

(2) *bucking*: bucker started to cross-cut the felled tree according to the marked point until all logs separated,

(3) *topping*: bucker started to cut the top of felled tree and finished when the top was cut.

In felling with chainsaw, one worker felled and bucked trees. After he finished felling trees in a row, he continued to buck those trees. In felling method with bulldozer, chainsaw worker was only for bucking operation. After the felled trees were sorted, he bucked the trees following at a safe distance from bulldozer felling operation.

Transportation

(1) *loading*: three loader crews started to load logs onto the pickup truck. Log was lift up to their shoulder one by one and by two crews for a big log. Then this work element ended when the rear cargo of pickup truck became full,

(2) *preparing*: the crews started to fasten the cargo with rope and finished when the truck got ready to leave plantation for the sawmill,

(3) *traveling with load*: the pickup truck left at a plantation and arrived at a sawmill,

(4) *weighing*: the time of pickup truck for weighing before and after unloading at the sawmill for log weight measurement,

(5) *unloading*: the pickup truck started to manually dump and ended when the truck became empty,

(6) *travelling without load*: the pickup truck left at the sawmill after second weighing and returned to the plantation.

A total of 40 cycles for felling with chainsaw, 70 cycles for felling with bulldozer, 27 cycles for bucking, and 49 cycles for pickup truck transporting were observed to statistical analysis and to make time prediction model for felling, bucking and transporting. The null hypotheses that there were significant differences between time consumption and variables in linear relationship were rejected when *p*-value was less than 0.05. Productivities were expressed in log volume per productivity machine hours, PMH, (m^3/PMH) for felling and bucking process, and in log weight per PMH (kg/PMH) for transportation. In this study, log products were larger than 5 inches in diameter. Cost calculation was based on the machine rate method including fixed cost, operating cost, and labor cost (Akay 1998, Miyata 1980). The machine rate calculated the hourly cost of the equipment with operator comprised of purchase cost, salvage value, depreciation cost~~s~~ and cost of interest. Cost information was obtained by interview from operators.

2.3 Results

2.3.1 Felling method with chainsaw

The summary statistics of the time consumption of felling operation is shown in Table 2.1. Back cut was the most time consumption, which was 31% of total time composition, followed by undercut and moving. The time consumption for felling with chainsaw was estimated as a mean value 38.8 seconds per one cycle. The productivity for felling with chainsaw averaged 25.1m^3/PMH from log volume.

Table 0.1 Statistics of operational variables of chainsaw felling

Variable	Mean	Std. Dev.	Min	Max	Time composition (%)
Stump diameter (cm)	19.2	4.7	11.1	33.0	-
Log volume (m^3)	0.27	0.15	0.07	0.77	-
Element time (sec)					
Walking	9.5	4.7	4.0	30.0	24
Clearing	3.7	5.6	0.0	21.0	9
Undercut	10.2	5.5	0.0	23.0	26
Back cut	12.3	3.9	7.0	24.0	31
Post cut	3.1	2.7	0.0	9.0	8
Delay	0.7	-	-	-	2
Total felling time per tree*	38.8	11.9	14.0	64.0	100

*Total felling time per tree does not include delays

The model of felling time with chainsaw (T_{CF}) including the consumed time of undercut, back cut and post cut, is derived to predict the time of felling using chainsaw in relation to stump diameter as

$$T_{CF} = k_1 \, (D_s)^2 \qquad \text{(sec)}, \qquad (1)$$

where D_s is stump diameter, cm; k_1= 0.059.

The felling time prediction model shows that increasing the stump diameter size will increase the felling time. The coefficient of determination of the regression (R^2) was 0.90, and it meant that stump diameter could explain 90% of the total felling time. The summary of the regression model is presented in Table 0.2. The model was significant at significance level of 0.05 (p-value < 0.001).

Table 0.2 Analysis of variance table for chainsaw felling model

Source	Degrees of freedom	Sum of square	Mean square	F value	p-value
Model	1	27,107.5	27,107.5	368.04	<0.001
Residual	39	2,872.5	73.7		
Total	40	29,980.0			

Here, if log volume, V, can be assumed as follows,

$$V = k_2(D_S)^2 \, , \tag{2}$$

where k_2 is constant and equal to 0.0006851, the productivity of felling tree can be derived by the ratio of log volume (V) to felling time (T_{CF}) as Eq. (3) from Eqs. (1) and (2),

$$\frac{V}{T_{CF}} = \frac{k_2}{k_1} = 25.1 \qquad (\mathrm{m}^3/\mathrm{PMH}) \, . \tag{3}$$

Figure 0.4 shows the relationship between log volume and productivity of felling tree and the average of productivity line, 25.1m^3/PMH.

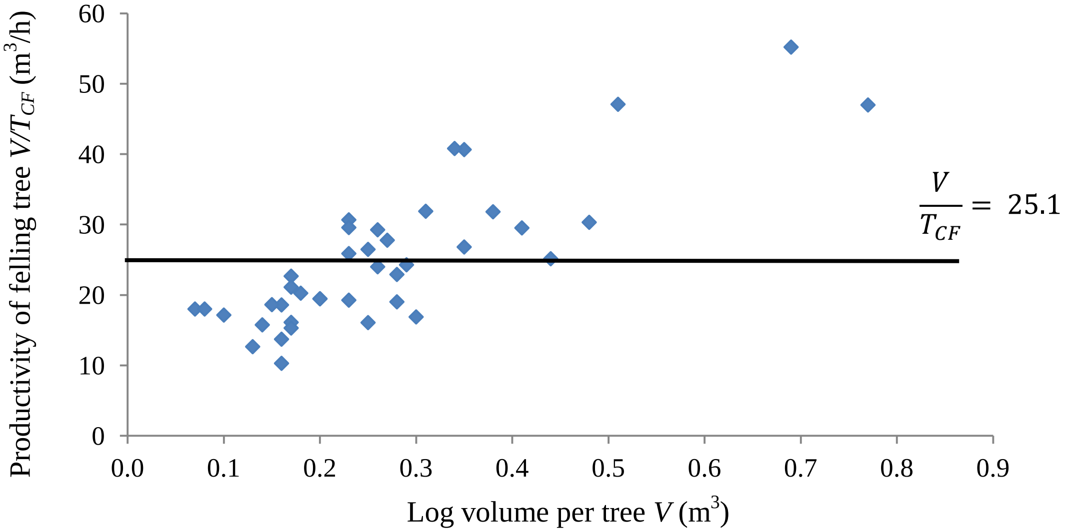

Figure 0.4 Relationship between log volume and productivity of felling tree

However, the relationship between stump diameter and log volume can be explained as Eq. (4) if tree height considered to be related to stump diameter

$$V = k_3(D_S)^3 \, , \tag{4}$$

where k_3 is constant and k_3 = 0.00002712.

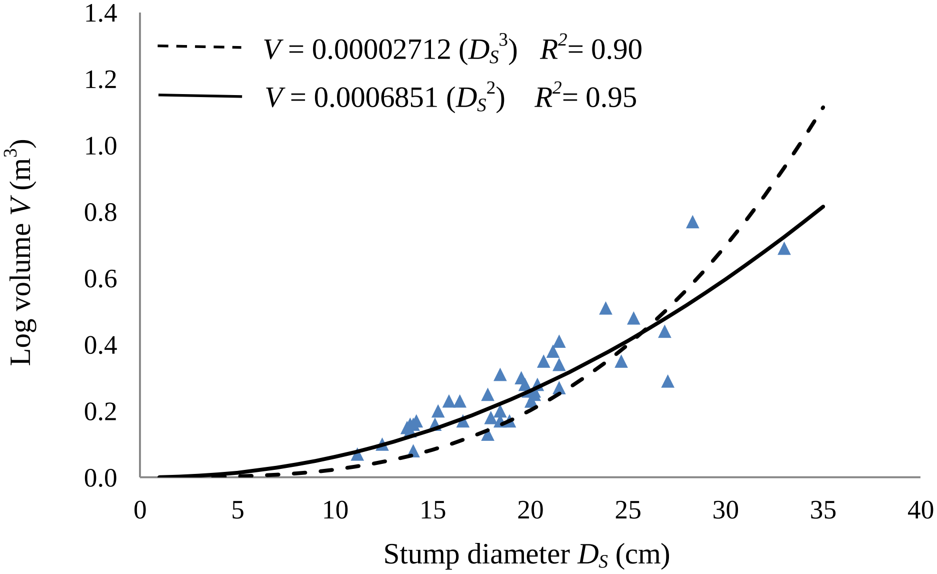

Figure 0.5 Relationship between stump diameter and log volume

Figure 0.5 shows the relationship between stump diameter and log volume, and both Eqs. (2) and (4) have high R^2 in this study. Then, the productivity of felling trees, P_F, can be also derived as Eq. (5) if Eq. (4) is adopted.

$$P_F = \frac{V}{T_{CF}} = \frac{k_3}{k_1} D_S = \frac{k_3^{2/3}}{k_1} \sqrt[3]{V}\ . \tag{5}$$

Figure 0.6 and Figure 0.7 show relationships between stump diameter or log volume and productivity based on Eq. (5). The coefficient of determination (R^2) of the model from Figure 0.6 and Figure 0.7 were same as 0.52 which *p-value* was under 0.01. This means that they were statistically significant probability that the relationship between the two variables exists. The model based on Eq. (5) also explained the variation of the productivity of felling.

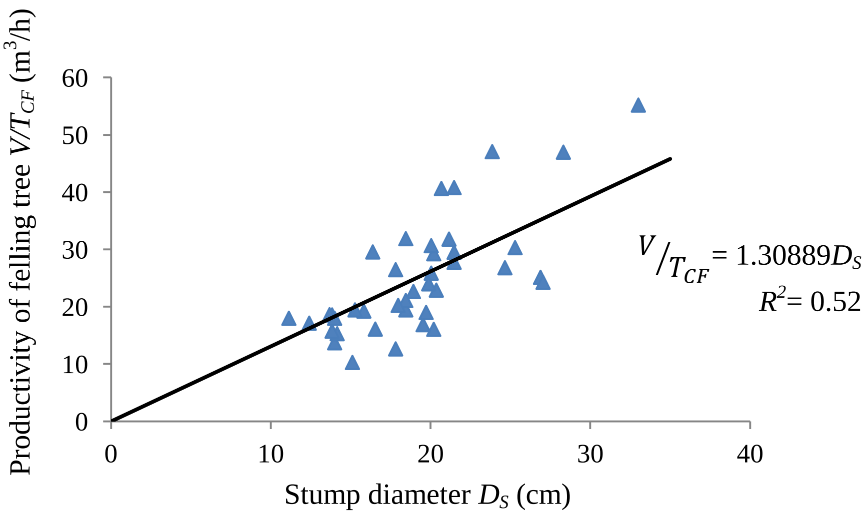

Figure 0.6 Relationship between stump diameter and productivity of felling tree

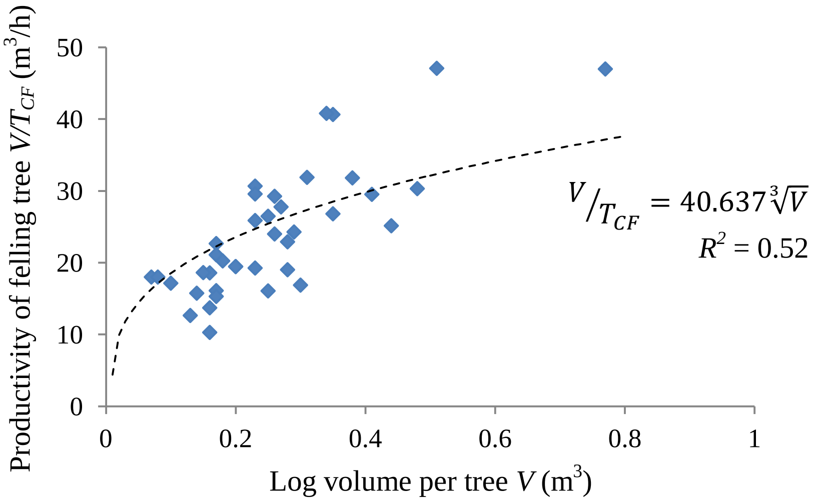

Figure 0.7 Relationship between log volume and productivity of felling tree

2.3.2 Felling method with bulldozer

Table 0.3 shows the statistics of time study of felling with bulldozer calculating from 70 observed cycles. The average total time per one cycle was 76 seconds excluding delay time. The delay was operational delay to remove the obstructive felled trees which were not avoidable. It was approximately 2 seconds per tree but was not included in the discussion. Stump diameter in study site was approximately 34.8 cm. Sorting process was the most time consumption, that was 27 seconds. The productivity was 30.1 m^3/PMH.

Table 0.3 Statistics of operational variables of felling operation with bulldozer

Variable	Mean	Std. Dev.	Min	Max	Time composition (%)
Stump diameter (cm)	34.8	7.5	21.3	51.9	
Elemental time (sec)					
Backward moving	9	5	0	23	10
Forward moving	6	6	0	26	7
Pushing	6	2	4	11	7
Uprooting	15	6	7	36	17
Sorting	27	53	15	184	59
Total felling time per tree*	76	21	44	146	100

*Total felling time per tree does not include delays

The regression model described the relationship between stump diameter (D_s) and effective felling time (T_{BF}) including the consumed time of backward and forward moving, and pushing, as follows

$$T_{BF} = k_4 \, (D_s)^2 \qquad \text{(sec)}, \qquad (6)$$

where k_4 = 0.015.

The felling time prediction model for bulldozer shows that increasing the stump diameter size will increase the felling time. The coefficient of determination of the regression (R^2) was 0.79, and it meant that stump diameter could explain 79% of the total felling time. The summary of the regression model is presented in Table 0.4. The model was significant at significance level of 0.05 (p-value < 0.001).

Table 0.4 Analysis of variance table for bulldozer felling model

Source	Degrees of freedom	Sum of square	Mean square	F value	P-value
Model	1	17,121.1	17,121.1	263.64	<0.001
Residual	69	4,480.9	64.9		
Total	70	21,602.0			

There was a positive relationship between stump diameter and the effective felling time for both felling methods (Figure 2.8). Although, range of stump diameter size differed effective felling time increased significantly for both methods. In this graph, the chainsaw line grew rapidly while the bulldozer line increased steadily from 15-25 cm in stump diameter.

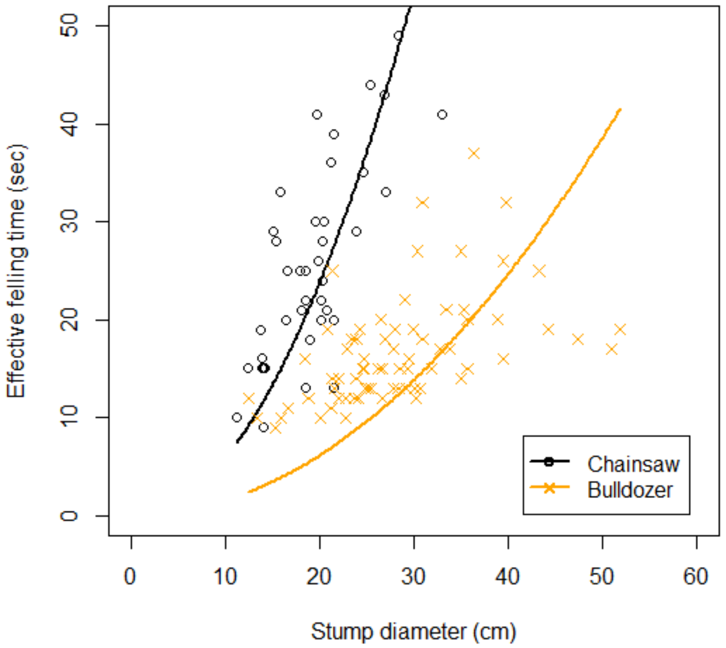

Figure 0.8 Effects of stump diameter on effective felling time

2.3.3 Processing operation

The time consumption for delimbing and scaling was observed and estimated as a mean value of 60 seconds/tree. The summary statistics of the time consumption of bucking operation is shown in Table 0.5. The time consumption for bucking averaged 114 seconds per one cycle. The most time consumption was bucking process, which was 69% of the total time composition.

Table 0.5 Statistics of operational variables of bucking operation

Variable	Mean	Std. Dev.	Min	Max	Time composition (%)
Number of logs per tree	15	6	5	31	-
Volume per tree (m^3)	0.73	0.42	0.13	1.95	-
Elemental time (sec)					
Bucking	78	41	16	199	69
Topping	9	5	3	25	7
Walking	27	16	10	81	24
Total bucking time per tree*	114	56	34	265	100

*Total bucking time per tree does not include delays

The productivity of bucking averaged 23.1m^3/PMH. The model of bucking time (T_B) is developed to predict the time of bucking in relation to the number of logs and log volume per tree as

$$T_B = 6.766 + 5.488\,N + 32.894\,V \qquad \text{(sec)}, \qquad (7)$$

where N is the number of logs per tree; V is log volume per tree, m^3.

The coefficient of determination (R^2) of the model was 0.66, that is, the number of logs and log volume can be described 66% of the total bucking time consumption. As shown in Table 0.6, the model is significant at significance level of 0.05.

Table 0.6 Analysis of variance table for bucking model

Term	Coefficient	Estimated std. error	*t*-test		*F*-test	
			t-value	*p*-value	*F*-value	*p*-value
constant	6.766	18.313	0.369	0.715	23.47	<0.001
N	5.488	1.972	2.782	0.0103		
V	32.894	28.093	1.171	0.2531		

Sakai *et al.* (1988) showed that bucking time related to log diameter, and log volume. Eq. (8) and Figure 0.9 showed the relationship in this study (R^2=0.41).

$$T_B = 141.7\,V. \tag{8}$$

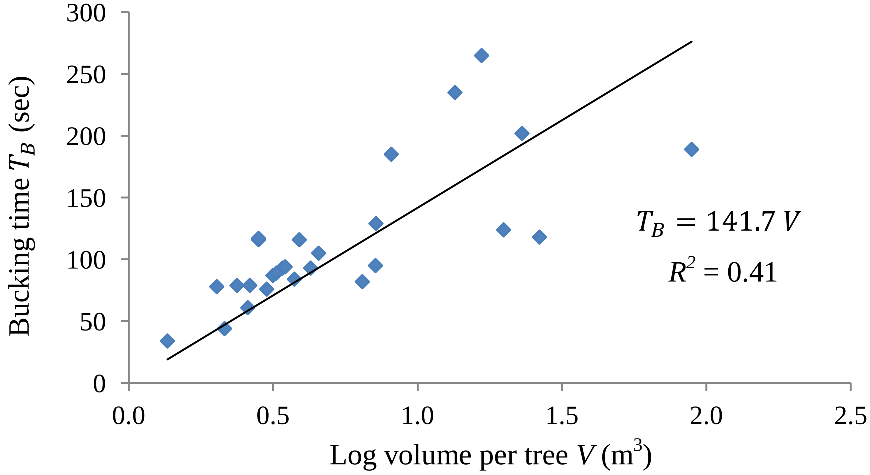

Figure 0.9 Relationship between log volume and bucking time

The productivity of bucking (P_B) can be assumed as Eqs. (9), and (10) and Figure 0.10 shows relationship between stump diameter and bucked log volume.

$$V = k_5 N(D_S)^2 \quad , \tag{9}$$

or $$V = k_6 N(D_S)^3 \quad , \tag{10}$$

if tree height or log length relates to stump diameter like as Eq. (4). Then, Eqs. (11) and (12) can be derived from Eqs. (9) and (10), respectively.

$$P_B = \frac{V}{T_B} = 23.1 \qquad (\mathrm{m}^3/\mathrm{h}). \qquad (11)$$

$$P_B = \frac{V}{T_B} = k_7 D_S = k_8 \sqrt[3]{V} \qquad (\mathrm{m}^3/\mathrm{h}) \qquad (12)$$

where k_5, k_6, k_7 and k_8 are constants.

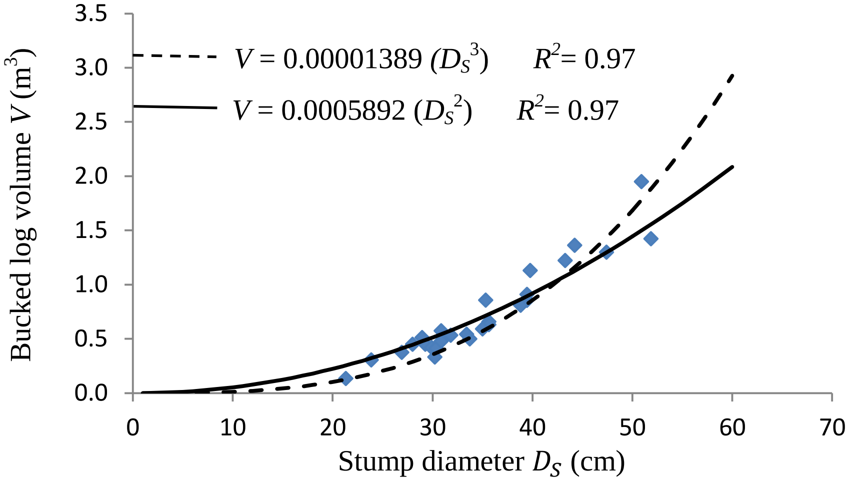

Figure 0.10 Relationship between stump diameter and bucked log volume

Figure 0.10 shows the relationship between stump diameter and bucked log volume. Although both Eqs. (9) and (10) have high R^2 values, the cubic function model which implies the log length is better use for bucking productivity prediction (Figure 0.11).

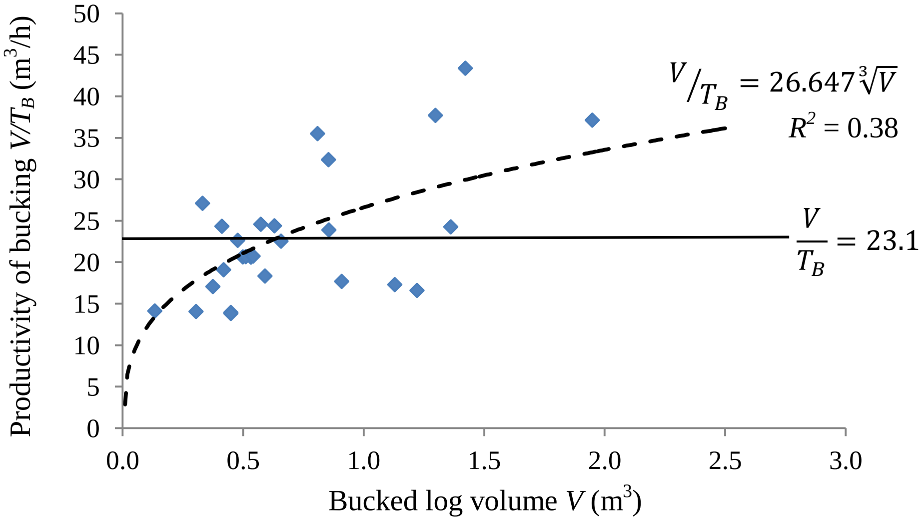

Figure 0.11 Relationship between bucked log volume and productivity of bucking

Figure 0.11 shows the relationship between bucked log volume and productivity of bucking based on Eqs. (11) and (12), and the coefficient of determination (R^2) of the cubic root model was 0.38 that was low according to the low R^2 from Eqs. (8). More sample data are required to prove this result and other variable maybe need.

2.3.4 Transportation using pickup truck

The average travelling distance between the plantation and the sawmill was 13 km on the public road in this study. The summary statistics of time consumption of transporting operation is shown in Table 2.7. The travelling time with load was the most time consumption, followed by travel without load and loading time. The average time consuming was about 133 minutes per one round trip. The average travel speeds with load and empty from plantation and sawmill were 19 and 20 km/h, respectively. The range of log weight was between 2500-3200 kg per truck. The productivity of transporting averaged 1313 kg/PMH. Increasing travelling distance will increase the transporting time (T_T). The basic theoretical model for hauling logs can be expressed as:

$$T_T = D\left(\frac{1}{v_l} + \frac{1}{v_n}\right) + T_{others} \quad , \qquad (13)$$

where D is transporting distance, km; v_l is velocity of truck with fully-loaded, km/h; v_n is velocity of truck with no load, km/h; T_{others} is the other time including loading, preparing, weighing, unloading and delay time, hours.

From Eq. (13), T_T is expressed as follows at the investigated site where v_l = 19 km/h, v_n= 20 km/h, and T_{others} = 0.91 hours,

$$T_T = D\left(\frac{1}{19} + \frac{1}{20}\right) + 0.91 \qquad \text{(hours).} \qquad (14)$$

Transporting productivity as a function of travelling distance $P_T(D)$ can be expressed as Eq. (15). Increasing travelling distance will increase travelling time and decrease productivity (Figure 0.12).

$$P_T(D) = \frac{W}{T_T} = \frac{2933}{D\left(\frac{1}{19}+\frac{1}{20}\right)+0.91} \qquad \text{(kg/PMH).} \qquad (15)$$

Table 0.7 Statistics of operational variables of logs transportation

Variable	Mean	Std. Dev.	Min	Max	Time composition (%)
Log weight per truck (kg)	2933	313	2190	3620	-
Elemental time (min)					
Loading	35	5	23	45	26
Preparing	8	4	2	17	6
Travelling with load	41	6	22	53	30
Weighing	7	2	4	12	6
Unloading	3	1	2	5	2
Travelling without load	39	6	23	49	29
Delay	1.5	-	-	-	1
Total transporting time per trip*	133	11	114	157	100

* Total transporting time per trip does not include delays

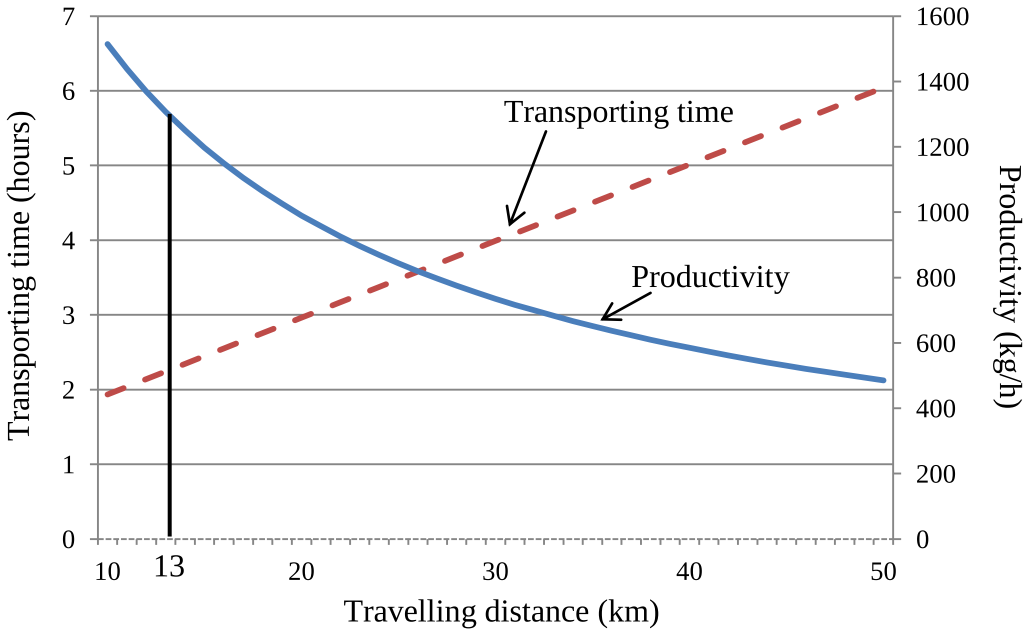

Figure 0.12 Relationship between travelling distance and transporting time and productivity

2.3.5 Cost estimation

Cost details and summary for each operation are shown in Table 2.8 and Table 0.9. The hourly costs are expressed per productivity machine hours (PMH). Each operation cost included fixed cost, operation cost and labor cost using machine rate (Akay 1998). Fixed costs were calculated from investment cost, depreciation of purchase price, economic life as well as interest rate. Operating costs varied according to working hours. They include maintenance and repair cost and fuel cost. Labor cost depended on the number of workers engaged in each machine and the production. In this study, almost all workers earned income by daily. The costs of felling with chainsaw and bucking were based on the machine cost of chainsaw. Initial purchase price of chainsaw was USD708.08. The cost of felling with bulldozer was based on bulldozer. The second used bulldozers were generally purchased, and its price was about USD10,500-21,000 depending on the condition of machine. The tree pusher was modified after purchased and the approximate price was USD700-1,050. The cost of transporting was based on the cost of pickup truck operation. The actual pickup truck purchase price and rear cargo attachment were approximately USD16,900 and 480, respectively. For the labor cost, cost rate normally calculated by the volume of logs. Bulldozer driver cost was 9 Baht/ton or USD0.29 per ton, and chainsaw operators cost for felling and bucking was 25 Baht/ton or USD0.8 per ton. The labor cost of transportation with pickup truck was divided into two parts; for driver and for loader crews. Pickup driver cost was 100 Baht/trip (or USD3.2 per trip) and loader crews cost was 130 Baht/ton/team (or USD4.2 per ton/team), normally four crews per team. The weight of rubber logs is a normal unit when purchase in front of sawmills. However using density of rubber wood at 15% moisture content, 650 kg/m^3, was used to calculate log volume.

Table 0.8 Cost details for chainsaw, bulldozer, and pickup truck

List	**Chainsaw**	**Bulldozer**	**Pickup truck**
Purchase price (USD)	708.08	17,058.26	17,444.48
Salvage value (USD)	141.62	1,705.83	1,744.45
Economic life (years)	1	3	3
Scheduled operating time (hrs/year)	2,000	2,000	2,000
Productive time (hrs/year)	1,000	1,000	1,000
Depreciation (USD/year)	566.46	5,117.48	5,233.34
Interest rate (%)	2.75	2.75	2.75
Fuel cost (USD/hour)	1.23	12.63	8.79
Maintenance and repair (USD/hour)	0.57	5.12	5.23
Labor cost (USD/hour)	20.22	18.77	9.68

Table 0.9 Cost estimation for each operation

Operation	Cost	
	USD/m^3	USD/PMH
Felling with chainsaw	0.90	22.69
Felling with bulldozer	1.57	47.28
Bucking	0.98	22.68
Transporting	15.28	30.86

Note: Currency rate: 1 USD = 31.07 Baht (July, 2013)

2.4 Discussion

The average productivity of felling rubber tree by using chainsaw was 25.1m^3/PMH and the stump diameter was a significant variable affecting on felling time, and increasing the stump diameter would increase felling time. Although distance between trees was also an important influencing factor on the model of felling time (Mousavi *et al*. 2011), it was not included. The walking time was high with 24% of total time consumption. Because of the planting systems in rubber plantation, spacing distance between rubber trees is equal and constant. The felling operation was cutting trees row by row so that workers walked same distance in every cycle time, and the distance between trees was not included in the analysis. It was said that the productivity of felling by chainsaw was constant (Sakai *et al*. 1988), but it was found that the productivity model in rubber felling by chainsaw was a function of stump diameter or log volume in this study. Productivity model as a function of stump diameter is so easy to measure that it may be useful for making harvest planning of rubber plantation. On the other hand, the felling method with bulldozer has high productivity than chainsaw, 30.1m^3/PMH, due to the shorter cycle times. The technique for applying leverage by attaching the tree pusher in front of bulldozer was an efficient way to increase the force for felling. Moreover the movement of bulldozer on the ground of plantation was fast and easy. However, following operations such as timber sorting, bucking, and site preparing depended on felling method. In addition, rubber stumps from felling method with chainsaw in the plantation area should be removed for site preparing. This operation leads to time and cost consuming while the felling method with bulldozer does not require.

Delimbing and scaling process was not mentioned by the model because this process was conducted during bucking operation. After a chainsaw operator finished tree felling, he could continue the bucking process, therefore delimbing and scaling was implied during the bucking operation. According to the regressed time prediction model of manual bucking operation, the number of logs and bucked log volume per tree were important variables. The bucked log volume mostly affected on the time predicting model (Ghaffarian and Sobhani 2007, Sakai *et al.* 1988), and the number of logs implied the frequency of cutting time. The number of bucking differs even if log volume is same, and depends on the specific of log length. Thus the number of logs should be included in the model of bucking time. In this study, although the average productivity of bucking process was constant as 23.1m^3/PMH, the productivity model of bucking was derived as function of bucked log volume with low coefficient of determination (R^2= 0.38). However, the relationship between bucked log volume and productivity of bucking was significant.

The log volume or log weight and traveling distance were recommendation variables for the transportation model (Ghaffariyan *et al*. 2012, Nurminen *et al.* 2006, Nurminen and Heinoen 2007). Due to the same distance, the log weight was a significant variable affecting on transportation time. However, the transporting time model as a function of travelling distance can be derived using the average velocity of truck with fully-load and empty (Eq. (14)). This model will be useful to determine marginal distance with pickup truck, and the productivity model of transportation can be obtained. All delay time in this study was rest and waiting time.

Transportation cost including loading, travelling, and unloading cost was the main cost of short wood system in rubber wood harvesting, USD15.28 per m^3. This may be because pickup truck has low capacity for timber transportation. However, pickup trucks are popular and indispensable for small scale rubber wood harvesting in Thailand. The result shows the limitation of travelling distance by using pickup truck, and it is recognized that the long distance will rapidly decrease the productivity of log transportation.

2.5 Conclusion

The felling methods in rubber plantations were mainly using chainsaws and bulldozers. Although the productivity of bulldozer was higher than chainsaw, the operation cost was more expensive and might cause soil damage. However, bulldozers have been used for both tree felling and stump/root removal to prevent root disease before regeneration planting of rubber trees. The most expensive cost was transportation cost depending on load volume and travel distance. The developed models and production rate of felling, bucking, and pickup truck transportation are useful tools for wood harvesting planners in order to predict the time and cost of rubber wood harvesting with similar site conditions.

2.6 References

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3 章、4 章は企業の個人情報が含まれており、インターネット公表に不適切であるため、公表しない。

Chapters 3 and 4 is not open on the Internet because they include private data of companies.

Chapter 5

Conclusions

Conclusions

Rubber woods from clear cutting are a large important source of the wood industrial. To support and improve the future supply of rubber wood, the rubber wood harvesting operations must be enhanced. This study was designed to provide operations information on the performance of rubber wood biomass harvesting in Thailand. Three topics were set in this research. The first was to analyze the time study, productivity, prediction model, and cost analysis of operations from felling to transportation to the sawmill. The second was to investigate and analyze the techniques of stump harvesting and its utilization. The third was to develop cost estimation of rubber wood supply chain based on short-distance transportation.

The harvesting operations on short wood method were practiced on private rubber plantations in Thailand. Stands were clear cut with either chainsaw-based method or bulldozer-based method. The productivity of felling operation with bulldozer was higher than that with chainsaw in 20%. The average time consumption for felling with chainsaw and bulldozer was 38.8 and 76 seconds per tree, respectively. Stump diameter was an important factor to perform the time prediction models. The felled trees were bucked manually by chainsaw in the plantation area. The bucking operation averaged 114 seconds per one cycle and the time prediction model was described by the number of logs and the log volume per tree. In addition, the time consuming for transportation including manual loading and unloading was approximately 133 minutes per one round trip by pickup truck with 13 km distance between the plantation and the sawmill. The average travel speeds with load and empty were 19 and 20 km/h, respectively. The range of log weight was between 2500-3200 kg per truck. The productivity of transporting averaged 1313 kg per productivity machine hours. The travel time was significantly affected by the travel distance, velocity, and other related operation time. Cost estimation based on machine rate method for felling with chainsaw, bulldozer, bucking, and pickup truck transportation were USD0.90, 1.57, 0.98, and 15.28 per cubic meter, respectively. Transportation cost including loading, travelling, and unloading cost was the main cost of short wood system in rubber wood harvesting. The result from this part can be used to manage the supply chain of rubber wood both harvesting time and cost.

Stump removal during forest road construction was practiced by using small excavator with bucket in Japanese forest. The average time consumed per stump was from 3.60 to 8.96 min, while mean diameter of stump was from 23.1 to 34.9 cm. In case of rubber stump removal in Thailand, the average of removal time per stump was 131 seconds when the average of stump diameter was 36.7 cm. Comparing the effect of felling method to stump removal operation was explained. Felling method based on chainsaw required the excavator to remove rubber stump, while using bulldozer to fell the tree can uproot in the felling process. The cost of excavator operation was so high that it becomes higher operation cost in case of felling method with chainsaw than using bulldozer. In addition, current removal of tree stumps for bioenergy is uncommon in Japan; however, stumps are placed on the slopes at the roadside to increase slope stability. On the contrary, rubber stump has become a new resource of biomass, which has about 38,200 kg/ha or 14% of total biomass of a rubber tree. A few markets were one of the important factors to increase the transportation cost of rubber stump supply chain. The utilization of rubber stump tends to increase. Stump harvesting techniques and transportation should be emphasized to meet the increasing of demand.

Cost estimation of rubber wood supply chain based on short-distance transportation was obtained by the working of Google Maps API. The results provided the shortest distances from sample plantations to sawmill with 1.93-18.16 km traveling distance per trip. The lowest costs of rubber wood harvesting using chainsaw and pickup truck were approximately USD2,962-38,272 based on the shortest distance and the quantity of rubber wood in the plantation. It can be concluded that Google Maps API, which can provide the shortest distance between two locations, has a powerful to develop the transportation cost estimation. The benefits of interactive maps and open sources are challenge in the timber transportation to increase the efficiency of supply chain and to safe the planning cost.

Because of the increasing demand of rubber wood, the suggestions for future research are outlined as follow;

- The future research should be concentrate to other trucks such as 10-wheel dump truck, 10-wheel stake body truck, 6-wheel dump truck, and motorcycle with sidecar to make an appropriate rubber wood transportation system.
- The study on environmental impact especially on soil when using bulldozer to felling rubber trees is needed. Although bulldozer operation seems to be more effective than chainsaw in felling operation, the large machines and old designs may have influence on soil.
- Long-term study on stability of stumps retaining on the banking slopes along the forest road should be evaluate and how to utilize the removed stump effectively.
- As increasing demand of rubber stumps, the supply chain of rubber stumps should be researched more. For example, to reduce stump size before load on the truck to increase productivity and reduce transportation cost should be researched.

- The development of Google Maps API on smart phones is an interesting topic. A mobile application on smart phones can support truck drivers for directions and time schedule.