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Original Article

Short wood harvesting and pickup truck transportation during regeneration of rubber plantations

Laddawan RIANTHAKOOL*, Hideo SAKAI*

Introduction

In Thailand, about 5.3% of the total area is covered with rubber (*Hevea brasiliensis*) plantations. Every year rubber trees are felled when latex yield tends to decrease, about every 25-30 years interval, to an uneconomical level at approximately 30,000 ha (RUBBER RESEARCH INSTITUTE OF THAILAND 2010). The most common harvesting method is clear cutting. Felled rubber trees are delimbed, scaled and bucked into mill specified length with chainsaw at the stump area. The process of this typical rubber wood harvesting is comprised of four tasks: felling, processing, loading and transporting. This paper define this system as short wood system, and investigated on its productivity, cost, and time prediction for chainsaw felling, manual processing with chainsaw, and transportation using a pickup truck.

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 0.81 USD/m^3, respectively. MOUSAVI *et al*. (2011) showed that the productivity of felling tree and average cost were 35 m^3 per effective hour and 0.22 USD/m^3 with chainsaw processing. GHAFFARIYAN and SOBHANI (2007) showed that the felling cost by chainsaw was approximately 5.81 USD per hour for the team work of three persons. But studies on the short wood system method in rubber plantation have been few. The study of MOUSAVI (2009) showed that the productivity increased with increased tree size and 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 (GHAFFARIYAN and SOBHANI 2007).

All required length logs of rubber wood are transported from plantation to sawmill directly by compact truck “pickup truck”. 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 of

＊ Department of Forest Science, Graduate School of Agricultural and Life Sciences, The University of Tokyo

timber transportation (Ghaffariyan *et al*. 2012, Mousavi 2009). The time study methods were usually practiced to understand forest operations (Adebayo 2006, Anderson *et al*. 2012, Ghaffariyan *et al*. 2012, Ghaffariyan *et al*. 2013, Nikooy *et al*. 2011, Nurminen *et al*. 2006).

In this study, harvesting operations from stump to sawmill were investigated by evaluating felling, processing, and transporting. The results can help operators and contractors for harvesting planning and productivity optimization in rubber plantation.

2. Material and Method

2-1 Study sites and data collection

The field study was conducted in January 2012 and February 2013 dry weather season in private rubber plantations at Surat Thani and Trang province in southern part of Thailand. These areas were flat land with less than 10% slope. Average day temperature was 35°C and the average relative humidity was approximately 46%. Tree spacing was 3 x 7 m. The study areas were close to the public road. Time study data were collected by a stopwatch and a video recorder to analyze elemental time for each operation. The related factors such as stump diameter, log length, number of logs, transporting distance, fuel consumption, and labor cost were recorded.

2-2 Harvesting method

In the private rubber plantation, short wood harvesting method used Stihl MS381 model chainsaw with 25 inches saw bar and 5.3 hp motor to fell and buck trees. Delimbing and scaling were done by manual with a big knife and a measuring stake. An operator, who was a marker, marked the felled tree from the bottom to the top by a stick of 1.13 m in length and also removed small limbs. All measured and bucked logs were transported to sawmill directly by pickup trucks. 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 1). Manual loading was applied in this case by three experienced crews per one pickup truck. The combination of one chainsaw and two pickup trucks was used, and the number of crew was seven

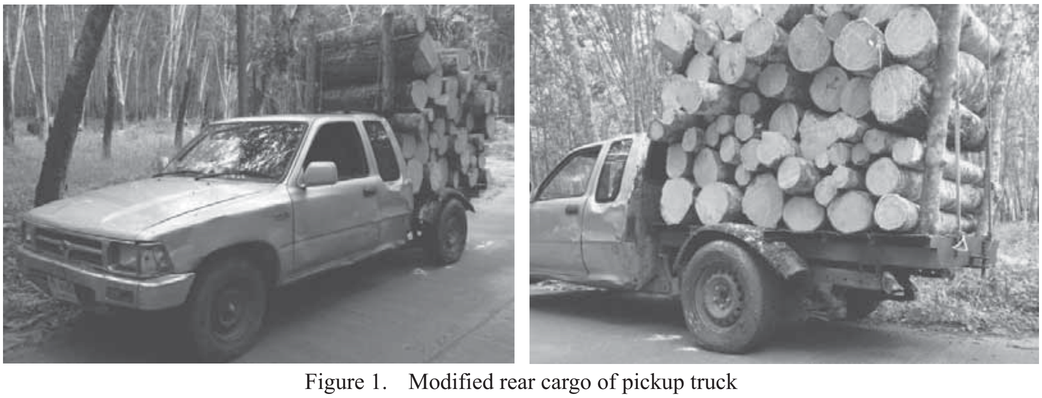

Figure 1. Modified rear cargo of pickup truck

in this study for all operations: one for felling and bucking, four for delimbing, scaling and loading, and two for driving.

This study separated the work cycle into each operation i.e. felling, bucking, and transporting. Delays referred any interruption during operation were also recorded.

Felling

Felling operations with chainsaw were performed by one man. Cycle time was broken down into work elements as follows: moving, worker started to walk to the target tree, and reached at the tree; clearing, worker cleared around the tree; undercut, worker started to cut horizontally, and finished a pie-shaped piece of wood in the falling direction; back cut, worker cut above undercut in opposite direction, removed the saw, and felled the tree on the ground; post cutting, worker cut the cross section area of the stump after felling to make smooth surface, and withdrew the saw from the timber.

Processing

Processing was concentrated on bucking process consisting of three work elements: walking, bucker walked during the bucking operation; bucking, bucker started to cross-cut the felled tree on the marked point until all logs separated; topping, bucker started to cut the top of felled tree and finished when top was cut.

Transporting

Cycle time of transportation was divided into six work elements: loading, loader crews started to load logs onto the pickup truck and ended when the rear cargo of pickup truck became full. This phase included truck driving when preparing; preparing, the crews started to fasten the cargo with rope and finished when the truck got ready to leave plantation for the sawmill; travel with load, the pickup truck left at a plantation and arrived at a sawmill; weighing, the time of pickup truck weighing before and after unloading at the sawmill for log weight measurement; unloading, the pickup truck started to dump and ended when the truck became empty; travel without load, the pickup truck left at the sawmill after second weighing and returned to the plantation.

2-3 Data analysis

A total of 40 cycles for felling with chainsaw, 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). Cost of the short wood system was also calculated for PMH.

3. Results

3.1 Felling

The summary statistics of the time consumption of felling operation is shown in Table 1. Back cut was the most time consumption, 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 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)					
Moving	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 (T_{CF}) was derived to predict the time of felling using chainsaw in relation to stump diameter as

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

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 2. The significant level of the ANOVA table shows that the model is significant at significance level of 0.05 (p-value < 0.001).

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

$$V = k_2(D_S)^2, \qquad (2)$$

where k_2 is constant and k_2 = 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),

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

Table 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			

Figure 2 shows the relationship between log volume and productivity of felling tree and the average of productivity line, 25.1m^3/PMH.

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 3 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 tree, P_F, can be also derived as Eq. (5) if Eq. (4) is adopted.

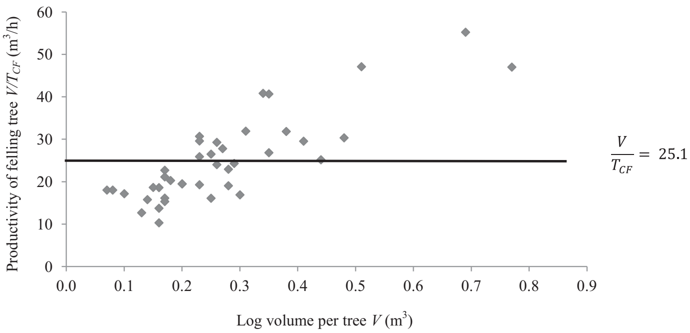

Figure 2. Relationship between log volume and productivity of felling

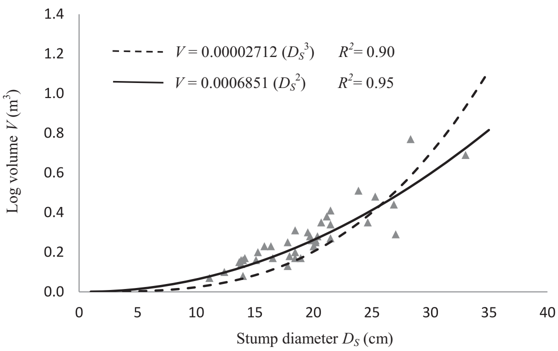

Figure 3. Relationship between stump diameter and log volume

$$P_F = \frac{V}{T_{CF}} = \frac{k_3}{k_1} D_S = \frac{k_3^{2/3}}{k_1} \sqrt[3]{V} \qquad (\mathrm{m}^3/\mathrm{PMH}). \qquad (5)$$

Figures 4 and 5 show relationships between stump diameter or log volume and productivity based on Eq. (5). The coefficient of determination (R^2) of the model from Figures 4 and 5 were same as 0.52. The model based on Eq. (5) explained well the variation of the productivity of felling.

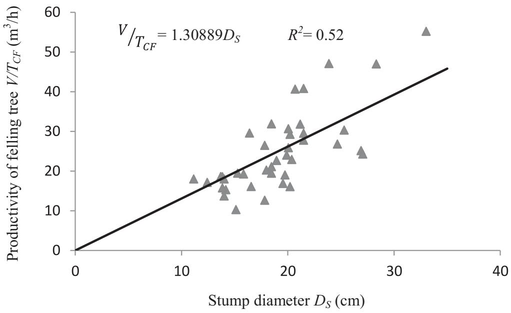

Figure 4. Relationship between stump diameter and productivity of felling

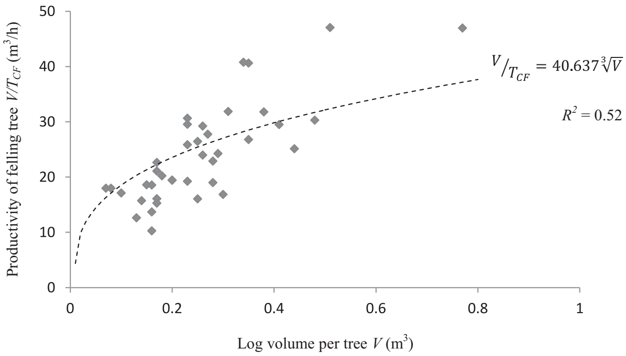

Figure 5. Relationship between log volume and productivity of felling

3.2 Processing

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 3. The time consumption for bucking averaged 114 seconds per one cycle.

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

$$T_B = 6.766 + 5.488\, N + 32.894\, V \qquad (\mathrm{sec}), \qquad (6)$$

Table 3. 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	-
Element 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

Table 4. 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		

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, and it meant that the number of logs and log volume can be described 66% of the total bucking time consumption. From Table 4, the model is significant at significance level of 0.05.

Sakai *et al*. (1988) showed that bucking time, T_B, related to log diameter and log volume. Eq. (7) and Figure 6 showed the relationship in this study (R^2=0.41).

$$T_B = 141.7\ V. \tag{7}$$

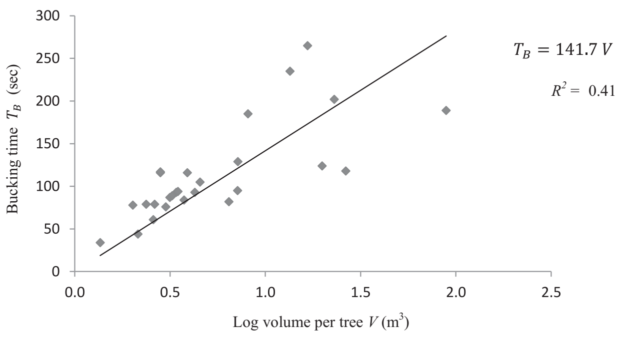

Figure 6. Relationship between log volume and bucking time

The productivity of bucking, P_B, can be assumed as Eqs. (8) and (9), and Figure 7 shows relationship between stump diameter and bucked log volume.

$$V = k_4 N (D_S)^2, \quad (8)$$

or

$$V = k_5 N (D_S)^3, \quad (9)$$

if tree height or log length relates to stump diameter like as Eq. (4). Then, Eqs. (10) and (11) can be derived from Eqs. (8) and (9), respectively.

$$P_B = \frac{V}{T_B} = 23.1 \quad \text{(m}^3\text{/PMH)}. \quad (10)$$

$$P_B = \frac{V}{T_B} = k_6 D_S = k_7 \sqrt[3]{V} \quad \text{(m}^3\text{/PMH)}, \quad (11)$$

where k_4, k_5, k_6 and k_7 are constants.

Although both Eqs. (8) and (9) have high R^2 value, the cubic function model which implies the log length is better use for bucking productivity prediction as shown in Figure 8. Figure 8 shows the relationship between bucked log volume and productivity of bucking based on Eqs. (10) and (11), and the coefficient of determination (R^2) of the cubic root model was 0.38.

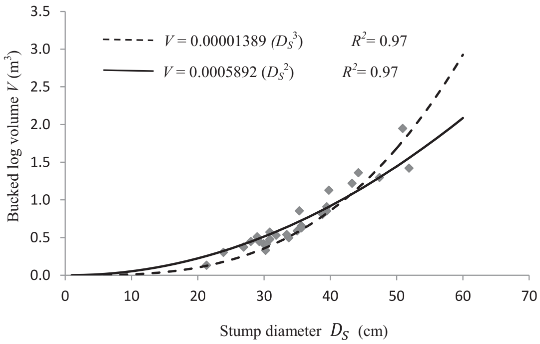

Figure 7. Relationship between stump diameter and bucked log volume

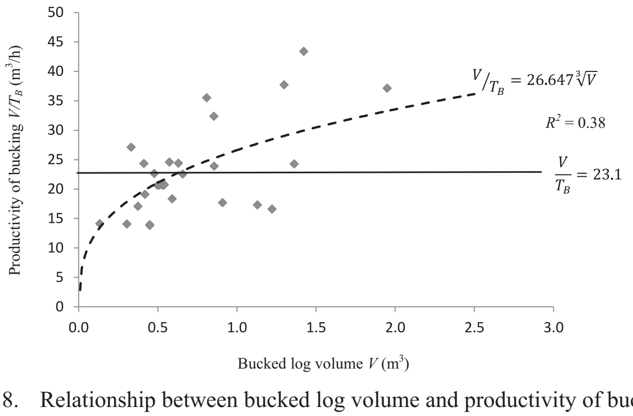

Figure 8. Relationship between bucked log volume and productivity of bucking

Table 5. Statistics of operational variables of logs transportation

Variable	Mean	Std. Dev.	Min	Max	Time composition (%)
Log weight per truck (kg)	2933	313	2190	3620	-
Element time (min)					
Loading	35	5	23	45	26
Preparing	8	4	2	17	6
Travel with load	41	6	22	53	30
Weighing	7	2	4	12	6
Unloading	3	1	2	5	2
Travel 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

3.3 Transportation

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 5. The travel time with load was the most time consumption, followed by travel without load and loading time.

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 transporting time. The transporting time, T_T (hours), can be expressed as:

$$T_T = D\left(\frac{1}{v_l} + \frac{1}{v_n}\right) + T_{others}, \quad (12)$$

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. (12), 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,

$$T_T = D\left(\frac{1}{19} + \frac{1}{20}\right) + 0.91 \quad \text{(hours).} \quad (13)$$

Transporting productivity as a function of travelling distance $P_T(D)$ can be expressed as Eq. (14), where W is truck payload 2933 kg. Increasing travelling distance will increase travelling time and decrease productivity (Figure 9).

$$P_T(D) = \frac{W}{T_T} = \frac{2933}{D\left(\frac{1}{19}+\frac{1}{20}\right)+0.91} \quad \text{(kg/PMH).} \qquad (14)$$

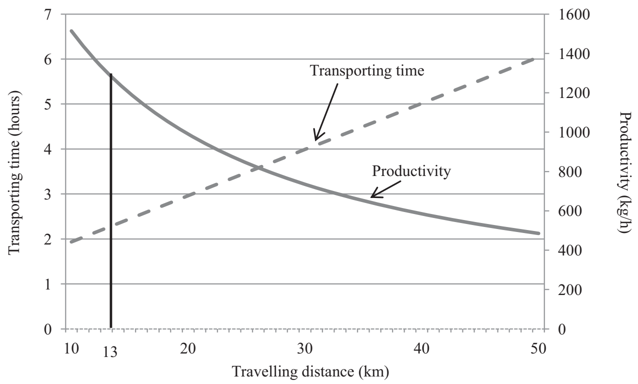

Figure 9. Relationship between travelling distance and transporting time and productivity

3.4 Cost estimation

The cost of each operation of the short wood system is shown in Table 6. 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). The cost of felling and bucking are based on the machine cost of chainsaw. The cost of transporting is based on the cost of pickup truck operation. The cost of transportation including loading, travelling and unloading was the highest and occupied 91.2% of total cost.

Table 6. Summary of cost for short wood system in rubber plantation

Operation	Cost	
	Baht/m^3	Baht/PMH
Felling	28.1	705.0
Bucking	30.5	704.6
Transporting	474.7	958.8
Total	533.3	2,368.4

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

4. Discussion

In this study, the average productivity of felling rubber tree 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 added because spacing distance between rubber trees was equal and constant. But the moving time was high with 24% of total felling time consumption in this study. 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 harvesting planning of rubber plantation.

Delimbing and scaling process was not mentioned by the model because this process was conducted during felling operation. After a chainsaw operator finished tree felling, he could continue the bucking process, therefore delimbing and scaling was implied during the felling 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 (Ghaffariyan 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). To improve this prediction model, the other parameter such as the number of logs should be considered in Figure 8.

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. (13)). This model will be useful to determine the 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. 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.

5. Conclusions

The time prediction model, productivity model and cost estimation are useful for harvesting planning to evaluate the time, production and cost of short wood method in rubber wood harvesting. The productivities rates for felling, and bucking averaged 25.1 m^3/PMH, and 23.1 m^3/PMH, respectively, and related to the stump diameter or log volume. Productivity model of felling and bucking can be measured by stump diameter and bucked log volume, respectively. Summary of the cost for short wood method based on chainsaw and pickup truck system was 16.6 USD/m^3. The most expansive cost was transportation cost approximately 91.2% of total cost. Decreasing log loading on the pickup truck will decrease the transporting time with same traveling distance, and will improve the productivity. The results can be applied to estimate the productivity and cost of short wood method in rubber plantation.

Summary

The short wood system is the most common method for rubber wood harvesting when regenerating rubber plantations in Thailand. The harvesting system consists of felling with chainsaw, manual processing with chainsaw and transporting by pickup truck. A time prediction model for each of these operations was developed. Stump diameter was a significant factor affecting the determination of felling time. Thus, the felling productivity model can be estimated by a stump diameter function. Processing time was found to depend on the number of logs and bucked log volume, and the productivity model of bucking was derived as a function of bucked log volume. Travelling distance was the main variable that affected transporting time. Log weight and transporting time was used to estimate transporting productivity. The total cost of rubber wood harvesting from plantation to sawmill was estimated to be 16.6 USD/m^3. It was found that transportation was the most expensive operation. The results of this research can be used for harvesting planning and improving operational efficiency.

Key words: chainsaw, pickup truck, productivity, rubber plantation, transportation

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ゴムプランテーションにおける更新時の短材収穫 およびピックアップトラック運材システム

ラッダワーン リアントラクーン *・酒井秀夫 *
＊東京大学大学院農学生命科学研究科森林科学専攻

要　旨

タイにおけるゴムプランテーションの更新作業において短材システムが最も一般的である。製材所までの収穫システムは，チェーンソー伐倒，チェーンソー造材，ピックアップトラック運材からなり，各作業の時間予測モデルを構築した。伐倒時間に対しては，伐根直径が有意な要因であった。伐倒の生産性モデルは，伐根直径によって予測することができる。造材時間は玉数，玉材材積によることが見出され，玉切りの生産性モデルは玉切り材積の関数として導かれた。製材工場までの運材距離がおもに運材時間に影響を与えていた。材の重量と運材時間予測が運材の生産性の予測に有用である。プランテーションから製材工場までのゴム材収穫のコストは 16.6 ドル /m^3 となった。運材が最も費用がかかっていることが確認された。本研究の結果はゴムプランテーションにおける更新時の収穫計画や作業能率改善に有用である。

キーワード：チェーンソー，ピックアップトラック，生産性，ゴムプランテーション，輸送