# Motor-Manual CTL Harvesting Techniques of Fast Growing Eucalyptus Plantations - Thailand

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**Abstract:**
*Commercialization of the forest products as well as the demand of small trees for pulp and wood chips has increased in Thailand. However, motor-manual harvesting still predominate the forest operations. Since there are ample cheap labour, expensive machinery, and shortage of skilled machine operators and technicians, the application of highly mechanized systems has not yet been introduced. These characteristics indicate that logging technology in developing countries is determined by its existing social-economic and physical conditions. However, large scale wood industries are interested in mechanization timber harvesting investment due to possible labour shortages in the future, as well as the improvement of productivity and work safety. Those problems lead the need for studies in system comparison and improvement. Aims of this study were to develop models of time consumption and to discover important factors influencing work productivity to rationalize work performance under eucalyptus plantations circumstances in Thailand.*
*The study was carried out in eucalyptus plantations with average 5-year rotation. The study found that there are three prevailing harvesting systems mainly employed which are cut to length method with 2 m long, but there are differences in order of working processes and equipment usage.*
*From this study, the findings show that ranges of the productivity varied from 12,21 to 28,79 $m^3$/day, whilst unit cost varies between 87,63 and 114,48 Baht/$m^3$ depending on the systems. Among prevailing systems, system 3 is the most productive and the cheapest one. All three systems provide the same results that the most expensive and least productive work process is bucking. Bucking is a key element which has significant impact on operating costs. Concerning cost structure, the largest share of operating cost was bucking process which varied between 33,33 to 43,55 percent of total cost. For this reason, the recommendation for further study is to reduce operating costs and to improve the productivity, for instance, less bucking, longer log lengths, introducing of new bucking technology, and reorganising the work processes.*

**Keywords:** harvesting systems, eucalyptus, plantations, productivity, CTL

## 1 Introduction

Commercialization of the forest products as well as the demand of small trees for pulp and wood chips has increased in Thailand. Consequently, forest plantations have become an alternative source of timber production in Thailand, particularly eucalyptus plantations. Due to their astonishing growth performance, climatic adaptability and utilization, eucalyptus trees have rapidly expanded and become the most important commercial tree species.

Generally, the procurement of eucalyptus wood in Thailand is based on the cut to length (CTL) method. This method consists of felling, delimbing and bucking trees into logs of specific lengths at the stump areas. Logs are then loaded and transported to the mills. This system offers several advantages, notably the small landing size is required and minimal damage to the logs (Spinelli et al. 2004). In timber harvesting, motor-manual harvesting is the dominant conventional method in developing countries, such as Thailand. This is an ineffective operation with low productivity and high risk. However, motor-manual harvesting still remains a predominant forest operations. Since there are cheap labour, expensive machinery, and shortage of skilled machine operators and technicians, the application of highly mechanized systems has not been introduced (Henrich 1987, Guangda et al. 1999). These characteristics indicate that logging technology in developing countries is determined by its existing social-economic and physical conditions.

Owing to possible labour shortages in the future, as well as the improvement of productivity and work safety, large scale wood industries are interested in mechanization timber harvesting investment. Those problems lead to the needs for comparative studies on system and improvement. Usually, this kind of problems can be addressed by the work study. The most typical task is to investigate the main factors affecting work productivity and to establish a base for cost calculations and payments. Moreover, the accurate models may be utilized in different kinds of simulations that aim to find new, more efficient work methods or optimize the operations.

The objective of this study was to evaluate the performance of conventional harvesting systems, in order to identify the important factors influencing work productivity and operating costs. Additionally, this study was conducted as a further step towards producing an overall simulation model of harvesting options for eucalyptus plantations.

## 2 Material and methods

### 2.1 Study area

This study was conducted during autumn 2010 and spring 2011 in central, northeastern, and eastern parts of Thailand. Those areas are the suitable sites for growing eucalyptus and located nearby pulp and paper mills. The study was carried out in final felling of eucalyptus plantations with 5-year rotation. Generally, the rotation of eucalyptus in Thailand is approximately five years, sometimes even shorter if those plantations are well managed, planted with suitable clone, as well as good site quality. From this study, an average dbh of eucalyptus was 11,00 cm with 13,98 m merchantable height. There were 18 experimental plots in this study (Table 1). All harvesting sites are monocrop of eucalyptus planted in the certain spacing, even-aged stand in small blocks. Clones (planting stock) may vary from place to place depending on site, climate, and other factors.

**Table 1: Harvesting stand characteristics**

| Sites | Area [ha] | dbh [cm] | Height [m] | Age [yr] | Survival [%] | Density [stems/ha] | Growing stock [m$^3$/ha] |
|---|---|---|---|---|---|---|---|
| 1 | 136,37 | 7,2 | 5,9 | 5 | 69,2 | 1152 | 39,375 |
| 2 | 2,96 | 16,74 | 19,73 | 5 | 55,6 | 617 | 99,831 |
| 3 | 4,48 | 7,58 | 10,8 | 4 | 89,31 | 1984 | 69,185 |
| 4 | 14,88 | 15,45 | 17,84 | 5 | 98,97 | 823 | 133,742 |
| 5 | 49,14 | 5,43 | 5,06 | NA | NA | 890 | 20,000 |
| 6 | NA | 8,09 | 8,58 | NA | NA | 1000 | 44,081 |
| 7 | NA | 7,63 | 7,6 | NA | 67,35 | 688 | 23,896 |
| 8 | NA | 7,16 | 10,21 | 4 | 75 | 864 | 33,200 |
| 9 | 49,28 | 8,7 | 17,92 | 6 | 82,7 | 1378 | 61,719 |
| 10 | 95,68 | 9,17 | 10,91 | 6 | 73,4 | 1223 | 61,160 |
| 11 | 8,90 | 10,26 | 14,72 | 5 | 70,66 | 1177 | 74,476 |
| 12 | 19,2 | 9,96 | 12,47 | 5 | 75,57 | 839 | 49,889 |
| 13 | 13,6 | 14,67 | 19,12 | 5 | 99 | 825 | 110,419 |
| 14 | 10,08 | 13,66 | 18,37 | 5 | 97,69 | 814 | 93,823 |
| 15 | 15,40 | 9,28 | 10,71 | 5 | 40 | 666 | 34,148 |
| 16 | 16,16 | 7,38 | 10,25 | 5 | 60 | 1200 | 38,073 |
| 17 | 7,2 | 17,21 | 15,89 | 6 | 75 | 625 | 116,889 |
| 18 | 13,12 | 9,65 | 12,21 | 5 | 83,07 | 1384 | 77,020 |
| Average | 32,93 | 11,00 | 13,98 | | 74,75 | | 56,23 |

There are three conventional harvesting systems mainly employed in Thailand in case of eucalyptus. All are CTL methods (Figure 1). Normally, a cutting team consists of 8 -10 workers. Typical tools which involved in prevailing timber harvesting are brushsaws, hand tools, and loaders. Firstly, system 1 is the most common practice, which is a labour intensive operation. Process starts from felling by brushsaws, manual delimbing, then bucking by brushsaws. While bucking is processing, stacking can be perform simultaneously by piling in lines or small piles. Afterwards, typical loading method will process manually. For this loading process, the work flow is halt, because all of the forest workers have to suspend their job and gathering for loading. System 2 is rather similar to system 1. However the difference is the loading process which is mechanized loading. Since it applies loader for loading process, thus, all of workers no longer need to get gathering for loading, workers can proceed their own jobs. In addition, there are waiting line before bucking, because bucker has to wait until delimbing is completed, this situation appears in both systems 1 and 2, while system 3 is slightly difference from others. After felling, bucking is immediately performed. Follow by combined delimbing and stacking into one process. The stacking should be done in small piles dispersed over the cutting area, in order to facilitate easier loading. The advantage of this system is that all workers can work continuously.

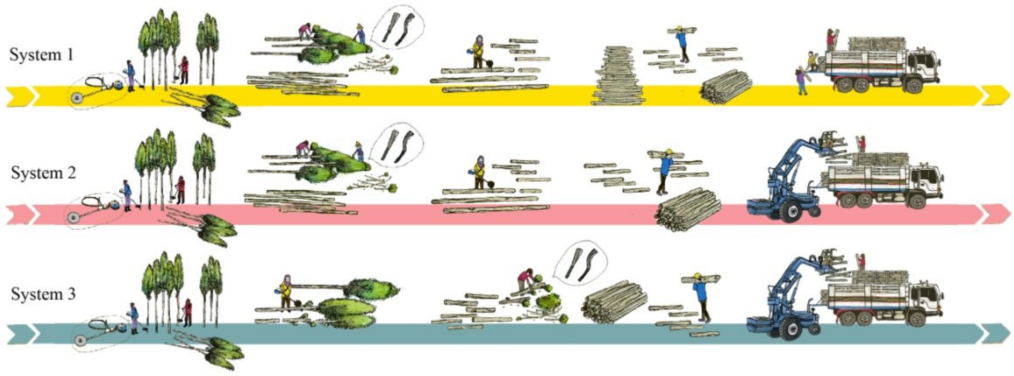


**Figure 1: Conventional eucalyptus CTL harvesting systems**

## 3 Method

All work phases were recorded in video (Björheden 1988, Nurminen, Korpunen and Uusitalo 2006, Nuutinen et al. 2008, Mousavi 2011). Time study was recorded by using handheld computer Psion (Ovaskainen 2005, Laitila, Asikainen and Nuutinen 2007) with specific time study software called UmtPlus (Laubrass 2008). Independent variables, for example, dbh, tree height, merchantable height, log volume, number of logs, walking distance, driving distance were recorded. Diameter at breast height (dbh) and log diameter were measured using calliper, while merchantable length, walking distance and driving distance done with measuring tape.

SPSS 18 was employed for processing the stepwise multiple regression analysis. Two different techniques were employed in forming model. Firstly, a delay-free time consumption model was formed separately for each work element. Secondly, work elements were established using average time consumption values, in case there were no significant independent variables. The model of total time consumption was established by combining the work element models. Eventually, the total time consumption was converted into productivity.

Estimates of hourly costs were computed using machine rate method. Theoretically, cost calculation composes of fixed cost and variable cost (Miyata 1980). The estimation was based on original delivery price, machine life time, fuel and lubricant cost, tyres, maintenance and repair, labour cost. Fixed costs are the expenses that are not dependent on function of the activity, hours of operation, no matter the machine are used or not. Fixed costs consist of depreciation, interest, insurance, and taxes. Variable costs are the expenses that vary with the number of units produced. Variable costs include those of fuel, lubricant, tyres, repair and maintenance, and labour. Eventually the unit cost is deduced by dividing the hourly operating cost (Baht/SMH) with hourly productivity ($m^3$/SMH).

Sensitivity analysis allows assessment the impact that changes in a certain parameter will have on the conclusions of the model. It helps determine which parameters are the key drivers of a total cost. There are two uncertainties which are productivity and operating costs. Sensitivity analysis was performed in spreadsheet by changing to examine the effects of different operations on the total cost.

## 4 Results

The comparison of time distribution of producing one cubic meter for three conventional harvesting systems is illustrated in Figure 2. It shows the largest time segment devoted to delimbing, and delimbing & stacking operation in all three conventional harvesting systems, accounting for over 35% of the total time. Since the delimbing was manual work, more time required to accomplish the task. Furthermore, the second largest time consuming was bucking process, accounting for over 24% of total time. Bucking process provided relatively high operating cost, and time consuming process, leading inefficient work phase.

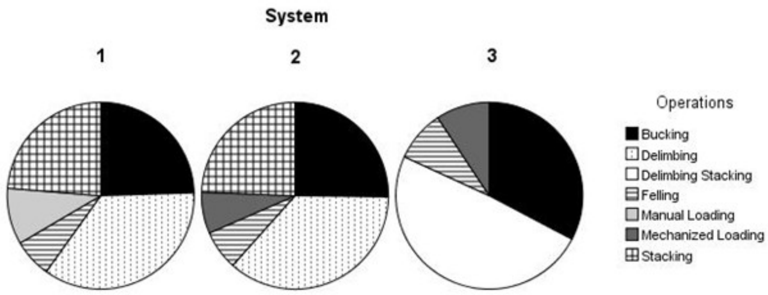


**Figure 2: Distribution of time consumption for three conventional harvesting systems**

The statistical characteristics of regression models are presented in Table 2. F-value and p-value indicate that the models are statistically significant.

Cutting:

The time consumption for cutting can be categorized into walking, undercut, and back cut. The cutting time depended on walking distance between trees, tree size, and tree volume. The average productivity of cutting was 11,72 $m^3$/PMH with an average operating cost of 11,45 Baht/$m^3$.

Bucking:

Bucking consists of walking, partial delimbing, and bucking itself. The bucking time slightly depended on log diameter and log volume. The walking time increased as a function of walking distance. Overall productivity was fairly low, only 3,18 $m^3$/PMH with 38,17 Baht/$m^3$ of operating cost.

Delimbing:

The delimbing time consumption model engaged with walking distance, stem size, and dbh. The average productivity of delimbing in effective time was 2,20 $m^3$/PMH. Since this operation was manual process, it caused the operating cost relatively low, 17,17 Baht/$m^3$.

Stacking:

Stacking operation composes of walking, hooking log, dragging, and dropping log, these work elements were performed manually. There was no significant difference of variable found on hooking, dragging, and dropping time consumption. The overall time consumption for stacking depended on log diameter and walking distance. Productivity and operating cost of stacking was rather similar to delimbing, which was 3,28 $m^3$/PMH and 13,16 Baht/$m^3$, respectively.

Manual loading:

Twelve loading trucks were engaged during this study. There was no significant difference of variable found *on manual loading process.* The average truck loading space was 39,25 $m^3$. However in terms of solid log volume point of view, an average volume of solid log was about 60% of total space (23,55 $m^3$). Manual loading for one truck required a group of 8-10 workers, the average time being 176,80 min/truck with productivity 7,99 $m^3$/PMH and 34,54 Baht/$m^3$ for operating cost.

Mechanized loading:

Mechanized loading was operated using modified farm tractor mounted with front end grapple loader. The main variables on time consumption were driving distances for both empty load and full load, and load volume per turn. The average productivity and operating cost of mechanized loading were 11,19 $m^3$/PMH, and 19,44 Baht/$m^3$, respectively.

**Table 2: Statistical characteristics of the regression analysis for time consumption models***

| Category | R2 | F-Test | | N | Terms | Coefficient | S.E. | T-Test | |
|---|---|---|---|---|---|---|---|---|---|
| | | F-value | P | | | | | t-value | P |
| (Felling) | | | | | | | | | |
| Walking | 0,862 | 2687,074 | <0,001 | 433 | Constant | 0,892 | 0,104 | 8,614 | <0,001 |
| | | | | | (Xdis) | 1,542 | 0,03 | 51,837 | <0,001 |
| Undercut | 0,349 | 214,575 | <0,001 | 402 | Constant | -10,323 | 1,528 | -6,758 | <0,001 |
| | | | | | (Xstd) | 1,268 | 0,087 | 14,648 | <0,001 |
| Backcut | 0,226 | 139,596 | <0,001 | 481 | Constant | 10,155 | 0,555 | 18,313 | <0,001 |
| | | | | | (Xv) | 44,406 | 3,758 | 11,815 | <0,001 |
| Overall | 0,517 | 255,745 | <0,001 | 481 | Constant | 11,367 | 1,398 | 8,13 | <0,001 |
| | | | | | (Xv) | 185,575 | 9,194 | 20,184 | <0,001 |
| | | | | | (Xdis) | 1,621 | 0,234 | 6,917 | <0,001 |
| (Bucking) | | | | | | | | | |
| Walking | 0,863 | 10548,154 | <0,001 | 1679 | Constant | 0,748 | 0,045 | 16,604 | <0,001 |
| | | | | | (Xdis) | 1,617 | 0,016 | 102,704 | <0,001 |
| Bucking | 0,291 | 692,101 | <0,001 | 1688 | Constant | 1,889 | 0,096 | 19,583 | <0,001 |
| | | | | | (eXdia) | 0,128 | 0,005 | 26,308 | <0,001 |
| Overall | 0,409 | 584,095 | <0,001 | 1688 | Constant | 3,802 | 0,439 | 8,653 | <0,001 |
| | | | | | (Xv) | 586,822 | 23,368 | 25,112 | <0,001 |
| | | | | | (Xdis) | 2,167 | 0,101 | 21,385 | <0,001 |
| (Delimbing) | | | | | | | | | |
| Walking | 0,872 | 640,033 | <0,001 | 96 | Constant | 3,205 | 1,888 | 1,697 | 0,093 |
| | | | | | (Xdis) | 1,03 | 0,041 | 25,299 | <0,001 |
| Delimbing | 0,33 | 46,755 | <0,001 | 97 | Constant | -10,417 | 11,165 | -0,933 | 0,353 |
| | | | | | (Xdbh) | 5,619 | 0,822 | 6,838 | <0,001 |
| Overall | 0,797 | 182,297 | <0,001 | 97 | Constant | -10,432 | 11,457 | -0,911 | 0,365 |
| | | | | | (Xv) | 1157,486 | 93,249 | 12,413 | <0,001 |
| | | | | | (Xdis) | 1,606 | 0,258 | 6,223 | <0,001 |
| (Stacking) | | | | | | | | | |
| Walking | 0,883 | 6710,155 | <0,001 | 887 | Constant | 1,208 | 0,095 | 12,694 | <0,001 |
| | | | | | (Xdis) | 0,809 | 0,01 | 81,916 | <0,001 |
| Overall | 0,527 | 486,098 | <0,001 | 874 | Constant | 6,453 | 0,496 | 13,005 | <0,001 |
| | | | | | (Xdis) | 0,797 | 0,027 | 29,948 | <0,001 |
| | | | | | (Xdia) | 0,321 | 0,054 | 5,960 | <0,001 |
| (Mechanized loading) | | | | | | | | | |
| Empty drive | 0,828 | 1678,208 | <0,001 | 350 | Constant | 9,934 | 1,094 | 9,079 | <0,001 |
| | | | | | (Xdis_emp) | 0,913 | 0,022 | 40,966 | <0,001 |
| Loaded drive | 0,771 | 583,415 | <0,001 | 350 | Constant | 21,598 | 2,312 | 9,34 | <0,001 |
| | | | | | (Xdis_full) | 0,985 | 0,029 | 33,979 | <0,001 |
| | | | | | (Xlv) | -19,483 | 4,209 | -4,629 | <0,001 |
| Overall | 0,799 | 459,435 | <0,001 | 350 | Constant | 81,598 | 4,967 | 16,428 | <0,001 |
| | | | | | (Xdis_full) | 1,367 | 0,075 | 18,126 | <0,001 |
| | | | | | (Xdis_emp) | 0,700 | 0,079 | 8,853 | <0,001 |
| | | | | | (Xlv) | -35,781 | 9,020 | -3,967 | <0,001 |

*Where $x_{dis}$ is walking distance (m.), $x_{std}$ is diameter at stump (cm.), $x_v$ is tree or log volume ($m^3$), $x_{dia}$ is log diameter (cm.), $x_{dbh}$ is diameter at breast height (cm.), $x_{dis\_emp}$ is driving distance with empty load (m.), $x_{dis\_full}$ is driving distance with full load (m.), and $x_{lv}$ is load volume, ($m^3$/turn).

The study results showed that the average productivity of systems 1, 2, and 3 were 12,21, 19,32 and 28,79 $m^3$/day, respectively. It clearly indicates that system 3 is the most economical system as far as the productivity is concerned (Figure 3). Moreover, the cost structure in Figure 3 specify that bucking is the remarkably largest share, 33,33%, 38,40% and 43,55% of total unit costs for systems 1, 2 and 3, respectively. In case of system 1, the share of manual loading is rather similar to that of bucking process.

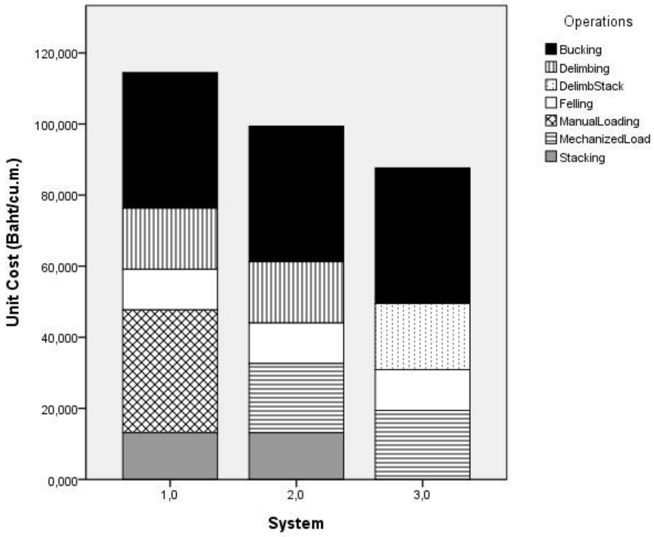


**Figure 3: The unit costs structure of three conventional harvesting systems**

To ensure the assumption that bucking is the most ineffective operation, sensitivity analysis has been conducted. It is apparent from Figure 4 that bucking significantly affects the total cost for all conventional harvesting systems. When increasing either operating costs or productivity, it highly affects the total cost. The overall results from sensitivity analysis indicates that bucking, delimbing, stacking, loading (either manual or mechanized) are key elements which have significant impact on productivity and operating costs, despite the priority may differ from system to system.

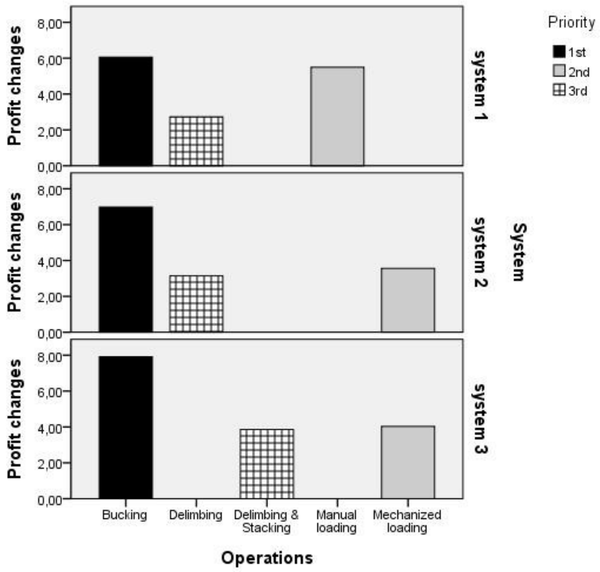


**Figure 4: Sensitivity analysis of conventional harvesting systems to examine the key element which have a strong impact on the total cost**

## 5 Discussion

This study provides time consumption, productivity, and cost of conventional timber harvesting systems which can be considered typical for supply chain of eucalyptus CTL operations in Thailand. Difficulty of time study was found in work element classifications, variables definitions and measurement systems which vary from study to study. In some aspect, the comparisons are valid and informative.

From the results, tree size and volume were the most significant variables affecting the felling time. The productivity increased with the increase in tree size. Holtzcher and Lanford (1997) also reported that when harvested tree increased in size, the felling and processing became more productive. Additionally, the larger tree size significantly affects longer delimbing time, due to increasing tree height and branches which is conform to the report of Nakagawa et al. (2007). Tufts (1997) also revealed that tree size, tree volume, and number of pieces processed per tree, were the variables with the greatest impact on harvesting productivity. That was rather similar to the findings from this study, where bucking operation was the significant key impact on harvesting productivity due to fairly short length (2 m.). The shorter log causes longer processing time, the longer log should be practiced. Furthermore, tree size had a significant effect on unit cost of wood produced. The unit cost of timber harvesting decreased as the tree size increased (Holtzcher and Lanford 1997). Besides, Wang et al. (2004) pointed out the more mechanized the harvesting system, the more productive. However, it should keep in mind that mechanized harvesting always requires higher operation cost.

Since bucking was denoted as the key work phase which had significant impact on operating cost in this study, the suggestion was to extend the log length in order to reduce bucking time, or introducing alternative logging systems. The further study should step forward to introduce alternative system through simulation. Bucking lengths, tree sizes, and other parameters should be taken into consideration as the key factors on system productivity.

Video has been using in several studies including this study. The advantages of using video technique are repeatable, slow down and speed up the motion, and material can be saved for additional analyses.

Even though brushsaws recently become commonly used for eucalyptus felling in Thailand, due to low investment, fairly small tree sizes, and improvement work postures. However, there are some negative opinions since it is inherently dangerous. The workers are unable to totally control the saw. The open blade is on the end of a wand, and can snag and swing violently to the side, making it more prone to injure other workers. Personal protective equipment (PPE) is required, for example, helmet, ear protection, eye protection, gloves, and leather boots.

Since the motor-manual harvesting operations may be considered as the physically demanding job, whereas workers often work under discomfort conditions (high temperature and high humidity). Operators occasionally are able to work less than usual, and take frequent breaks. This may lead to inefficient outcomes. Developing of labour saving devices or techniques, work organization, work design may improve the work efficiency.

## 6 Conclusions

Though all three conventional harvesting systems compose of the same type of tools and machines, but varied in the order of work, it conducted the different results. Thus it can be concluded that the work organization is an essential factor strongly influencing the outcomes. The appropriate work arrangement is able to improve the work efficiency, enhance the productivity, and reduce the unit cost.

Nevertheless, forest work is considered as a physically demanding and poorly paid job in Thailand, it is difficult to recruit new workers, and a shortage of labour will become the main challenge in forestry sector. In the long term, mechanized timber harvesting should be considered to replace labour-intensive operations. On the other hand, entrepreneur should create some incentives in order to attract new crew.

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