# LOG HAULING PRODUCTIVITY IN TIMBER HARVESTING OPERATION IN PENINSULAR MALAYSIA FOREST

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**NORIZAH K, MOHD-HASMADI I, HUSNA S & CHUNG W. 2016. Log hauling productivity in timber harvesting operation in Peninsular Malaysia forest.** The study continuously recorded working elements and log hauling activities of log trucks. The variables measured were travel distance, number of logs and log volume which were regressed with hauling time and productive machine hour ($m^3$ $PMH^{-1}$) using stepwise method via data analysis in Excel. Travel distance and the number of logs hauled per truck were found to be significantly corelated with hauling time, while all the three variables were significantly corelated with productivity. The equation models for both hauling time and productivity were developed using significantly tested variables. On average, productivity of free delay time of log hauling at the study area was $8.36 \pm 2.49$ $m^3$ $PMH^{-1}$ and the operation cost of log truck was RM25.08. Thus, the unit cost of log hauling activities was estimated at RM3.80 $m^{-3}$. The developed prediction model of hauling time, productivity and cost analysis could be used to plan timber harvesting activities with improved productivity and decreased cost.

Keywords: Cost, prediction model, log trucks, log volume, travel distance

## INTRODUCTION

The development of forest management systems and practices since 1940s has led Peninsular Malaysia into excessive timber logging where harvesting tools and equipment were mechanised. Mechanised harvesting methods included 1) tree felling by using chain saw, 2) log extraction by using crawler tractor or log fisher and 3) log hauling by using forwarder or log truck (Norizah et al. 2011, 2012). A combination of machineries used in timber harvesting operation reduced overall operational cost and increased productivity. However, detailed time consumption and cost fraction have not been studied in overall timber harvesting operations. A prediction model could be developed by examining the working elements with continuous time records and costs, associated with harvesting operations (Ghaffariyan et al. 2009, Norizah et al. 2012, Mousavi & Naghdi 2013).

Researchers have studied and predicted the productivity of harvesting operations in Peninsular Malaysia. Previous studies reported on felling and log extraction activities using log fisher extraction system in inland forest and log extraction activities of winch-mounted steel sled system in peat swamp forest (Ismail & Kamaruzaman 2008, Norizah et al. 2012, Mohd-Hasmadi et al. 2013). However, due to varied forest types and timber harvesting activities, the productivity reported did not represent the overall timber harvesting operations of Peninsular Malaysia.

Log hauling is an activity of a truck, also known as a forwarder, used to haul logs from loading site to delivery site. A forwarder is equipped with a loader that loads and unloads logs, while a truck is a typical hauling machine used in Malaysian forests without an attached loader. Forwarder productivity was studied by time records of loading and unloading of logs and travel loaded and travel empty within a trip. Species composition, stem size, climate condition and harvesting prescription affected the productivity of log hauling. Operator's skills also influenced the prediction of log hauling productivity. The variables measured were hauling distance, piece volume, total load volume and slope travelled. These were tested significant and were used to predict the productivity of a forwarder. Hauling productivity could be affected by hauling distance and load size. High operational cost incurred for bigger machines but declined with high productivity (Ghaffariyan et al. 2007, Jirousek et al. 2007, Hiesl 2013).

Estimation of log hauling is very important, since productivity and operational costs are good predictors for overall timber harvesting operations. It has similar characteristics with productivity equations developed for felling and extraction (Norizah et al. 2012, Mohd-Hasmadi et al. 2013). A detailed time study and operational costs of log hauling was modelled and evaluated in inland forest. The model took into consideration log volume, number of logs and distance travelled within a hauling trip. This study was aimed to predict the efficiency of log hauling activities in terms of productivity with volume ($m^3$) and operational costs.

## MATERIALS AND METHODS

### Study area

The study was carried out in a 144 ha harvest unit within Compartment 30 of Balah Forest Reserve, Kelantan, Peninsular Malaysia (Figure 1). There were 24 loading sites and 5.7 km of existing roads connecting to feeder roads. The terrain slopes ranged between 10° and 40°. The hauling distance averaged about 22 km. Ten logs with an average size of 12 $m^3$ per log were hauled for a travel loaded. The study was conducted during dry season in March which was ideal for timber harvesting operation in the East Coast of Peninsular Malaysia.

Hauling activities were carried out by log trucks popularly known as king of the forest or 'san tai wong' (Figure 2). The trucks were modified lorries with various engine power. Each truck was operated by a driver and hauled logs from the loading site within a harvest unit to the log delivery site outside the harvest unit. It was operable at maximum slope conditions of 25°. Since no loader was attached to the truck, log loading and unloading activities were handled by a separate log loader machine. Log trucks were the only transportation vehicles that operated without road tax and insurance which were compulsory for most mechanised transportation vehicles in Malaysia. General specifications of the log trucks were 5 m length of the body and 2.5 m width of the front head. Horse power depended on the engine used. Load capacity was up to 15 tonnes per journey.

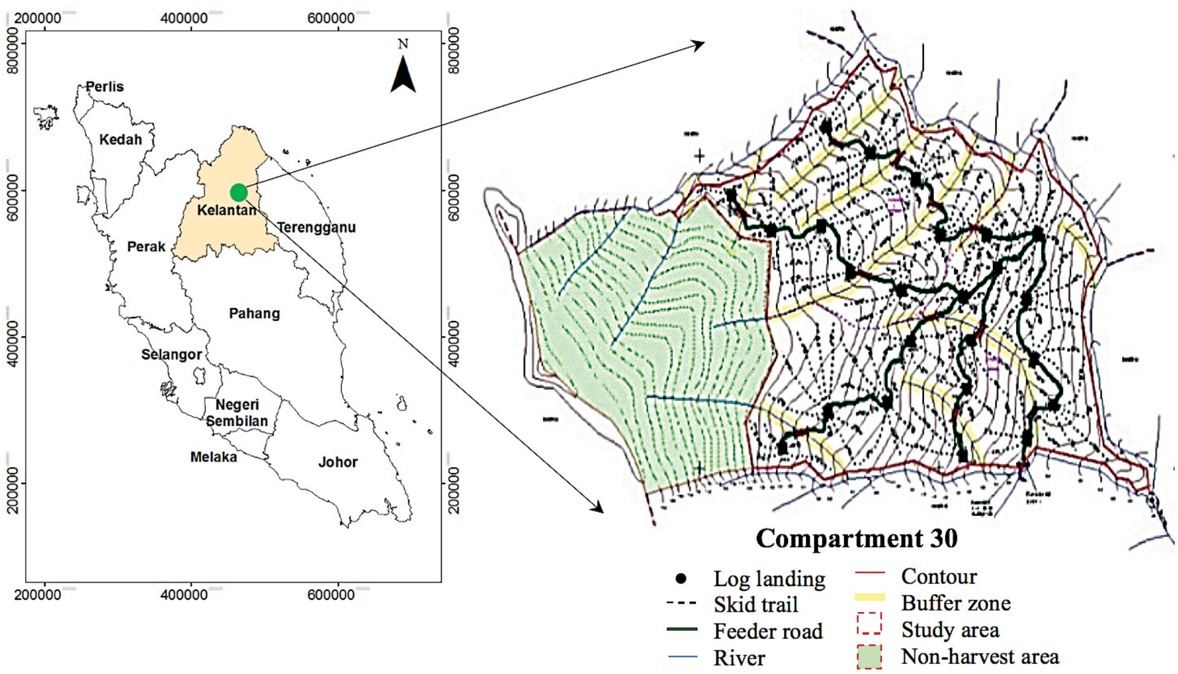


**Figure 1** Location of study area at Compartment 30, Balah Forest Reserve, Kelantan

**Figure 2** Common log truck used for log hauling in Peninsular Malaysia

## Time records

Log hauling activities were divided into four main working elements, (1) travel empty, (2) log loading, (3) travel loaded and (4) unloading (Table 1).

Time durations of working elements were recorded using a digital stop watch. Since travel distance was involved, two observers communicated through a radio transmitter. The first observer recorded the loading time and departing time for travel loaded at a loading site and informed the second observer at the delivery site. The information transmitted was start time, log number, trip number and operator's name. When the truck arrived at the log delivery site, the second observer recorded the end time of travel loaded, unloading time and start time for travel empty. Information transmitted to the first observer was start time, trip number and operator's name. The first observer would the record the end time for travel empty. At the end of a working day, all data collected were merged based on trip numbers and operators' names for productivity analysis.

Problems during log hauling process introduced delay time. Delays of less than 10 min resulting from operational, mechanical and personal reasons were recorded as productive time, otherwise defined as delay time. If delay occurred in the middle of log hauling where both observers were not present, the operator recorded the delay time and cause so as to minimise data errors. A total of 50 trips of log hauling were recorded.

**Table 1** Working elements with respect to time for log hauling

| Working elements | Explanation |
|---|---|
| Travel empty | Time spent for log truck to travel without load from log delivery site to a temporary loading site<br>Start → when a truck starts moving from the log delivery site<br>End → after the truck stops and is ready to receive logs at a loading site |
| Log loading | Time spent to load logs onto a truck at a loading site<br>Start → when a loader grabs the first log from the forest floor<br>End → after the loader puts the last log onto the truck and is ready to move |
| Travel loaded | Time spent to haul logs from a loading site to the log delivery site<br>Start → when a truck starts moving from a loading site<br>End → after the truck positions at the log delivery site is and ready for unloading |
| Unloading | Time spent to unload logs at the log delivery site<br>Start → when a loader grabs the first log from a truck.<br>End → after the last log is stacked on the floor and the truck is ready to move off without any load for the next cycle of activity |

## Variables measured

Log hauling was assumed to be the function of number of logs, log volume and distance travelled. The number of logs hauled within a trip was recorded at the loading site. The length and diameter of each log was measured and the log volume was estimated based on log volume table of the Forestry Department of Peninsular Malaysia. The log volume was then totalled according to the number of logs hauled. The length of road traversed by each log truck was measured based on road map scales 1:50,000 provided by the forest concessionaire. The start and end points of travel were georeferenced by using Global Positioning System and merged with road map in order to compute the distance travelled between the two points.

## Cost calculation

Three types of costs were considered for the estimation of overall log truck operational cost, i.e fixed cost, variable cost and labour cost (Norizah et al. 2012). Fixed cost involved acquisition of a log truck and did not affect the activity of log hauling. However, since the machine has been used for several years, a depreciated present value was calculated. Fixed costs were shown in scheduled machine hour (SMH). Variable cost affected the activities performed by a log truck. During log hauling activities, time recorded was based on productive working hours. Thus, variable costs were shown in productive machine hour (PMH). For labour costs, workers were paid according to total log volume hauled within the scheduled operation. The current rate of wages for workers was RM166.67 $m^{-3}$. Approximately, the scheduled working hours for log hauling in timber harvesting operations were 9 hours $day^{-1}$. Moving logs from loading site to delivery site in a harvest unit could be completed within 4 months. Therefore, labour cost was calculated based on the log volume hauled within the scheduled machine hour. Essential costs used to calculate log hauling operational costs are shown in Table 2.

The following formulas were used to calculate total operational cost:

(1) Operational cost (RM/SMH)= fixed cost + variable cost + labour cost

(2) Depreciation (RM/SMH) = $\dfrac{\text{purchase price} - \text{salvage value}}{\text{life in years} \times \text{scheduled hours}}$

(3) Variable cost (RM/PMH) = fuel and lubricant (RM/PMH) + tires (RM/PMH) + (repair and maintenance) (RM/PMH)

(4) Repair and maintenance (RM/PMH) = depreciation (RM/SMH) × repair and maintenance rate (%)

(5) Total variable cost (RM/SMH) = variable cost (RM/PMH) × expected utilisation (PMH/SMH)

where RM = Ringgit Malaysia, SMH = scheduled machine hour, PMH = productive machine hour,

**Table 2** Essential costs of log hauling operation

| Machine information | Unit |
|---|---|
| Purchase price | RM210,000/SMH |
| Salvage value | RM42,000/SMH |
| Fuel and lubricant | RM5.98/PMH |
| Tyres | RM0.70/PMH (for 10 tyres) |
| Machine life in years | 7 years |
| Scheduled machine hour (annually) | 2460 hours |
| Repair and maintenance rate | 20% |
| Expected utilisation rate (productive working hour / scheduled working hour) × 100 | 86% |
| Labour rate | RM7.90/SMH |

Fuel price = RM1.75/litre, SMH = scheduled machine hour, PMH = productive machine hour expected utilisation = rate of time a log truck actually works without delays.

In this log hauling productivity study, interest, taxes and insurance rate were omitted from the calculation as log trucks were exempted from road tax and machinery insurance. Calculation of variable cost involved three factors, (1) fuel and lubricant, (2) tyres and (3) repair and maintenance. The three component cost factors varied with log truck activities. Costs for fuel and lubricant as well as tyres were direct costs acquired from log truck operation, while repair and maintenance were calculated by considering the depreciation rate of a log truck. The rate for repair and maintenance was estimated from the productive hours of log truck operation. In order to determine the unit for total cost in scheduled machine hour, variable costs (in PMH) was converted to SMH.

## Analysis

The total time and productivity of log hauling were subjected to multiple linear regression using stepwise regression method of backward elimination in Excel. Backward elimination compared a series of measured variables and identified the significant interactions between each variable, while variables not significant to hauling time and productivity were omitted. The variables with major influence on hauling time and productivity were examined for *R*-square, coefficients and p-value.

## RESULTS AND DISCUSSION

The descriptive statistics resulting from continuous time study records including variables measured are shown in Table 3. Figure 3 presents

**Table 3** Descriptive statistics of log hauling activities, 50 trips (n = 50)

| Working elements | Minimum | Mean | Maximum | Standard deviation |
|---|---|---|---|---|
| Travel empty (min cycle$^{-1}$) | 54.00 | 88.72 | 129.7 | 15.03 |
| Loading (min cycle$^{-1}$) | 6.15 | 17.01 | 54.6 | 6.90 |
| Travel loaded (min cycle$^{-1}$) | 60.00 | 139.04 | 300 | 39.81 |
| Unloading (min cycle$^{-1}$) | 5.00 | 9.27 | 17.08 | 3.53 |
| Distance travelled (m) | 11800 | 22188 | 24000 | 604.19 |
| Load volume (m$^3$) | 5.49 | 11.95 | 15.67 | 0.30 |
| Number of load log | 3.00 | 9.71 | 16.00 | 0.32 |

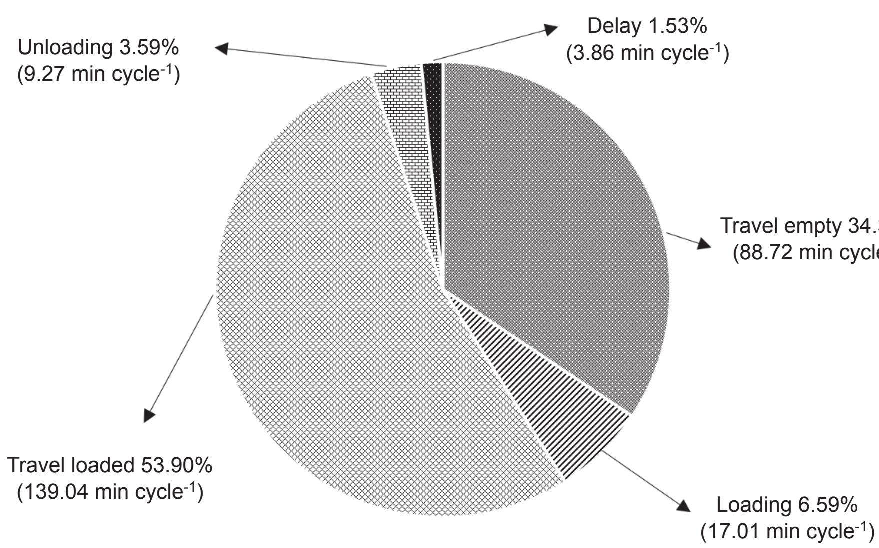


**Figure 3** Distribution of log hauling time

the distribution of time recorded for log hauling activities of a log truck.

In the study, travel loaded occupied the largest share of time while delay time was a smaller element. The speed of truck increased when it was not loaded with logs. Thus, travel empty time was 2/3 of travel loaded time. Lanford and Stokes (1996) reported a contrast time record for travel empty and travel loaded, suggesting that there was no difference between these two working elements should the route and distance travelled were similar. The area of log delivery site, 0.3 ha, was bigger than the loading site, 0.25 ha. This gave ease of manoeuvrability resulting in less time at delivery site compared with loading site.

The analysis of total time and operational cost of log trucks were presented according to time and log production volume to develop a cost effective model of log hauling activities (Figure 4). In an attempt to develop the prediction model for log hauling time and productivity, a correlation analysis between the independent variables was carried out. The result confirmed that the independent variables had no correlation with one another (Table 4). Significant dependant variables were regressed and included in the model.

## Log hauling time model

Total hauling gross hours were estimated as minimum = 2.30, maximum = 6.81, average = 4.23 and standard deviation = 0.84. Hauling time data was fitted into exponential form to reduce the outliers and regressed for hauling time model. The step wise regression eliminated log volume as a function to estimate hauling time (Table 5). Eventually, the following model was developed to predict hauling time:

$$\text{Hauling time} = e^{-4.88 + 0.67\,\text{Distance} - 0.17\,\text{Number of logs}}$$
$$r^2 = 0.56$$

where e = exponent and $r^2$ = coefficient of determination

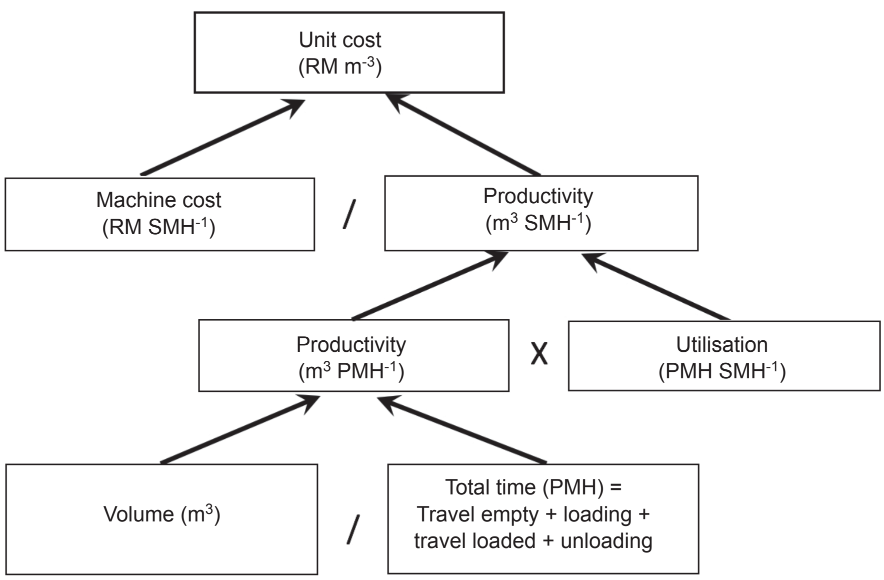


**Figure 4** Flow chart of log hauling time and production; / = division, x = multiplication

**Table 4** Correlation matrix of variables in log hauling activities

| Variables | Distance (m) | Volume ($m^3$) | No. of logs |
|---|---|---|---|
| Distance (m) | 1 | | |
| Volume ($m^3$) | -0.0167 | 1 | |
| No. of logs | 0.2876 | 0.5980 | 1 |

**Table 5** Regression coefficient for the cycle time prediction function for log truck

| | Coefficient | Standard Error | t-stat | p-value |
|---|---|---|---|---|
| Intercept | -5.5049 | 0.9266 | -5.9408 | 3.55E-07 |
| ln distance | 0.7053 | 0.0894 | 7.8901 | 4.3E-10 |
| ln volume | 0.1842 | 0.1276 | 1.4436 | 0.1556 |
| ln logs | -0.2529 | 0.0945 | -2.6769 | 0.0103 |
| | | Backward elimination | | |
| Intercept | -4.8803 | 0.8288 | -5.8882 | 3.97E-07 |
| ln distance | 0.6697 | 0.0869 | 7.7062 | 7.01E-10 |
| ln logs | -0.1704 | 0.0761 | -2.2394 | 0.029 |

t = statistical examination of two population means

Based on the developed model, greater distance increased hauling time while smaller number of logs decreased hauling time. Previous studies found that total hauling time increased with distance travelled. However, the numbers of logs hauled were not regressed with hauling time (Adebayo et al. 2007, Ghaffariyan et al. 2007, Hiesl 2013). About 56% of the independent variables caused variation in hauling time model resulting from regression. The ANOVA test confirmed the significance of predicted hauling time model at level 5% (Table 6).

A log truck travelling time could be improved with good road specification and grade, thus reducing the total time of log hauling. The condition of the log truck, e.g. the ability to travel long distances without slope restriction or delays, contributed to good hauling time. When less logs were hauled, the loading and unloading was completed in a shorter time. However, the loading and unloading time differed because the process of stacking logs during loading is relatively easier and required shorter time than that of unloading (Dowling 2010). Grasping a log from the narrow space of a truck required the operator to be very careful as to avoid untoward incidents. The same volume of a truckload may consist of small or large logs depending on the sizes of individual logs. Hence, the loading and unloading time could differ for different truckloads as the log loader can only grasp one log at each cycle. The positioning of the log loader also contributed towards time spent (Nurminen et al. 2006, Hiesl 2013). Thus, it was found that the number of logs influenced hauling time, while no significant relationship was observed with log volume. Shorter time spent in log loading and unloading could be achieved with loader attached to the truck and minimum movement of the boom.

## Productivity model

The average production values estimated from the delay free time study were 8.36 $m^3$ $PMH^{-1}$ with 3.41 $m^3$ $PMH^{-1}$ as minimum value, 16.75 $m^3$ $PMH^{-1}$ as maximum value and standard deviation 2.49 $m^3$ $PMH^{-1}$. Productivity estimated in this study was similar to previous ones, yet number of logs transported was lower. Previous studies had loads ranging from 100 to 200 logs per trip (Hiesl 2013, Li et al. 2006). Differences of timber species in tropical and temperate forests could be the reason for such productivity reported. Using the step wise regression (Table 7), the productivity of hauling can be expressed as:

**Table 6** ANOVA table for log hauling time model

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 2 | 1.199031 | 0.599515 | 29.7239 | 4.54E-09 |
| Residual | 47 | 0.947965 | 0.020169 | | |
| Total | 49 | 2.146996 | | | |

df =degree of freedom, SS = sum of squares, MS = mean square, F = variance of the group mean

**Table 7** Regression coefficient for productivity prediction

| | Coefficient | Standard error | t-stat | p-value |
|---|---|---|---|---|
| Intercept | 8.4455 | 1.4280 | 5.9116 | 3.92858E-07 |
| ln Distance | -0.0004 | 0.00005 | -8.5878 | 4.08405E-11 |
| ln Volume | 0.5098 | 0.1103 | 4.6225 | 3.08245E-05 |
| ln logs | 0.2662 | 0.1073 | 2.4818 | 1.67859E-02 |

t = statistical examination of two population means

Hauling productivity ($PMH_0$) = 8.44 – 0.0004 distance + 0.18 volume + 0.2662 no. of logs
$r^2 = 0.75$

When log volume and number of logs increased, productivity increased. However, increasing distance travelled decreased productivity. The predicted hauling productivity model developed explained that 75% of the hauling productivity varied with independent variables. The resulting test statistics revealed that log hauling productivity model was significant at level 5% (Table 8).

The prediction model for hauling productivity in this study was found to be consistent with prediction function developed in Hiesl (2013). The productivity equation could be useful to represent log hauling productivity for future timber harvesting operations with similar characteristics. However, limitations such as differed capacity of log truck, operator's experience, road specifications and harvesting treatments could influence the hauling productivity. For a better productivity prediction model, additional variables could be recorded and included in the regression (Mendell & Sydor 2006, Hiesl 2013).

## Operational costs

The hourly cost estimated for operational work of a log truck is presented in Table 9. The respective cost factors were estimated using a standard cost estimation method by FAO (1992). Based on

**Table 8** ANOVA table for log hauling productivity model

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 3 | 228.2638 | 76.08793 | 46.64161 | 5.37E-14 |
| Residual | 46 | 75.04124 | 1.631331 | | |
| Total | 49 | 303.305 | | | |

df = degree of freedom, SS = sum of squares, MS = mean square, F = variance of the group mean

**Table 9** Cost of log hauling activities

| Costing factor | Cost type unit$^{-1}$ | Cost |
|---|---|---|
| Fixed cost | Depreciation / hour (RM $SMH^{-1}$) | 9.76 |
| Variable cost | Fuel and lubricant (RM $PMH^{-1}$) | 5.98 |
| | Tires (RM $PMH^{-1}$) | 0.70 |
| | Repair and maintenance (RM $PMH^{-1}$) | 1.95 |
| | Total variable cost (RM $SMH^{-1}$) | 7.42 |
| Labour cost | Wage (RM $SMH^{-1}$) | 7.80 |
| TOTAL (RM $SMH^{-1}$) | (Fixed cost + total variable cost + labour cost) | 25.08 |

RM = Ringgit Malaysia, SMH = scheduled machine hour, PMH = productive machine hour total cost, the unit cost of log hauling activities was derived from dividing the cost per hour (RM $SMH^{-1}$) by productivity per hour ($m^3$ $SMH^{-1}$). Therefore, the unit cost of log hauling activities was estimated to be RM1.74 $m^{-3}$ as minimum value, RM8.54 $m^{-3}$ as maximum value, average as RM3.80 $m^{-3}$ and standard deviation RM1.21 $m^{-3}$. The unit cost could be reduced by increasing the efficiency of future hauling activities. As for distance, the unit cost of log hauling activities was divided by the distance travelled by a log truck for a round trip, which worked out to an average rate of RM0.35 $m^{-3}$ $km^{-1}$.

## CONCLUSIONS

Distance travelled was found to be significant with hauling time model and productivity model. Decreasing distance travelled reduced hauling time and resulted in higher productivity. Shortening the travel distance could be achieved through road construction and centralised yards. However this could incur extra costs. Thus, operational cost of hauling should be minimised to counter road construction costs. Loading and unloading were found to be significant with productivity of log hauling, but not in a cycle time. The productivity equation modelled in this study showed that productivity of log hauling increased as the number of logs and log volume increased. This phenomenon could result in low unit cost for log hauling activities in future if proper log hauling activities were planned and implemented efficiently. Felling the trees into right direction and skidded timbers into loading sites outlined by harvesting practices of selective management systems could promise a high timber volume and reduced overall costs of timber harvesting operation.

Further investigation is needed to include the time requirements of log loader activities and its operational costs which will serve to strengthen the predictive model developed for log hauling activities. Time for loading and unloading of logs could be shortened with attached loader boom. If unavailable, a working pattern for loader machine should be examined to support optimum working cycle with minimum manoeuvre. Therefore profitability calculation could be done for the entire log hauling activity. In addition, extended study could be useful to measure additional influential factors that have effects on hauling time and productivity such as the conditions of forest roads (topography and soil condition), weather and operator's experience.

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