Productivity of heli-loging with the Sikorsky S-61F, S-64E and S-64F in Sarawak

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Abstract

Selection logging in the tropics is increasingly moving to systems that reduce the impact of harvesting operations on forests and soils. While much of the focus has been on modifying the tractor logging system using RIL principles, alternative harvesting systems have also been introduced. One of the alternative systems is the use of helicopters, which eliminates the need for skid trails and reduces the number of roads required. WTK pioneered helicopter logging in Malaysia when it started using the helicopter logging system in Sarawak in the early 1990’s. Beginning in 2002, the company started using Sikorsky helicopters and since then has used three different models, including the Sikorsky 61F, 64E and 64F. While the use of helicopters creates a significant improvement in environmental impact of logging, the operating cost of helicopters is also significantly higher. Given the cost of using helicopters, a key element of harvest planning is understanding the factors that influence productivity. This paper provides an analysis of logging productivity in the tropics for the Sikorsky helicopters using daily production data collected by WTK on three different timber licenses between 2002 and 2009. The regression results show that average hourly volume produced is a function of the average distance flown per turn, the weighted average number of logs carried per turn, and the type of helicopter. The results also show the importance of pre-harvest inventory and planning that ensures that helicopters are used productively.

Keywords: reduced impact logging, helicopter logging, productivity

Introduction

In the tropics, logging is usually associated with manual tree felling and the use of a crawler tractor to build skid trails and extract logs to landings, known as conventional logging. The single most important characteristic of conventional logging is that it is largely unplanned. As usually practiced, a feller goes through a block finding trees and cutting them down, and after that the skidder creates trails to extract logs. The result of this unplanned logging is that the number, length and impact of skid trails is significant. Crawler tractors were designed for road building rather than harvesting and the impact of building skid trails is significant due to
blading of topsoil and compaction of the ground. There also ends up being a large number skid trails. As a result, 10 to 30% of the forest area ends up being compacted by skid trails, roads and landings (Forshed, 2006; Ahmad and Kamaruzaman, 2003). In addition, there is a significant level of damage to the residual crop (Forshed, 2006; Ahmad and Kamaruzaman, 2003). Conventional logging logging damages or destroys up to 60% of the residual crop (Forshed, 2006).

Efforts to reduce the impact of conventional logging are generally captured under the title of ‘Reduced Impact Logging’ or ‘RIL’. RIL typically involves two broad approaches to addressing the impacts of conventional logging, reduce the number and impact of skid trails, and reduce stand damage. There are a number of ways to reduce the number and impact of skid trails. Most approaches involve changing the way that crawler tractors are used, however the technique of conventional logging means that there are still limitations on the slope where tractors can operate. Another approach is to change the machines that are used so that the limitations of crawler tractors can be overcome. One alternative machine is the use of helicopters.

The concept of aerial timber harvesting using helicopters in Sarawak was first raised in 1992 by the Forest Operations Manager of the WTK Group of Companies, Peter Ling Kwong Hung. A trial operation was undertaken in early 1993 using a Kamov 32, and since April 1993, WTK has been using helicopters as a standard part of its mix of logging systems to log some parts of their timber concessions, and the company has now produced more than 1.2 million m³ of logs using helicopters. In 2002, WTK began to use Sikorsky helicopters, starting with the S-64F between 2002 and 2006, the S-64E between 2006 and 2007, and the S-61F between 2007 and 2009.

The areas being logged using helicopters in Sarawak are composed of mixed dipterocarp forests located in rugged terrain. The forests are managed under a selection harvesting system that specifies minimum diameter limits for particular species and a target number and spacing of trees to be harvested per hectare. WTK has developed its own system for helicopter logging, which includes both the planning and execution of logging operations, as well as training of staff. The system has 5 components, each of which is an important part of ensuring an efficient logging operation and sustainable forest management.

- **Pre-felling** planning which includes identification of block boundaries, access roads and landing/drop zones for helicopters, and a 100% enumeration of the forest. In the enumeration trees to be felled as well as trees that will be reserved from felling are marked, and the tree location recorded using GPS. The flying range is normally 1 to 2 kilometres to optimise productivity (Eg. Minimum of 20 turns per hour).
- **Felling** which is normally done 2 to 4 weeks before the helicopter arrives. Each helicopter requires 40 to 50 cutting teams, felling an average of 5 trees per day. Felling crews are supervised by load-masters and surveyors, ensuring that felled trees are cut to lengths that create optimum lifting loads. Each log is painted with an identifying number, and heavy logs are marked with special symbols that can be seen by the helicopter pilot.
- **Lifting** is done using a 80 to 100 metre cable with a grapple. Two pilots manage the helicopter, one flying and controlling the grapple and the other monitoring the aircraft performance and recording the lifting operation.
Heavy logs are extracted in the last few turns before refuelling when the helicopter is lighter.

- At the drop zone logs are debarked, tagged, measured and loaded onto trucks for transport. This must be done quickly to prevent congestion on the landing, with a log being dropped by the helicopter every few minutes. The drop zones are sited along the road 3 to 4 kilometres apart. In difficult terrain, the road may be widened to form a drop zone.
- Post-felling involves surveying the forest to ensure that logging has been carried out according to specifications. Given the low impact of helicopter extraction, damage to the forest is generally minimal.

The planning and organisation of activities to ensure efficient operations are critical for the profitability of helicopter logging operations, since they cost about 50% more than conventional, ground-based logging. While WTK has had many years now to refine their helicopter logging operation, this has mostly been done as an operational process. There has been no formal study of the factors influencing the variability of helicopter logging productivity in the WTK operations. The purpose of this paper is to study the factors that influence helicopter logging productivity in selection harvesting systems in the tropics. By understanding the broader influences on helicopter logging productivity, there is greater potential for this system to be used as part of the RIL mix in other tropical areas.

**Logging Productivity**

There are only a few published studies of helicopter logging productivity. Some have been done to examine the effect of silvicultural prescriptions on helicopter logging productivity (Lyons et al., 2010; Christian and Brackely, 2007; Lyons and McNeel, 2004). Other studies have been done to compare the costs of using helicopters relative to other harvesting systems (Dykstra, 1975; Han et al., 2004; Sloan and Sherar, 1997), or the accuracy of estimating log weights (Waddell, 1989). Some studies have looked specifically at productivity of helicopter logging (Stampfer et al., 2002; Wang et al., 2005; Akay et al., 2008). A number of common factors are used in these studies to measure helicopter production, including cycle or turn time, volume or weight per turn or per log, horizontal and vertical distance, turns per hour, and logs per turn.

A number of factors have been identified as being critical to helicopter productivity, including flight hours per shift and year, flight distance and turn time, payload, turn weight and weight per flight hour and weight to volume conversion (Dunham, n.d.). Two studies that have used regression analysis to study helicopter productivity are Wang et al. (2005) and Stampfer et al. (2002). Wang et al. (2005) look at productivity in terms of elemental time (ET), such as cycle time or hourly production, as a function of the mean value of what is being used to measure the elemental time (μ), TP and an error term (ε).

\[ ET = \mu + TP + \epsilon \]

TP is a measure called Turn Payload or the weight carried on each cycle. TP is based on volume (V), density (D) and total turn (TT) data.
\[ TP = \frac{(V \times D)}{TT} \]

Wang et al. (2005) also calculate a payload utilization factor \((PU)\) based on the lifting capacity \((LC)\) of the helicopter to measure how effectively the lifting capacity of the helicopter was used.

\[ PU = \frac{TP}{LC} \]

Stampfer et al. (2002) looked a productivity of helicopter logging in terms of volume per unit time. Productivity was calculated as the total load for a cycle divided by cycle time for one load. The independent variables used in their regression included average stem piece size per cycle, number of stems per load, horizontal and vertical distance, productive system hours, and time for approach and departure from fueling point and fueling, as well as, dummy variables for silvicultural system being used, experience of helicopter pilot, and whether return flight uses a choker.

A key difference between the studies by Wang et al. (2005) and Stampfer et al. (2002) and the present study is the data used for the study. In the case of the data collected by both Wang et al. (2005) and Stampfer et al. (2002) the data was collected specifically for their studies after the models were developed. For this study, the daily production data already exists and the key use of the variables identified in the studies by Wang et al. (2005) and Stampfer et al. (2002) is to provide indications of what types of variables might be generated from the WTK data. As such, Wang et al. (2005) and Stampfer et al. (2002) provide alternatives for modeling the helicopter logging in Sarawak. WTK has already developed a method for ensuring payload optimization so the focus here is only on productivity.

**Methods**

WTK maintains a database that summarises daily production information from its logging operations. The daily data for the Sikorsky operations includes the following information:

- Date
- License area
- Helicopter type
- Productive time (hours per day)
- Total logs extracted (number per day)
- Volume extracted (m\(^3\) per day)
- Total turns (number per day)
- Single (one log) turns (number per day)
- Choker (two logs) turns (number per day)
- Total distance flown or average distance per turn (kilometres)

Following Wang et al. (2005) and Stampfer et al. (2002), the variable chosen to measure logging productivity in this study is volume produced per hour (m\(^3\)/hr). This is calculated by dividing the total volume extracted per day by the productive
time per day. Given the data, there are a number of possible independent variables, including proportion of choker turns, total turns per hour, average distance flown, average volume per log (m³), minutes per turn, helicopter type and license area. Proportion of choker turns is calculated by dividing the number of choker turns per day by the total turns. Turns per hour is calculated by dividing total turns by productive hours. Average volume per log is calculated by dividing volume extracted per day by the total number of logs extracted. Minutes per turn is calculated from productive time and total turns per day.

WTK has used three different types of Sikorsky helicopters. Table 1 summarises basic information about the helicopters that have been used by WTK.

Table 1: Sikorsky helicopters used by WTK since 1993

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Rated payload capacity (kg.)</th>
<th>Engines (no.)</th>
<th>Engine Powera (kW)</th>
<th>Diameter main rotor (m)</th>
<th>Diameter tail rotor (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikorskyb</td>
<td>S-64E</td>
<td>9000</td>
<td>2</td>
<td>3356 (each)</td>
<td>22.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Sikorskyb</td>
<td>S-64F</td>
<td>11000</td>
<td>2</td>
<td>3579 (each)</td>
<td>22.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Sikorsky</td>
<td>S-61N</td>
<td>4990</td>
<td>2</td>
<td>1120 (each)</td>
<td>18.9</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Source: Adapted from BC Timber Sales (2009), http://www.airliners.net/aircraft-data/stats.main?id=359

a Engine power at takeoff.
b Now manufactured by Erickson Air-Crane.

The differences in lifting capacity shown in Table 1 would be expected to show up in terms of differences in production rates between the models of helicopters. The extent to which differences in production rates will be manifested will also depend on area-related factors such as terrain, timber stocking, road and landing location that will affect flying time, tree and log size, and the use of chokers. Table 2 summarises a number of key production parameters from the data set by license area and helicopter type.

As can be seen in Table 2, the S-64F was used for 73% of the days in the data set, and 78% of the data is from license area T/4171. License T/4171 is also the only area to have had all three helicopters operate in it and the data from this license can be used to directly compare each helicopter. For example, the volume per hour data for License Area T/4171 in Table 2 shows the effect of helicopter lift capacity on production. The average daily production of the S-61F is 44% of the S-64F compared to the rated capacity difference of 33% from Table 1, while the S-64E produced 76% of the S-64F compared to a 82% difference in rated capacity. This suggests that the S-61F was on average using more of its lifting capacity than the other two helicopters.
Table 2: Helicopter Production by License

<table>
<thead>
<tr>
<th></th>
<th>License Area</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T/3024</td>
<td>T/4171</td>
<td>T/3476</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Total Days</td>
<td>S-61F</td>
<td>0</td>
<td>56</td>
<td>10</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>S-64E</td>
<td>0</td>
<td>24</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>S-64F</td>
<td>63</td>
<td>184</td>
<td>0</td>
<td>247</td>
</tr>
<tr>
<td>Average Volume</td>
<td>S-61F</td>
<td></td>
<td>73</td>
<td></td>
<td>71</td>
</tr>
<tr>
<td>Per Hour (m³)</td>
<td>S-64E</td>
<td></td>
<td>126</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S-64F</td>
<td></td>
<td>153</td>
<td></td>
<td>166</td>
</tr>
<tr>
<td>Choker Days¹</td>
<td>S-61F</td>
<td>0</td>
<td>52</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S-64E</td>
<td>0</td>
<td>24</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S-64F</td>
<td>63</td>
<td>184</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Average Daily</td>
<td>S-61F</td>
<td></td>
<td>0.079</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Proportion of</td>
<td>S-64E</td>
<td></td>
<td>0.648</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choker Turns</td>
<td>S-64F</td>
<td>0.358</td>
<td>0.674</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Log Volume</td>
<td>S-61F</td>
<td></td>
<td>2.87</td>
<td>3.49</td>
<td></td>
</tr>
<tr>
<td>(m³)</td>
<td>S-64E</td>
<td></td>
<td>2.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S-64F</td>
<td></td>
<td>4.02</td>
<td>3.11</td>
<td></td>
</tr>
<tr>
<td>Average Turns Per</td>
<td>S-61F</td>
<td></td>
<td>24</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Hour</td>
<td>S-64E</td>
<td></td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S-64F</td>
<td></td>
<td>27</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Average Distance</td>
<td>S-61F</td>
<td></td>
<td>0.548</td>
<td></td>
<td>0.831</td>
</tr>
<tr>
<td>Per Turn (km)</td>
<td>S-64E</td>
<td></td>
<td>0.660</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S-64F</td>
<td>0.905</td>
<td>0.788</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Days in which there was at least one choker run.

Table 2 also shows choker use. The S-64 models had at least one choker run on every day that they operated. The S-61F used a choker on 93% of the days it operated in license area T/4171, and did not use a choker at all in license area T/3476. The reason for not using a choker in T/3476 can be seen by the high average log volume for that license area in Table 2.

The data set allows the calculation of the proportion of turns in a day that a choker was used. As can be seen in Table 2, the S-64 models used a choker about 65% of the time in T/4171, and only 35% of the time in T/3024. Again the lower proportion of choker turns in T/3024 can be explained by the high average log volume. The S-61F used a choker on only 8% of its turns in T/4171. The inverse relationship between average log volume and the proportion of choker turns is clearly seen in Figure 1.
Table 2 also provides information about productivity in terms of flying time and distance. The average distance per turn for all helicopters is less than one kilometer. This reflects the general guidelines of locating landings so that the helicopter does not need to fly more than two kilometres on a turn. The average number of turns per hour is between 20 and 27. Generally, it would be expected that as the average distance flown increases, the number of turns per hour would decrease. This is evident in the data for the S-61F in Table 2.

Given these observations, a number of variables can be considered as factors that affect productivity in terms of hourly production. These include average turns per hour, average distance flown per turn, choker use and average log volume. Some of these variables are closely related and there will be collinearity issues if they are used together in a regression. This includes turns per hour, minutes per turn, and distance per turn. For this paper, average distance per turn will be used. One particular consideration was that productivity is linked to the number of logs the helicopter picks up on each turn. This study had daily production data that included the total number of logs produced, the number of single turns and the number of choker turns. This facilitates the creation of a variable that measures the weighted average number of logs per turn each day. The effect of a higher number of logs per turn on hourly production depends on the trade-off between the extra time taken to lift the logs and the increased production per turn.

In addition, there will be differences due to climatic factors, particularly rainfall. However, this type of data is not available. One way of trying to capture the effect rainfall impacts is to assume that the variability in the number of productive hours per day is largely a function of weather. It could be expected that as the number of productive hours goes up per day that the efficiency of the logging operation is increased, as the air crew would have more opportunities to optimize their flying
patterns and the ground crew would get to full operation. A variable covering the total productive hours per day could be used to capture this effect.

Given this initial analysis of the data, and potential collinearity issues, the following regression model was used in the study,

\[ PROD_i = f(DIST, WLPT, PRODHOUR, S61) \]

where \( PROD_i \) is hourly production, \( DIST \) is average distance per turn (km), \( WLPT \) is the weighted average number of logs per turn, \( PRODHOUR \) is total productive hours per day, and \( S61 \) is the dummy variables for the Sikorsky S-61 helicopter. The data covers the period from May 2002 to March 2009, and resulted in 337 observations, or days of helicopter logging production information, that could be used for the analysis. The regression was carried out using SPSS 16.0.

**Results**

Figures 2 and 3 show the relationship between hourly production by each of the three models of Sikorsky helicopter involved in logging for WTK, and the number of turns per hour and the average distance flown per turn. Figures 2 and 3 show the link between the average distance flown per turn and the number of turns per hour, and the effect this has on hourly production. Average distance flown is inversely related to hourly production, while the number of turns per hour is positively related to production.

Figure 2  Hourly production by each of the three models of Sikorsky helicopter involved in logging for WTK, and the number of turns per hour.
Figure 3: Relationship between average hourly production and the average distance per turn.

Figures 4 and 5 show the effects of the use of chokers on hourly production. In Figure 4, the proportion of choker turns per day appears to have a positive, although less distinct relationship to hourly production than the weighted average number of logs per turn shown in Figure 5.

Figure 4: Hourly production and the proportion of choker turns for each of the three models of Sikorsky helicopter involved in logging for WTK.
Figure 5: Relationship between average hourly production and the weighted average number of logs per turn.

Figure 6 shows that one factor that contributes to the positive relationship between choker use and hourly production is that there is a relatively constant average turn time even as the number of logs per turn increases. Another factor that influences hourly production and use of chokers is the distance flown. As can be seen in Figure 7, there is a clear tendency to shorten the average distance flown when the number of logs per turn increases.

Figure 6: Relationship between the average turn time and the weighted average number of logs per turn.
In effect, what these figures show is the importance of planning, and how this contributes to the ability of the WTK logging operations to maintain a relatively constant hourly production rate by balancing log size, choker turns, and distance flown. The net effect of this planning is shown in the results of the regression in Table 3.

Table 3. Regression results for hourly volume produced (m³)

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>174.334</td>
<td>7.078</td>
<td>24.629</td>
<td>.000</td>
</tr>
<tr>
<td>Average distance per turn (km)</td>
<td>-30.198</td>
<td>3.605</td>
<td>-8.377</td>
<td>.000</td>
</tr>
<tr>
<td>Weighted average logs per turn</td>
<td>4.795</td>
<td>2.821</td>
<td>1.700</td>
<td>.090</td>
</tr>
<tr>
<td>Helicopter type S61F</td>
<td>-88.975</td>
<td>3.854</td>
<td>-23.085</td>
<td>.000</td>
</tr>
</tbody>
</table>

R² 0.782, Adjusted R² 0.780  
F 398.797, Sig. 0.000

The variable for the number of productive hours in a day (PRODHOUR) was not significant and was dropped from the regression. All the remaining coefficients are significant and the R² shows that the model explains most of the variability in helicopter logging productivity. As expected, productivity is negatively correlated to the average distance per turn. The weighted average number of logs per turn is positively correlated to hourly production. Hourly production is lower when the S-61 is used.
Conclusions

The purpose of this paper has been to study the factors that influence helicopter logging productivity using Sikorsky helicopters in selection harvesting systems in the tropics. The study is based on 7 years of data from WTK’s Sarawak operations covering the period 2002 to 2009. Daily production records covering three license areas and different helicopter types provided 337 observations. The data included information on the number of productive hour per day, the total number of logs extracted, the total volume extracted and the number of turns in terms of single or choker. The results show that helicopter logging productivity in the WTK operations in Sarawak is positively influenced by the weighted average number of logs per turns and negatively influenced by the average distance per turn.

It is important to keep in mind that the regression variables reflect a wider, and more complex logging operation, and it is necessary to consider the other factors that in turn influence the regression variables. The average number of logs produced per turn goes back to the initial inventory and planning stages of the harvesting operation, key components of RIL, as well as the actual logging operation. It captures decisions about what trees to harvest, how trees will be processed into logs, and where landings should be located. Since planning will take into account the helicopter being used in terms of lifting capacity and the optimal log size for a particular helicopter, this shows up in the results largely as a lower average log volume for the S-61F, and the large proportion of choker runs for the S-64. Although the relationship between hourly production and the average distance per turn is more obvious, even it captures a range of decisions. Both of these factor point to the importance of the planning and felling stages outlined earlier in the paper for ensuring that the number of logs being produced and the average distance flown is maintained at an optimal level.

This study has identified key components that contribute to what has been demonstrated by experience over many years as a profitable approach to reducing the impact of logging in the tropics. In particular, the paper has shown the importance of average distance flown, as well as the ability of the logging planning to balance average log size and the use of chokers to maintain productivity.

References


