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Evaluating the machine utilisation rate of harvester and forwarder using on-board computers in Southern Tasmania (Australia)

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ABSTRACT: This project used the recorded machine utilisation of two machines (harvester and forwarder) by MultiDATs in pine plantations of Southern Tasmania (Australia) to verify the impact of site conditions on utilisation rates over a long study period. The parameters of site conditions included type of forest operations, stand age, site productivity, ground slope and forwarding distance. The correlation ratio between each parameter and machine utilisation was low and not significant at a significance level of 0.05. Harvester's utilisation rate varied from 48.6% to 100.3% while it averaged at 77.3%. Forwarder's utilisation in this case varied from 47.8% to 96.5%. The average rate for forwarder in this study was 81.1%. The long-term machine utilisation rates can be applied by the operation management to control the current level of machine utilisation and to calculate the machine hourly cost accurately to obtain unit harvesting costs.

Keywords: cut-to-length method; harvester-processor; multiDAT on-board computer; correlation ratio

One of the common harvesting systems in pine plantations is the combination of mechanical felling and processing with forwarding. Studies on the application of the cut-to-length (CTL) system have been carried out in commercial thinning in North America (Kellogg, Bettinger 1994; Hossain, Olsen 1998; Turner, Han 2003; Kellogg, Spong 2004) and Europe (Glode 1999; Hanell et al. 2000; Spinelli et al. 2002; Nurminen et al. 2006; Ghaffariyan et al. 2007; Rottensteiner et al. 2008). In Australia, the efficiency of a harvester-processor was found to be higher than the combination of feller buncher and processor in native forest thinning (Acuna, Kellogg 2009; Ghaffariyan et al. 2012). Another study in New South Wales compared integrated residue log extraction with normal cut-to-length harvesting using harvester and forwarder in a clear felling operation of *Pinus radiata*. Integration of residue log extraction diminished the productivity of forwarding up to 14% (Walsh et al. 2011). These studies have been conducted to measure the productivity of harvester and forwarder. The productivity studies have been carried out using short-term studies by the researchers who watched and timed the machine activities during harvesting operations using stopwatches or data loggers. One of the methods to improve machine productivity is increasing machine utilisation as it is defined as the percentage of scheduled or expected working time that the forest machine actually works (Strandgard 2011). There are four types of on-board computers proposed by CRC for Forestry in Australia (2010) (cited by literature review of Laforest, Pulkki 2011); vibration, GPS, purpose-built and manufacturer. The vibration on-board computers collect basic information with low user input and GPS types can collect the geographical information of the machines. Purpose-built computers are designed for specific forestry machines while manufacturer on-board computers are the units that have been set up by the machine manufacturer to monitor and control the machine's performance.

MultiDATs are on-board computers developed by FPInnovations in Canada to monitor and record machine utilisation over a long-term period (Castonguay, Gingras 2014). In Canada FPDat, FPCom & FPTrak work together to collect and centralize data about operations to enable forest operations managers for a fast reaction when deviations occur. About 20 MultiDATs have been set up on different forest harvesting machines in Australia (Strandgard 2011). This project used the recorded machine utilisation of two machines (harvester and forwarder) operating in Southern Tasmania to verify the impact of site conditions on utilisation rates over a long study period as Laforest and Pulkki (2014) have recently suggested using on-board computers for a longer study period to cover more seasons and operations conditions. The site conditions in this project were defined by factors included type of forest operations, stand age, site productivity, ground slope and forwarding distance.

MATERIAL AND METHODS

Study area. In Norske-Skog plantations [located in Southern Tasmania (Australia)] 22 coupes were identified that harvester and forwarder worked from 17/01/2011 to 10/10/2012 and data recorded in 19 coupes were considered for the analysis. The plantations were established by *Pinus radiata*. The ground slope ranged from 2° to 12° with an average of 7.8°. Prior to the study two Multidats were set up in the cabin of each machine (Fig. 1). The harvester model was Tigercat H822C and the machine was 4 years old used to fell the pine trees and process into short logs to be extracted by a Valmet 890.3 forwarder (a typical cut-to-length method). Harvester's operator had 500 h of work experience with this machine and over 10 years in timber harvesting. The forwarder was 6 months old and had the payload of 16 GMt (Fig. 2). Its driver had 20 years of experience working on forwarding operations. Average forwarding distance was 111.1 m in the study area.

Method. Average machine utilisation for each coupe was determined based on the length of working period in each coupe from the provided copy of the utilisation records (expected schedule hours were 10 hours per day). The machine utilisation was defined as the percentage of scheduled or expected working time that the forest machine actually works (Strandgard 2011). The forwarding distance was calculated using the maps of the coupes where landings, extraction direction and coupe boundaries could be seen. Using 10 samples on each map the average forwarding distance was calculated and modified based on the average slope of the coupe. The site productivity (indication of harvesting volume per ha) was provided by the Norske-Skog Ltd as classified data ranging from 1 (very high) to 10 (very low) for each coupe.

The data were analysed in statistical software SPSS 21. The descriptive statistics including minimum, maximum and mean value of each parameter was calculated. The Pearson correlation ratio was calculated between each variable and machine utilisation. The significance level of each correlation ratio was also determined to check if the ratio was statistically significant at α = 0.05. Then stepwise regression was applied to test if the mentioned variables had any significant impact on machine utilisation. This approach included two procedures: forward selection and backward selection. In forward selection, a variable entered in the earlier stages may be eliminated at later stages. If any variable has a significant impact on the residual mean square of the model, it is retained in the equation. Often, different levels of significance are assumed for inclusion and exclusion of variables from the equation. In this study the significance level of 0.05 was applied for modelling (Chatterjee, Price 1991). The backward stepwise procedure was used to develop the regression model in SPSS 21, as Chatterjee and Price (1991) recommended the backward stepwise procedure over the forward step-

Fig. 1. MultiDAT set up on the cabin

Fig. 2. Valmet 890.3 forwarder

Table 1. Descriptive statistics of variables and utilisation rates

Variable	Minimum	Maximum	Mean
Plantation age (year)	15.0	25.0	17.6
Slope (°)	2.0	12.0	7.8
Forwarding distance (m)	34.0	191.0	111.1
Stand yield classification	1	10	5
Harvester utilisation (%)	48.6	100.3	77.3
Forwarder utilisation (%)	47.8	96.5	81.1

wise one. One obvious reason is that in the backward stepwise procedure the equation with the full variable set is calculated and available for inspection even though it may not be used as the final equation.

RESULTS

Harvester's utilisation rate varied from 48.6% to 100.3% while it averaged at 77.3%. The minimum and maximum effective working time per day for harvester was 4.8 h and 10.0 h, respectively. The effective working time per day averaged at 7.7 h during the study period. Average slope in the operating area was 7.8 degrees while forwarding distance averaged at 111.1 m. The plantation age varied from 15 to 25 years (with an average of 17.6 years). Minimum, maximum and mean value of variables used for modelling is presented in Table 1. Type of operation was another variable which included first thinning, second thinning and clear fell. Tree diameter, volume or basal area were not provided by the forest company to be considered in this analysis.

The Pearson correlation coefficient was calculated for each variable in relation with harvester utilisation or forwarder utilisation (Table 2). The correlation coefficient of each variable versus machine utilisation was not significant based on the significance level calculated in Table 2. The correlation ratios were very low varying from –0.17 (operation type vs. forwarder utilisation), 0 (slope vs. forwarder utilisation) to 0.21 (stand yield vs. forwarder utilisation). Fig. 3 illustrates the utilisations records of both harvesters and forwarders for different slopes in this case study. This fact resulted in non-significant regression models developed to test the impact of each variable on machine utilisation. One reason might be due to the small sample size, or alternatively, the site conditions may not have any significant impact on machine utilisation in planation operations.

It is suggested that machine utilisation (% of scheduled hours) should be combined with work productivity (t per hour) to be recorded by using other types of on-board computers that have more capability to capture data and provide a clearer picture of what operational parameters most significantly impact on the long-term machine performance.

In this case forwarder's utilisation varied from 47.8% to 96.5%, which corresponds to effective working time per day varying from 4.8 h to 9.6 h. The main reason for such a widespread utilisation (for both forwarder and harvester) was due to some mechanical breakdowns and repairs which caused very low utilisation records during the study period. The high utilisation records were caused by operating for longer working hours by the studied

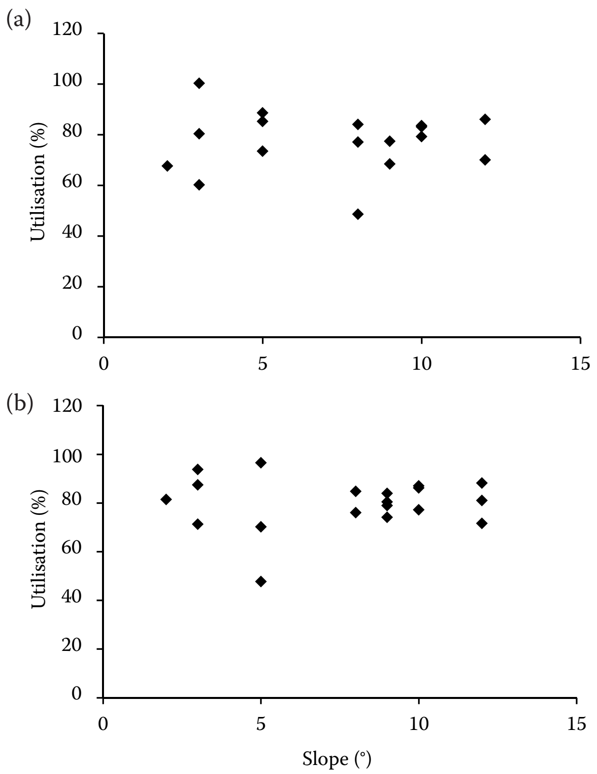

Fig. 3. Utilisation rates of harvester (a) and forwarder (b) versus slope

Table 2. Pearson correlation between variables and machine utilisation

Utilisation	Statistics	Plantation age	Slope	Forwarding distance	Stand yield	Type of operation
Harvester	pearson correlation	0.06	–0.01	0.15	–0.01	0.04
	sig. (2-tailed)	0.80	0.96	0.56	0.95	0.86
	n	18	17	18	18	18
Forwarder	pearson correlation	–0.14	0.00	–0.07	0.21	–0.17
	sig. (2-tailed)	0.57	0.99	0.76	0.40	0.49
	n	19	18	19	19	19

harvesting contractor. The average rate for forwarder in this study was 81.1% (with average effective working time of 8.1 h/day), which seems to be high compared to a previous Australian case study which found average utilisation of 46% for feller-buncher, 55% for skidder and 70% for excavator in Victoria's Central Highlands in Eucalypt stands. Typical utilisation of these three types of machines is about 65% (Strandgard 2011). Also in a Canadian case study in Ontario (Laforest, Pulkki 2014) the machine utilisation rates measured by MultiDATs (considering productive machine hours) for feller-bunchers, skidders, roadside processors, excavators and gravel trucks varied from 74.5% to 79.3%, which seems to be close to average utilisation rates of forwarder (81.1%) and harvester (77.3%) in our case study. The FPInnovations MultiDATs combined with GPS were set up on three skidders in South Africa where the machine utilisation in three different sites averaged at 77.3%, 83.1% and 85.3% (Pellegrini et al. 2013). The forwarder's utilisation rate in this study (81.1%) was slightly higher than in the first site of the South African case study, however, it was lower than the average of machine utilisation in two other sites reported by Pellegrini et al. (2013). Another case study by MultiDATs tracked the utilisation of harvester and forwarder in eastern Canada where the utilisation rate for harvester averaged at 85%, which is slightly higher than what was found in this case study. However, the forwarder yielded a lower utilisation rate of 65% in the Canadian trial, which is lower than forwarder's utilisation rate in this paper (CRC for Forestry 2011). Average utilisation rates of both machines (harvester and forwarder) in this case study are high compared to the average utilisation rate of 65% for both harvester and forwarder suggested by Brinker et al. (1989) for the standard machine cost calculation.

CONCLUSIONS

The on-board computers are effective tools to monitor the machine utilisation rate over a long-term period. As Laforest and Pulkki (2011) stated, the implementation of these technologies within wood procurement would provide valuable information that would help improve operational efficiency as this could be driven by the need to increase efficiency and to lower costs. In this case study the average utilisation rate for a harvester-processor was 77.3% while for the forwarder the utilisation averaged at 81.1%. The long-term machine utilisation rates can be applied by the operation management to control the current level of machine utilisation and to calculate the machine hourly cost accurately to obtain unit harvesting costs. To verify the real impact of operational factors on the long-term machine performance, more detailed machine utilisation case studies combined with machine productivity records will be required.

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