Modelling the economics of extended shift and 24/7 forest harvesting*

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Abstract

Extending the amount of time allotted to the harvesting process (e.g., working longer periods within shifts, or adding shifts) has become more common in forest operations in some parts of the world in order to meet the growing demand for increased production efficiency and overall monetary returns. However, there are many factors that must be considered when analysing the effectiveness of extending the amount of time in which harvesting operations are active if the overall goal is maximising production efficiency for an increased profit margin.

Using the best information available in the literature related to the forest industry as well as other industries, a model was constructed that allowed the evaluation of the economic impacts of altering shift lengths and total number of hours worked per year for ground-based mechanised harvesting and cable harvesting operations. The model takes into consideration the effects of these on both human-related performance and equipment performance. Production impacts, equipment impacts (e.g. depreciation, interest costs, and maintenance costs), value recovery impacts, and accident impacts are modelled. Sensitivity analysis was carried out to determine the relative importance of some of the key variables.

The research provides insight into how extending the working annual hours of harvesting operations is likely to affect overall production economics. It also highlights deficiencies in knowledge related to this area and where further research needs to be undertaken.

Key Words: value recovery, forest harvesting, extended shift, costs, productivity.

Introduction

The forest products industries in many parts of the world are continually looking for ways to improve the performance of their wood supply systems in order to compete in the ever-changing global wood products marketplace. Although the productivity of timber harvesting operations is many times not considered to be the limiting factor of a particular wood supply system, inefficiencies in the production process can affect both harvesting and fibre procurement costs (Greene *et al*. 2004).

Extending yearly operating hours has been considered in the past by the New Zealand forest sector as a means of spreading high equipment fixed costs. For example, in the mid-1970's, research on night-time gravity rolling for land clearing of steep terrain was undertaken by Page (1975) and research on multiple shift harvesting of ponderosa pine stands with highly mechanised equipment was undertaken by Terlesk and Walker (1982).

In some countries, such as Australia (Nicholls *et al*. 2004), Sweden (Andersson 1999), Brazil (Santiago 2007), Chile (Cordero *et al*. 2006) and the USA (Celone 2007), there is renewed interest in extended shift and multiple shift forest operations in order to meet the growing demand for increased production efficiency and overall monetary returns (Nicholls 2003).

However, there are many factors that must be considered when analysing the economic effectiveness of extending the amount of time in which harvesting operations are active if the overall goal is maximising production efficiency for an increased profit margin. These can be broadly split into two categories; factors effecting machine performance and factors effecting employee performance.

The increased demand on equipment and machinery operating in a multiple-shift/extended-shift forest harvesting environment could affect their mechanical availability and utilisation. For example, night time harvesting operations are likely to have limited access to repair and maintenance capabilities and greater risk of delays occurring due to reduced vision. These could reduce the potential production efficiency and overall profit.

The second general area of concern is employee performance. Whereas equipment has a more static nature with respect to specifications, capabilities, and limitations, the human employee could be considered to be much more variable. This makes the prediction of individual or collective human employee performance potentially more complex. Implications from the increased physical, mental, and emotional demands placed on human employees associated with extended working hours or shift work could impact productivity, safety (as human safety-related accidents often lead to a less productive forest harvesting operation due to lost time as well as the potential for a reduced workforce), and value recovery.

In order to quantify the effects of an extended operating hour work environment on forest harvesting productivity,

* *Note: This is also a Refereed Paper.*

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a new model has been developed by the authors. The 24/7 Forest Harvesting model takes a broad approach to productivity analysis, and has been constructed to evaluate the economics of production from the perspective of a forest owner purchasing the services of a harvesting contractor and selling logs.

Model Structure

The 24/7 Forest Harvesting model determines total net revenue from three types of harvesting operations (shovel (a.k.a. excavator logging), ground skidding (grapple skidder/grapple tractor), and cable yarding systems) based on productivity, hourly costs of equipment and labour, and net value recovery calculations. Production functions from over 60 published detailed time studies of felling, extraction, processing and loading operations were built into the model. Among other factors these production functions include a tree size variable. Hourly costs were calculated using procedures similar to those described in Miyata (1980). They include such cost components as equipment depreciation, interest, taxes, insurance, fuel, and repair and maintenance costs, as well as labour factors, such as overtime wages (for more than 40 hours per week) and fringe benefits. They also include overheads, profit and risk allowance, vehicle costs and move in/out costs. The effects of extended working hours (night shifts and extended shifts) are determined by the predicted impact on productivity, potential accident rates, and potential operator error rates affecting value recovery.

The human factor model calculations are based on a variety of literature pertaining to forest harvesting, construction, manufacturing, medicine, and other shift-based operations. The night shift effect was based on five related publications (Nicholls *et al*. 2004, Maxwell 1982, Terlesk and Walker 1982, Vernon 1940, LaJeunesse 1999). An average drop in productivity due to night shift was found to be approximately 10% (range 0% to 22%). This was increased to 12.5% to reflect higher production losses reported in the few studies of forest operations (Nicholls *et al*. 2004, Maxwell 1982, Terlesk and Walker 1982).

The effect of extended work hours on production was also modelled on five related publications (Hanna *et al*. 2005, Veasey *et al* 2002, Tyson 1997, Vernon 1940, and Atack *et al*. 2000). The loss of production due to extended work hours follows the following criteria: if the shift length is greater than 9 hours (i.e., 10, 11, 12 hours), then production loss is affected at a rate of 6% per hour (e.g., production for a 10 hour shift is decreased by 6%, whereas production for an 11 hour shift is decreased by 12%). Also, if the shift duration schedule is greater than 25 weeks, then the production is reduced by another 1%.

The effect of night shift on human cognitive performance relating to value-based decision making was modelled on four related publications (Folkard and Lombardi 2006, Sibergleit and Kronick 2004, Veasey 2002, Freidman *et al*. 1971). A value loss multiplier, which represents an average relative increase in value loss of 30% for night shift compared to day shift operations, was used in the model. For example, if the expected value loss for a day shift was 10%, the assumed value loss for a night shift would be 13%.

The effect of extended working hours on accident rates is modelled after four related publications (WorkSafe BC 2007, Folkard and Lombardi 2006, Parker *et al*. 2003, Vernon 1940). The model accounts for these effects in several calculations. The base number of lost time accidents is set at 16 per 100 man-years for cable operations and 7 per 100 man-years for ground-based operations (WorkSafe BC 2007, Parker *et al*. 2003). The night shift accident rate is increased by 30% (Folkard and Lombardi 2006), and if the shift length is greater than 8 hours the accident rate is increased by another 3.5%, whereas if the shift length is greater than 10 hours the accident rate is increased by another 7% (Folkard and Lombardi 2006, Vernon 1940). In the current version of the model, accident rates affect worker's insurance costs but not system productivity.

Overall, the 24/7 Forest Harvesting model takes both equipment and human factors into account when predicting net revenue from the three major types of harvesting operations. Net revenue prediction is determined also by accounting for extended operating hours, whether hours are extended by daily shift length, shift duration, work week length, or any combination of the three. The effect of night shift, relative to day shift, is also accounted for in the model.

Model Demonstrations

The effects of extended operating hours on the productivity of forest harvesting operations can be shown in several model demonstrations. Simulations were run for all harvesting systems (shovel, ground-skidding, cable yarding) under two forest stand conditions. Stand 1 'Big Trees' (31.6 ha, 800 m^3/ha, 296 spha, 2.7 m^3 per tree, gross value of US$37545/ha, 90% value recovery). Stand 2 'Small Trees' (14.2 ha, 652 m^3/ha, 544 spha, gross value of US$14080/ha, 95% value recovery) had smaller trees (1.2 m^3 per tree). Average yarding distance for the three systems was held at 90, 135, and 180 m for shovel operations, ground-skidding operations, and cable yarding operations, respectively.

Ten shift configurations were investigated for the two ground-based systems and compared to a Base shift in terms of change in net revenue. Each shift includes a 1 hour break (i.e. a 9 hour shift equates to 8 working hours, etc.). The ten shift configurations were as follows: single shifts of 10, 11, and 12 hours (S10, S11, S12); double shifts of 9, 10, 11, and 12 hours (D9, D10, D11, D12); a triple 9 hour shift (T9); a single 11 hour shift over 4 days (4S11); and a 9 hour night-time shift (Night). All the above shifts revolve around a 5 weekday work schedule, with the exception of 4S11, which only includes 4 weekdays. Two additional shift configurations were evaluated for each of the ground-based systems; a D9 shift operating seven days per week (7D9) and a T9 shift operating seven days per week (7T9). The cable yarding system was only evaluated for the Base shift and for the S10, S11 and S12 shifts operating five days per week. The combination of shift configurations, harvesting systems, and stand characteristics yielded 62 simulations including the 6 baseline scenarios.

Felling costs for the base shift were US$1243 per shift for the shovel and ground skidding systems and US$1065 per shift for the cable yarding system. Extraction, processing and loading costs for the base shift were US$3111, US$3964, and US$4262 per shift for the shovel, ground skidding and cable yarding systems respectively. As noted above, these costs include overheads, profit and risk allowance, and moving costs as well as fixed and operating costs of machinery and labour.

The model assumes that average shift productivity is determined by the limiting production of the extraction, processing and loading activities. Felling was assumed to be a separate and non-limiting activity. Base shift average productivity depended on harvesting system and tree size. For the Big Trees it was 311 tonnes per shift for the shovel and ground-based systems and 300 tonnes per shift for the cable yarding system. For the Small Trees it was 211, 259 and 167 tonnes per shift for the shovel, ground-based and cable yarding systems respectively.

Results

The model simulation results will be discussed by harvesting system and stand characteristics. Comparisons between harvesting systems, stand characteristics, and shift configurations can be seen in Table 1 and Figures 1 and 2. To provide a bit more detail, Table 2 shows the impact of shift configuration on productivity, revenues and costs for one of the systems - the ground-based in the "Big Trees" harvest unit.

Results for the shovel harvesting operations consistently showed the lowest losses in net revenue due to extended work hours, whereas the results for the cable yarding operations consistently showed the highest losses in net revenue. Results for ground-skidding operations were consistently closer in magnitude to shovel operations, as opposed to cable yarding operations.

In the big tree stand, the highest amount of net revenue loss for a five day work week was found to occur during the D12 shift configuration for both ground-based harvesting systems (13 and 10% loss for ground-skidding and shovel operations, respectively). In the small tree stand, the highest amount of net revenue loss was also found to occur during the D12 shift configuration (88 and 74% loss for ground-skidding and shovel operations, respectively). The D9 shift configuration led to slight increases in net revenue for the large tree stand (~1%), as well as the small tree stand (~ 7%), depending on the harvesting system. The T9 shift configuration led to slight decreases in net revenue for the large tree stand (~1%). The T9 shift configuration had little effect on net revenue for the ground-skidding harvesting system in the small stand, and increased net revenue for the shovel logging system (2%).

All of the other five-day week shift configurations (S10, S11, S12, D10, D11 and Night) reflected losses in net revenue for all harvesting systems. The net revenue loss increased as the shift length increased for the same type of

Table 1. - Predicted base net revenue and percent change (+/-) in net revenue due to extended working hours for three harvesting systems in two stand conditions (n.a. = not applicable). A negative change means a drop in net revenue.

	Big Tree Stand			Small Tree Stand		
Shift type	Cable Yarding	Ground Skdding	Shovel Logging	Cable Yarding	Ground Skidding	Shovel Logging
Base Net Revenue (US$)	$640,214	$690,451	$740,972	-$41,841	$42,452	$48,368
Base	0.0	0.0	0.0	0.0	0.0	0.0
S10	-3.1	-2.4	-1.8	-33.1	-18.2	-15.8
S11	-6.7	-4.8	-3.6	-70.8	-37.1	-32.1
S12	-10.7	-7.6	-5.7	-109.9	-58.6	-50.5
D9	n.a.	0.8	0.8	n.a.	6.9	7.5
D10	n.a.	-6.7	-5.2	n.a.	-37.6	-30.6
D11	n.a.	-9.8	-7.5	n.a.	-61.7	-51.3
D12	n.a.	-13.3	-10.1	n.a.	-88.9	-74.5
T9	n.a.	-1.2	-0.9	n.a.	-0.5	2.2
4S11	-4.3	-3.9	-2.9	-45.9	-29.9	-25.7
Night	n.a.	-9.6	-8.0	n.a.	-46.1	-39.3
7D9	n.a.	1.7	1.5	n.a.	14.6	13.9
7T9	n.a.	-0.6	-0.4	n.a.	5.1	6.9

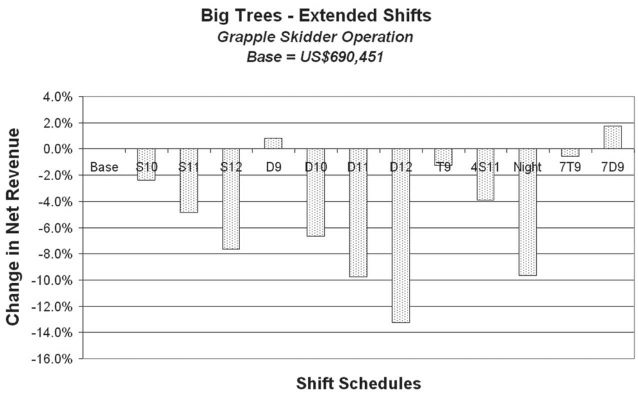

Figure 1. - Change in net revenue for a ground-skidding harvesting system operating in large tree stand conditions for different shift configurations for a four or five day work week.

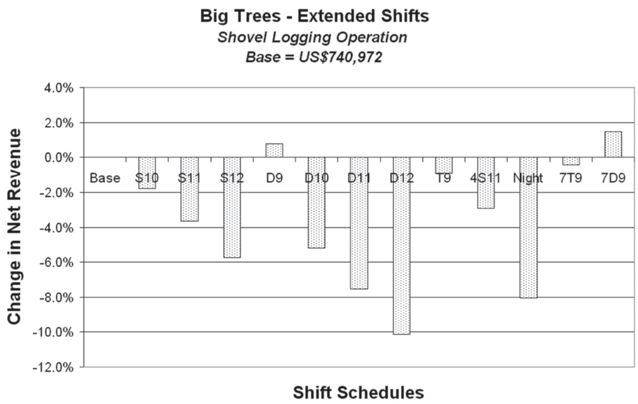

Figure 2. - Change in net revenue for a shovel harvesting system operating in large tree stand conditions for different shift configurations for a four or five day work week.

shift (S or D). The 4S11 scenario resulted in lower losses than the five day week S11 scenario; primarily due to lower overtime rates. The 7D9 shift scenario gave the greatest improvement in net revenue for both of the ground-based operations.

Discussion

The 24/7 Forest Harvesting model shows, through simulation, that the extended hour operating environment can have both positive and negative effects on net revenues from forest harvesting operations, depending on the shift configuration.

When compared to the baseline shift configuration of a single 9 hour shift with a one hour break, the model predicts negative impacts to net revenue for all shifts in cable yarding operations and in all but two (D9 and 7D9) of the shift scenarios for the ground-based operations in both big and small tree stands. The 7T9 shift configuration also showed an increase in net revenue for small tree stand conditions for both ground-based harvesting systems, while only the 7T9 scenario showed an increase for the ground-skidding system. The T9 and 7T9 shift configurations are affected by night-time factors in the model, whereas the D9 and 7D9 shifts are not.

The net revenues from the big tree stand conditions were less affected by extended working hours when compared to the small tree stand conditions. The cable yarding harvesting system was consistently the most affected of the three systems in terms of net revenue loss due to extended working hours, which could be due to the increased accident rate found for cable systems. The shovel harvesting system was consistently the least affected of the three systems in terms of net revenue loss due to extended working hours, and ground-skidding systems appeared to be more closely related to shovel systems than cable yarding systems. Again, this could be partly due to the lower accident rate found for ground-based (shovel and ground-skidding) harvesting systems.

The simulation scenarios point towards an increasing negative effect (with the exception of D9 and 7D9, which

Table 2. - Predicted productivity, revenues and costs for the ground-based system in the 31.6 ha "Big Trees" harvest unit.

Shift Type	Daily Productivity (tonnes)	"Gross" Revenue* (US$/tonne)	Costs (US$/tonne)	Net Revenue (US$/tonne)
Base	311	51.16	13.69	37.47
S10	325	51.16	14.58	36.58
S11	338	51.16	15.50	35.65
S12	346	51.16	16.55	34.61
D9	622	51.16	13.38	37.78
D10	607	50.37	15.39	34.98
D11	628.	50.37	16.56	33.81
D12	639	50.38	17.88	32.50
T9	894	50.64	13.64	37.00
4S11	338	51.16	15.16	36.00
Night	272	49.45	15.60	33.85
7D9	894	50.64	13.39	37.25
7T9	622	51.16	13.04	38.11

** These are revenues that are net of value losses but not costs.*

have a positive effect) on net revenue as both shift length and number of shifts per day increase. The effect is relative to the baseline shift of 9 daytime hours with one 1-hour break. This finding includes the 4S11 daytime shift, or the "four 10's" shift, which potentially shows that extended working days, rather than hours per week, may also have a negative effect on net revenue.

It appears then that extending the hours worked per year may not be a panacea for improving the profitability of all harvesting operations. Even though hourly cost rates are reduced, hourly productivity and safety may be negatively impacted.

Value recovery may also be negatively impacted by the extended operating environment. The value recovery assumptions in the model have a significant effect on net revenue. We would note that in harvesting operations where a single product is produced (e.g. pulp) there should be no, or very little, loss in value due to operating extended or multiple shifts. In this case, the 24/7 Forest Harvesting Model indicates that spreading fixed costs, may compensate for potential losses in productivity and higher labour costs (due to overtime compensation and insurance costs) in the D9, 7D9, T9 and 7T9 shift configurations, but not for the other configurations.

Concluding Remarks

The 24/7 Forest Harvesting model is based on Pacific Northwest USA costs and productivity studies. It is also preliminary in nature, and is partially reliant on values found in related occupational literature pertaining to extended operating environments. Results should be interpreted with these caveats in mind. However, the conceptual framework of the model appears to be sound and encompassing. More research must be conducted in order to validate the 24/7 Forest Harvesting model. With validation there may also be potential for the incorporation of optimal shift scheduling and extension of the model to include other harvesting systems. The benefits of the model may be felt on both a productivity and value recovery level, as well as influence the well-being of human operators.

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