Shift Length and Time of Day Impacts on Forest Operations Productivity and Value Recovery in Southern Hemisphere Plantations

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Abstract
Data-bases maintained by two southern hemisphere companies in Chile and New Zealand allowed us to evaluate the effects of shift length and time of day on productivity and value recovery.

A Chilean long-term data base, containing over 30,000 machine-day records, provided the opportunity to assess the effects of work schedules on the productivity mechanized processing of radiata pine stems into logs and mechanized harvesting of eucalypt trees. Daily production increased as working hours increased. However, average hourly productivity fell by 9 to 30% as the working day length for equipment was extended from 9 to 18 hours.

A second data-base, containing over 120,000 records on radiata pine stems processed during 200 work shifts, allowed us to gauge the impact of time of day on value recovery and productivity of a scanning optimizer and a mechanized processor operating in a central processing yard in New Zealand. Analyses indicate there were no or little differences in productivity or value recovery for the scanning optimizer between the first shift operating mainly in daylight hours and the second shift operating mainly during night hours. No difference in productivity was noted between daylight and dark for the mechanized processor. Possible reasons for these seemingly conflicting Chilean and New Zealand results are covered in the paper.

Keywords: work shifts, mechanized harvesting, central processing yards, human factors, productivity, value recovery

Introduction
Over the last three decades extended working hours – multiple shifts in particular – have been tried and failed in some parts of the world but in other parts have been used successfully for many years to increase production. In some countries, such as Australia, New Zealand, Sweden, Brazil, Uruguay, Chile and the south eastern USA, there is renewed interest in extended shift and multiple shift forest operations. Meeting the growing demand for improved monetary returns, increasing production efficiency and reducing obsolescence of forestry equipment are reasons given for this renewed interest.

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Kirk (1998) noted, however, that studies worldwide have linked poorly designed work schedules, with mental and physical fatigue, low productivity and low value recovery. Many researchers from a wide range of industries, including forestry, have found that hourly production declines as the shift length increases (Vernon 1921, Golsse 1991, Nevison 1992, Hanna et al. 2005). Productivity can also be lower for night shifts than for day shifts. Kerin and Carbone (2003) report an average drop in productivity of 5% for night shifts across all major U.S. industries based on surveys of employees and managers from over 1000 companies. Studies of forest harvesting operations in North America and Australasia report a 4 to 40% drop in hourly productivity for night shifts versus day shifts (Maxwell 1982, Nicholls et al. 2004, Mitchell 2008).

Murphy and Vanderberg (2007) and Mitchell (2008) note that, while there is a potential for a reduction in logging costs resulting from increased daily production by working extended hours, the size of the production increase is sometimes insufficient for logging cost reductions to be realised. They also note that the impacts of extended hours on other tangible and intangible costs such as value recovery losses and human factors (such employee turnover rates, accident risk, and opportunity for employees to participate in social affairs and domestic activities) need to be considered.

In this paper, we report the results of two case studies looking at the effects of extended working hours on the productivity and value recovery of (1) in-forest operations in Chile and (2) an off-forest, central processing yard in New Zealand. Results are based on long-term data of that have been collected by indirect methods.

Methods
Chilean Study
Forestal Mininco is one of the largest forest companies in Chile with an annual harvest of about 8.6 million m³. This study relates only to their ground-based operations. In pine plantations tree-length harvesting systems are used. Delimbing and processing is carried out at roadside with a dangle-head processor on an excavator base (e.g. Waratah 622 processor on Komatsu P200 excavator). In eucalypt plantations cut-to-length harvesting systems are used. Trees are felled, debarked and processed into logs with a mechanised harvester (e.g. Valmet 370 or 380) and then the logs are extracted to roadside with a forwarder. Both the processors in pine plantations and the harvesters in eucalypt plantations are fitted with halogen or xenon lighting systems which produce 30 lux or greater of illuminance in the boom working area for night operation.

Forestal Mininco’s logging contractors usually work 30 days per month. Four types of work schedules are used in both pine and eucalypt plantations. These include (a) single shift of 9 work hours, (b) single shift of 12 work hours, (c) double shift of 16 work hours, and (d) double shift of 18 work hours.

For each shift there is a single operator per machine. The operator works for about four hours then takes a “lunch” break (~ 1 hour). For the 12-hour single shift the operator takes additional short rest and food breaks (~10 minutes).
Machine operators record daily tree count data obtained from the machines' computers. Average tree size for the stand is combined with tree counts to obtain productivity per shift hour (m$^3$/hr). Over 22 thousand data points (one productivity value for one machine for one day) collected on processors and over 9 thousand collected on harvesters were analyzed to determine productivity by species, tree size, season, work schedule and equipment type.

In Chile, approximately 75% of daily costs for mechanised harvesting operations are related to equipment costs and 25% are related to labor costs. Fixed costs for depreciation, insurance, and interest account for about half of equipment related daily costs. The combined effects of changes in daily production and spreading fixed costs over greater numbers of scheduled hours were evaluated for different work schedule designs.

New Zealand Study
Panpac Forest Products Limited is an integrated forest products company that owns 33,000 hectares of forest plantation on the east coast of the North Island. Their Forestry and Logistics Division manages an annual volume of 1.5 million m$^3$ of which about 0.75 to 0.9 million m$^3$ comes from their own estate. Panpac produces pulp, lumber, export chip and export logs from its operations.

In 2004 began operating the Panpac “3PY” (Pan Pac Processing Yard) attached to their lumber and pulp processing plants. Delimbed stems, or stem segments, are transported from their forests to the 3PY. The stems are then passed through a two (or three) machine mobile optimizing plant, known as Logmaister. The system consists of a scanner cab that runs parallel to a delimbed stem, creating a stem profile (up to 38 m in length) that is virtually bucked by the Logmaister optimiser algorithm (Figure 1). A secondary machine with a processing head mounted on an excavator base takes the scanned solution (wirelessly) and cuts the log sorts as prescribed by the Logmaister scanner. Cutting strategies and log grade prices are relayed from company offices wirelessly and all production data is uploaded, instantly, to a remote server and reports are available via internet and direct SQL query.

The Logmaister system operates for six days per week, two shifts per day. The first shift for the scanner runs from 4am to 1.30pm. The second shift runs from 2pm to 10pm or until a “sufficient” stockpile of scanned stems has been built up. Finishing times for the second shift can extend to 3am. One 30 minute break per shift is taken. For each shift there is a single machine operator. One, sometimes two, processors cut the stems into logs. Shift lengths for the processors vary from 8 to 12 hours. The 3PY is well lit with overhead floodlights.

The time of day, machine operator, number of quality codes called, and stem attributes measured are automatically recorded for each stem that is scanned or processed. Records from approximately 120,000 radiata pine stems scanned and processed during 200 work shifts were analyzed to determine productivity and value recovery by tree size,
time of day, operator, and equipment type. Changes in markets were accounted for by virtually re-bucking the scanned stems using a standard set of log types and prices.

Figure 1. The Logmaister scanner (left) runs on rails parallel to the log and virtually bucks the stem. The bucked stem solution is wirelessly passed to a second machine (right) with a processor head which cuts the stems into logs.

**Results**

**Chilean Study**

Increasing the number of hours worked per day generally resulted in greater daily production for both types of operations; processors in radiata pine plantations and harvesters in eucalypt plantations (Figure 2). The exception was for processors where extending the working hours from 16 to 18 resulted in no increase in daily production. Figure 2 also shows that increasing the number of hours worked per day resulted in a drop in average hourly productivity for both processors and harvesters; that is, the rate of production decreases as the working day length is increased. However, the magnitude of the drop in productivity differs between processors and harvesters, between seasons, between species and between tree size categories.

Operator fatigue and mechanical problems are more exacerbated by extended working hours during the hot summers (up to 34% drop) than the cooler winters (up to 29% drop) for both processor and harvester operations. Processor productivity declines at a faster relative rate for big trees (up to 28% drop) than small trees (up to 7% drop) as the number of working hours per day is increased. Productivity drops were also larger for harvesters working in *E. globulus* stands than in *E. nitens* stands.

Estimated costs per unit of production increased by close to 30% for the processors and 15% for the harvesters when scheduled hours per day was increased from 9 to 18. Unit production costs were greater for all three work schedules above 9 hours per day. Lower hourly productivity associated with longer work schedules negated the reduction in hourly fixed costs.
Figure 2. Effect of daily hours worked in Chile on daily production and average hourly productivity for mechanised processors operating in radiata pine plantations and harvesters operating in eucalypt plantations. Production and productivity are the averages for all seasons, all tree size classes, and all species for each machine type.

New Zealand Study
Preliminary analysis of the data indicates that there was no statistically significant difference (p=0.05) in hourly scanner productivity between the first \(123 \text{ m}^3 \text{ h}^{-1}, 56\) stems \text{ h}^{-1}\) and second \(105 \text{ m}^3 \text{ h}^{-1}, 59\) stems \text{ h}^{-1}\) shifts of the day. When hours in which rest breaks or end of shift activities (usually tidying up small pieces) were excluded, no statistically significant difference in productivity was found between hours of daylight \(134 \text{ m}^3 \text{ h}^{-1}\) and dark \(135 \text{ m}^3 \text{ h}^{-1}\).

Figure 3. Effect of time of day on average value recovered based on measured stem dimensions, actual quality calls, and virtual bucking of over 120,000 stems by five scanner operators in New Zealand.
Analysis of the processor productivity data indicated that there was no statistically significant difference in productivity between daylight hours (63 m³ h⁻¹) and dark hours (69 m³ h⁻¹). More stems per hour were processed during daylight hours but these were smaller in piece size than stems processed during dark hours.

Figure 3 shows the average value ($/m³) recovered at different times of the day. The average value recovery was the same for the first and second shifts ($87.11 per m³). Differences at different times of the day were partially due to differences in average piece size. More detailed analysis revealed that there were significant differences in value recovery between the five scanner operators. Once operator differences were accounted for a 1% difference in recovery was found between daylight hours and dark hours; dark hour recovery being higher. The difference was statistically significant at p=0.05 level.

**Discussion and Concluding Comments**

The case study of on-forest Chilean harvesting operations showed that, although daily production increased with extended working hours and multiple shift schedules, the increased production would likely be insufficient to reduce unit production costs below those of a 9-hour single shift. Other forest operations researchers have identified approaches for improving this situation. Gingras (2004) comments that with proper equipment selection (i.e., a good lighting package), maintenance scheduling (i.e., during the day shift where possible), and production planning (e.g. allocating the worst ground for the day shift) the differences between the productivity of day and night work shifts can be minimised for forest harvesting operations. Swedish experience has highlighted the importance of focusing on the human factor. Gellerstedt (1997) notes that high levels of harvesting crew productivity can be sustained throughout the day by rotating jobs within a crew and allowing operators to select the day or evening shift that suits them best in a multi-shift operation.

The case study of the off-forest central processing yard in New Zealand runs counter to the Chilean study in that no difference in productivity for the scanning optimizer was found between the first shift operating mainly in daylight hours and the second shift operating mainly during night hours. Similarly, no difference in the productivity of processing stems into logs was found between daylight and darkness hours. These findings agree, however, with those of Rose (2007) who essentially found no drop in productivity for the night shift compared with the day shift of a large, non-mobile, centralized processing yard in New Zealand. Very good lighting outside of normal daylight hours was a feature of the Logmaister operation (and the CPY studied by Rose 2007); this was considerably better than the illumination from the halogen or xenon lighting packages attached to the in-forest log processing and harvesting operations in the Chilean study.

A small difference in average value recovery was found in the New Zealand study; recovery being higher during hours of darkness. This was unexpected. Comment is often made in the literature on the effect of circadian rhythm on error rates which are at their highest between mid-night and 6 am, peaking in the early hours of the morning (2 to 4 am) (Folkard and Tucker 2003). It was expected that increased error rates would
lead to lower value recovery. Two possible reasons for no drop in value recovery are good lighting and operating conditions for the scanner operator, and the use of a scanning optimizer. The operator identifies and calls changes in quality along the stem but does not have to decide what log types should be cut. Future research should explore the impact of time of day on value recovery for processors operating on-forest, particularly if these are not fitted with an optimizing computer.

Further work is needed on work schedule design. Understanding the effects of extended work hours and different work schedules on productivity and value recovery of both on- and off-forest mechanised operations will allow planners to better manage log supply, labor force requirements, and harvesting economics.

**Literature Cited**


