

Predicting the productivity of motor-manual workers in precommercial thinning operations

by Luc G. LeBel¹ and Denise Dubeau²

ABSTRACT

Precommercial thinning is an important part of intensive management in northern forests. Precommercial thinning is largely carried out by motor manual means, and workers are usually paid on a production basis. To establish a piece-rate system that fairly compensates workers, it is important to accurately predict their production for various site conditions. Based on the observation of 129 workers, a model that predicts the number of hours required to thin one hectare of forest as a function of the number of stems per hectare was developed. It was not possible to detect a statistically significant effect from site factors such as slash, rocks, stumps, and terrain slope. The model is compared with similar attempts reported in the literature. The proposed model will be especially useful to those concerned with labour productivity, compensation systems and benefit-cost analysis in silviculture.

Key words: workers' performance, productivity modeling, time consumption, thinning, brushsaw

RÉSUMÉ

L'éclaircie précommerciale est un élément important de l'aménagement intensif des forêts nordiques. L'éclaircie précommerciale s'effectue principalement au moyen d'outils motorisés utilisés individuellement et les travailleurs sont habituellement rémunérés en fonction de leur productivité. Afin de mettre en place un système de rémunération à la pièce qui soit équitable pour les travailleurs, il est important de prédire avec précision la productivité en fonction de diverses conditions de terrain. À partir de l'observation de 129 travailleurs, un modèle de prédiction du nombre d'heures requises pour éclaircir un hectare de forêt a été élaboré. Il n'a pas été possible de détecter un effet statistiquement significatif à partir des facteurs de la station comme les débris, les roches, les souches et la pente du terrain. Le modèle est comparé à d'autres tentatives similaires publiées dans la littérature. Le modèle proposé sera particulièrement utile aux personnes intéressées par la productivité des travailleurs, les systèmes de rémunération et les analyses de coûts et bénéfices en sylviculture.

Mots clés : performance des travailleurs, modélisation de la productivité, temps requis, éclaircie, scie de débroussaillage



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Introduction

Precommercial thinning, often referred to as spacing, is an important component of the silvicultural strategy in northern forests. In Quebec, for example, the total annual area treated has increased from approximately 19 000 ha in 1990 to 117 875 ha in 2003 (Parent and Fortin 2006). Such an increase has induced strong demand for qualified labour. Workers involved in this line of work are usually paid on a

production basis (Bouliane 2002). Criticism concerning the pay scale offered to labourers is endemic. Productivity models can help establish a fair compensation system. Precise and up-to-date information regarding forest workers' productivity is also required to evaluate the cost effectiveness of this silvicultural treatment.

The method used to determine a forest worker's monetary compensation is often based on time and motion studies. The model currently in use to establish guidelines for motor-manual spacing costs on Quebec's public land was developed between 1990 and 1993. In recent years, both workers and employers have expressed concerns about the model's ability to properly account for the changes in site conditions. In their opinion, work site conditions had become more difficult and, therefore, the productivity model based on data collected during the early 1990s did not properly predict productivity. In particular, they argued that steep slopes were now more frequent, and that obstacles on the ground such as slash, rocks, and stumps have become more numerous. This is an annoyance to the workers, as they know that the productivity model used for Quebec's public land did not account for slope or obstacles. Although these results contradict the workers' opinion, studies in other regions, such as several

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Canadian provinces (Murray and Cameron 1987, Needham and Clements 1989, Needham and Hart 1991), the United States (Seymour and Gadzik 1985) and Norway (Samset 1986) have reached similar conclusions. Yet, the opinion of those performing a job must not be overlooked. Therefore, it seemed important to carefully investigate the relationship between site conditions and productivity, especially when considering present and anticipated labour shortages.

Bouliane (2002) reported that 25% of silvicultural labour would prefer another line of work. The result is not that different to what has been documented for loggers. Research conducted by Egan and Taggart (2004) compared loggers from Quebec and Maine, both groups working in northern Maine. The research compared occupational choice, perceived occupational prestige and familial attachment to logging among the two groups of workers. The research revealed that, for different reasons, both groups would not encourage their siblings to be loggers. Quebecois loggers seem to be resigned to their work as their only choice and Maine's loggers invoke a lack of occupational prestige to explain their opinions. Egan and Taggart conclude that labour shortages may worsen in time if loggers' perception of their work does not improve. A fair pay rate may contribute to modifying perceptions of forestry work.

In an attempt to develop a better productivity model for brushsaw operators, a large-scale research project was carried out. The project's objectives were as follows:

- Update an existing productivity model and establish if it still adequately predicts labour productivity in spacing operations;
- Develop and test a data collection protocol to identify work site variables that have the most influence on labour productivity.

In this article, a review of existing productivity models is presented. Next, the method followed to produce an improved productivity model is described. The new model is then compared to the model actually used in Quebec. Results are discussed and suggestions are made to develop a more accurate model for motor manual operations where labourers are paid on a piece-rate basis.

Productivity Modeling of Motor-Manual Operations

Svensson (1971) presented what is probably the first published productivity model for brushsaw operations. Based on 204 observations collected on 12 different thinners, Svensson established that the variables having the greatest effect on workers' productivity were the number of stems to be removed and the arithmetic mean height of these stems. The coefficient of correlation (R) for the proposed model was 0.77. Site slope did not appear to influence a worker's performance in Svensson's study. Adding estimation classes for slash and ground roughness, stem distribution, and standard deviation for tree heights improved the coefficient of correlation (0.82). At the time of Svensson's study, brushsaws were still in an early phase of development.

In North America, for various reasons, chain saws were commonly used in spacing operations until the early 1990s. A study, performed in Nova Scotia, comparing the productivity achieved by workers using chainsaw and brushsaw clearly demonstrated the superiority of the latter (NSDNR 1992). Using data provided by a forest company, a brushsaw productivity model based only on stand density with a coefficient of determination (R^2) of 0.48 was presented.

In New Brunswick, Needham and Clements (1989) studied stand factors affecting worker performance. Based on 51 observations, the authors established that the most important factor was the density of trees greater than 1.0 m tall. Species type (hardwood, softwood, mixed-wood), average tree diameter and stem distribution influenced productivity, but the relationship could not be precisely defined. The authors found that the relationship between terrain slope and productivity was the opposite of what they had expected: worker's productivity increased with slope. They hypothesized that, because productivity studies took place in low to moderate slopes, proper evaluation of this factor was not achieved. In a subsequent study, Needham and Hart (1991) searched for factors other than density that affected performance. Based on 147 observations, they found that terrain slope, ground roughness or rockiness did not influence workers' productivity and hypothesized that it may be due to poor definition of the variables or low occurrence of these factors. In Québec, a study has yielded results similar to those obtained in New Brunswick—time studies on 161 precommercial thinning workers led Labbé (1995) to conclude that terrain slope, ground roughness and other obstacles (stumps, rocks, slash) did not significantly influence productivity. Therefore, a productivity model based strictly on density of stems over 1.3 m tall was developed and applied ($R^2 = 0.54$).

In the absence of significant relationship between terrain factors and productivity, visual estimations of those factors can be attempted in order to adjust predictions for terrain slope and roughness. However, the arbitrary nature of these estimates may sometimes generate more frustration for the workers. In practical terms, the impact that a factor may have on productivity must be greater than the transaction cost (the cost of collecting all the data required to adequately estimate this same factor).

Method

In order to assess if Labbé's model still adequately predicted productivity (Labbé 1995), new data were collected in 2000 and 2001 using a protocol that was only slightly modified to focus on site factors. The protocol consisted of carefully selected study sites, detailed time and motion studies, precise area measurements, and a complete tally of obstacles. A hand-held computer was used to record every significant activity during the time and motion studies. Work elements measured in 2000 and 2001 are described in Table 1. Productive time included walking, selecting the stem to be protected, swinging the brush saw, and sawing. As pointed out by Bergstrand (1991), these elements tend to merge into each other and it is virtually impossible for an observer to measure them separately. Each time study started with the worker filling up the brushsaw and ended when the fuel tank was empty (mean time = 56 minutes, $\sigma = 27$ minutes). Studies always took place between 6:00 and 11:00 AM so as to minimize the effect of cumulative fatigue. In this study, effective time occupied a mean proportion of 85% of observed time. However, the short time span of the studies may not provide an accurate reflection of delays for a complete work week. Before using the proposed model to establish a pay system, a more reliable estimate of the proportion of effective time for a whole week should be obtained.

As the worker progressed within a block, an observer would mark the area with surveying flag. Once the time study was over, bearings along the cleared area were measured with

Table 1. Description and importance of work elements (2000–2001).

Work element	Description	Mean time consumption (hr/ha)	Standard deviation (hr/ha)	Proportion of total time
Productive time	Effective time ^a	19.9	9.4	84.7%
Unproductive time	Non-working time (except lunch hour)	4.3	4.5	15.3%
Operational delay	Walk to and from site, talk to foreman	2.6	2.5	—
Mechanical delay	Repairing on site	0.2	1.5	—
Personal delay	Resting, snack, drinking	1.5	2.8	—

^a Walking, selecting a stem, sawing

Table 2. Sample statistics (2000–2001).

Variable	Units	Mean	Std Dev	Min	Q1	Q3	Max
Density (height over 1.3 m)	Stems/ hectare	23 793	13 524	4 880	13 700	29 867	77 067
Total density	Stems/ hectare	46 557	30 742	8 933	24 667	57 600	184 667
Residual stems height	decimetres	29.6	10.1	17.1	23.3	31.3	81.7
Terrain mean slope	%	17.0	13.5	0	4.1	25.0	55.0
Obstacles	Number/ hectare	1700	1008	0	933	2 267	5 333
Slash	Number/ hectare	883	703	0	400	1333	3 467
Holes, rocks	Number/ hectare	190	235	0	0	267	1 200
Stumps	Number/ hectare	626	465	0	267	800	2 133

a compass and segment lengths with a string box to calculate the area cleared by the worker. This method was more precise than GPS (Global Positioning System) when under a canopy. Depending on the size of the area cleared by the worker, three to five 400-m² survey plots were established to measure the number of stems. The diameter at stump height (DSH) was measured for every stem removed. The height, diameter at breast height (DBH), and DSH of all residual stems higher than 1.30 m were recorded. Shorter stems were compiled for each species within one of two height classes: 0 m to 0.60 m and 0.61 m to 1.30 m.

Results already published in the literature suggested that a different measurement method should be used to better describe the relationship between productivity and obstacles in the field (Svensson 1971, Samset 1986, Needham and Hart 1991). Accordingly, every obstacle that had the potential to interfere with work was classified in one of six classes, namely: stump, rock, slash, snag, and ground depression (hole). In order to better represent the difficulty level, the height of every obstacle higher than 0.3 m was measured. It was hypothesized that obstacles lower than 0.3 m were less prone to affect a worker's progression on the site. Slope measurements were taken in every survey plot. Temperature, type of precipitation, wind strength and direction were noted.

Statistical Analysis

A total of 129 workers, aged 18 to 64 years took part in the 2000–2001 study. Their productivity ranged from 4.2 to 51.4 effective hour per hectare, averaging 19.9 hours per hectare (Table 1). The pre-treatment stand's density ranged from 8 933 to 184 667 stems per hectare (mean = 46 557) (Table 2).

Prediction models were developed using linear regression with the MINR (Minimum R² improvement) selection method (SAS Institute 1988). First, a model was developed using only the data collected in 2000 and 2001. At that stage, 30 independent variables and 11 interactions were included in the analysis (Table 3). In the end, the new model included only one variable to predict time consumption (eq. 1).

$$[1] \quad \text{Time consumption} = -77.95 + 9.87 \ln(D) \\ R^2 = 0.44, \text{RMSE} = 0.0504, n = 129$$

where:

Time consumption = number of effective hours/hectare treated

$\ln(D)$ = natural logarithm of the number of stems taller than 1.3 m /hectare

In order to determine if the worker's productivity or stand characteristics changed over time, this new model was then compared to Labbé's 1992–1993 model (Labbé 1995) (eq. 2):

$$[2] \quad \text{Time consumption} = -95.46 + 11.81 \ln(D) \\ R^2 = 0.54, \text{RMSE} = 0.0409, n = 161$$

The compared models are not statistically different and include the same independent variable. The difference was tested with the introduction of a dummy variable including the sampling year, and an interaction between sampling year and density. The regression was run with these new variables. If the sampling year variables were significant (p-value lower

Table 3. Independent variables and interactions tested.

Vegetation	Site factors	Interactions
(S) = Species	(Sl) = mean terrain slope %	$\ln(D) * (Sl)$
(D ₀) = # ^a stems/ha of DSH ^b ≤ 1.5 cm	(Lr) = # slash/ha	$\ln(D) * (Lr)$
(D ₁) = # cut stems/ha of DSH > 1.5 cm	(Hr) = # holes and rocks/ha	$\ln(D) * (Hr)$
(D ₂) = # stems/ha left after treatment	(St) = # mature tree stumps/ha	$\ln(D) * (St)$
(D) = (D ₁ + D ₂) = # stems/ha > 1.5 cm DSH	(LrM) = minimal logging residue height	$\ln(D) * (Obs)$
(Rh) = residual stems mean height	(LrH) = mean logging residue height	(Sl) * (Lr)
(D ₃) = (D ₀ + D ₁ + D ₂) = total # stems/ha	(LrX) = maximal logging residue height	(Sl) * (Hr)
$\ln(D)^c$	(Ch) = Chicot	(Sl) * (St)
$\ln(D)^2$	(Wd) = walking direction according to terrain slope	(Sl) * (Obs)
$1/\ln(D)$	(Obs) = all obstacles on site = Lr + Hr + St + Ch	$\ln(D) * (Sl) * (Lr)$
(D) ²	(Sl) ²	$\ln(D) * (Sl) * (Obs)$
$\ln(D_3)^2$	(Lr) ²	—
(D ₃) ²	(Hr) ²	—
$\sqrt{D_3}$	(St) ²	—
$\sqrt{D}$	(Obs) ²	—

^a# = number

^bDSH = diameter at stump height. A DSH of 1.5 cm corresponds to a height of 1.3 m.

^cln = natural logarithm

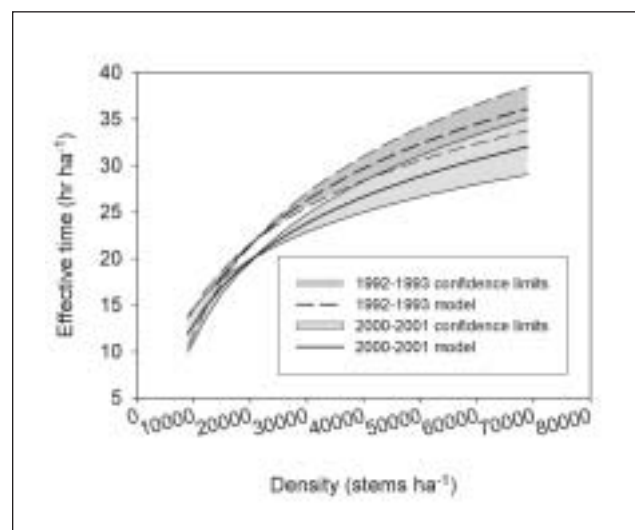


Fig 1. Both models presented with upper and lower prediction's confidence limits (95%).

than 0.05), then the two models would be deemed different. The sampling year was not significant (p-values of 0.16 and 0.138), so the observed difference is not considered significant. The models' prediction 95% upper (uclm) and lower (lclm) confidence limits are plotted on Fig. 1. The upper bound of a 100(1-α)% confidence interval for the expected value (mean) of the dependent variable (time consumption) is represented by uclm, while lclm shows the lower bound. Both models are located in the center of the area delimited by uclm and lclm. It can be observed that the 95% confidence intervals partly overlap each other for most observed densities, especially those below 18 000 stem per hectare.

Table 4. Contribution of other variables to the model.

Variables	P – value	R ²	RMSE
$\ln(D)$	< 0.0001*	0.44	0.0504
$\ln(D)$ + Slope	0.0514	0.45	0.0498
$\ln(D)$ + Slash	0.0710	0.45	0.0500
$\ln(D)$ + Obstacles	0.1512	0.45	0.0502
$\ln(D)$ + Slope × Slash	0.0241*	0.46	0.0496

*significant (α = 0.05)

Other variables suspected to affect productivity were examined (Table 4). None of these variables is worth including in the model; they do not increase the R² noticeably, and, except for the interaction of “Slope and slash,” their p-value is not significant at the 5% level, although “Slope” is “near significant.” Even with a significant interaction, the transaction cost of measuring these variables in order to adjust pay scales is too important to justify the procedure. A simpler, cheaper method should be developed to integrate consideration for site factors in pay scales.

Although an effort was made in the current project to include site conditions judged the most difficult by the workers, the range of site conditions was similar to the conditions observed in the previous study (Table 5). Except for maximum effective time observed, both distributions are similar. Distributions of stems higher than 1.3 m were similar in both studies. Mean slope was higher in the 2000–2001 study but was not significantly linked to productivity (R² = 0.009, p-value = 0.0980, α = 0.05). In fact, worker's productivity was slightly better in this study compared to the previous. It was not possible to compare obstacle densities (slash and woody debris) because a different measurement method was used in the second study.

Table 5. Field data compared for the two studies.

Study Period	Variable	Mean	Std Dev	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
1991–1993	Effective Time	20.85	8.16	4.02	14.66	20.52	25.66	41.22
	# Stems DSH > 1.51	21 268	10 257	4 160	13 600	20 717	26 100	61600
	Mean Slope	13.0	13.7	0.0	3.0	10.0	20.0	92.0
2000–2001	Effective Time	19.91	9.40	4.21	12.81	18.58	26.46	51.42
	# Stems DSH > 1.51	23 793	13 524	4 880	13 700	20 800	29 867	77 067
	Mean Slope	17.0	13.5	0.0	4.0	17.0	25.0	55.0

Discussion

While not statistically different from the model that is based on data collected in the early 1990s, a slight improvement in labour productivity was noticed in 2000–2001. For a stand of 20 000 stems per hectare, a worker in 2000–2001 would take approximately 1.7 hours less than what would have been predicted 10 years before. This could be partly explained by improvements in brushsaw technology that occurred during that period; the equipment used by workers is now lighter and more reliable. Also, labour training programs have been developed for brushsaw operators. However, few workers in our sample had received formal training. Therefore, more productivity gains might still be achievable through the use of better work technique and improved job layout.

Our results are consistent with those of similar studies. It was not possible to demonstrate a statically significant relationship between site factors, other than stem density, and workers' productivity. It is unclear why these variables, thought to be important, are not statistically significant determinants of labour productivity. However, part of the explanation most probably lies with the measurement method as well as the financial compensation system in place. Piece rate is known to influence workers' productivity (Seiler 1984, Sundström-Frisk 1984, Paarsch and Shearer 1996). In order to maintain their production rate, workers may compensate with an increased effort when needed. To further validate this hypothesis would require the precise measure of work load. A follow-up to this project is therefore underway to evaluate the work load of brushsaw operator in relation to site conditions.

Conclusion

Since its introduction as a silvicultural work technique, many models have been proposed to predict productivity of pre-commercial thinning with a brushsaw in relation with work sites conditions. Stem density has always been identified as the factor with the most influence. Our results are consistent with this. No clear relationship was found between productivity and other factors believed by the workers to have a significant influence on productivity such as ground roughness (obstacles, slash) and slope. Time and motion studies on 129 forest workers paired with thorough ground roughness measurements have not allowed this research project to reach a different conclusion. No statistical evidence was found to confirm that site conditions were more difficult than in the early 1990s. Moreover, a comparison with productivity studies indicates that today's workers have slightly improved their productivity.

These results may indicate that more important productivity improvement can only be expected through increased mechanization of thinning operation. That being said, it is likely that brushsaw operators will still be needed in the near term. Accordingly, it remains vital to properly evaluate the effort required to perform this operation. The measurement of physiologic cost could provide a means to take terrain roughness and slope into account when attempting to construct a better productivity model.

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