WOOD HARVESTING
Technical Note TN-219 October 1994
FERIC

ESTABLISHING THE OPTIMAL SKIDDING OR FORWARDING DISTANCE AS A FUNCTION OF ROAD COST

J.A. Plamondon, F.E.* and J. Favreau, F.E.**

Abstract

This report describes a model that calculates the combined cost of roads and skidding and an optimal skidding distance for four types of machines used in eastern Canada. The road construction cost and the volume to be harvested must be specified by the user. Skidding productivity estimates based on FERIC time studies were integrated into the model. The results show that deviating somewhat from the calculated optimal skidding distance does not produce any large increase in cost and thus, that there is a considerable range within which efforts to adjust skidding distances are not warranted.

For road costs of less than $12 000/km, clambunk skidders provide the lowest combined cost for roads and skidding. For road costs of greater than $12 000/km, cable skidders give the lowest combined cost for roads and skidding. The machine whose optimal combined cost was the most influenced by road construction cost was the grapple skidder, whereas the shortwood forwarder's optimum was the least influenced by road cost. The model will prove of most use as an analysis tool for evaluating the relative impact of various skidding and road construction scenarios.

Introduction

The manager, confronted by the task of planning a network of extraction roads, must decide whether it is preferable to increase the average skidding distance or to build more roads. The optimal choice depends primarily on the cost of road construction and that of skidding[1]. Matthews (1942) developed a simple model that permitted users to calculate the optimal skidding distance by determining the minimum combined cost of roads and skidding. Peters (1981) described several refinements that let Matthews' model account for winding skid trails, the costs of road maintenance over several years, and harvesting in successive passes.

The objective of this report is to present a model that permits the manager to estimate a minimum combined cost for roads and skidding and an optimal skidding distance in terms of skidding productivity, road construction cost per kilometre, merchantable volume harvested, and the hourly cost of the machines. Matthews' simple approach was retained, and skidding cost and productivity estimates under eastern Canadian conditions for four types of machines were used as inputs for the model. The model can be used to quickly evaluate the impact of a change in operational practices.

[1] To simplify the text, the term "skidding" is used to describe both skidding and forwarding.

* Jean A. Plamondon is a researcher with the Wood Harvesting Group, Eastern Division.
** Jean Favreau (M.Sc.E.) is a researcher with the Wood Harvesting Group, Eastern Division.
KEYWORDS: Optimal skidding distance, Skidding, Forwarding, Productivity, Road construction, Costs.

Cette Fiche Technique est disponible en français.

FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER
580, boul. Saint-Jean, Pointe-Claire, Québec, Canada H9R 3J9, (514) 694-1140
2601 East Mall, Vancouver, B.C., Canada V6T 1Z4, (604) 228-1555

 ISSN 0381-7741

The Model and its Components

The base assumption used in the model is that the forest is covered by a network of evenly spaced, parallel extraction roads. The skidding distance thus depends directly on road spacing. Figure 1 illustrates the optimization scenario that was selected. The road cost curve ($/m^3) decreases as the skidding distance increases, since each kilometre of road accesses a larger area of forest and thus a larger volume of timber. The skidding cost curve ($/m^3) increases with increasing skidding distance. The sum of these two curves represents the combined cost for roads and skidding. The minimum point on this curve is the value sought by the model. Other costs, such as felling and transport, were considered independent of skidding distance. Since it is impossible to find a perfectly uniform road network in practice, the calculated optimum should be used as a basis for analysis rather than as an absolute value. Moreover, the logistical and planning consequences of an increase or a decrease in the average skidding distance are not considered in this report.

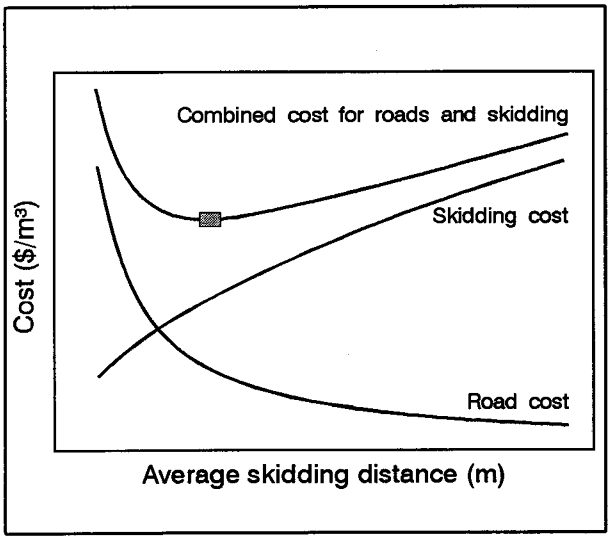

Figure 1. Combined cost for roads and skidding as a function of the average skidding distance (box = minimum cost).

The variables used to develop the curves were:

1. The **volume to be harvested per hectare** (m^3/ha). This volume corresponds, for a clearcut[2], to the merchantable volume and was considered to vary between 50 and 200 m^3/ha for the purposes of this report.

2. The **cost of building extraction roads** ($/km). A survey of 24 respondents carried out by FERIC (Provencher and Favreau, in preparation) indicated that this cost can vary between $2 000 and $28 000 per kilometre, depending on the conditions encountered. For a harvested volume of 100 m^3/ha, Figure 2 shows the road cost in $/m^3 as a function of the average skidding distance, for five road costs in $/km.

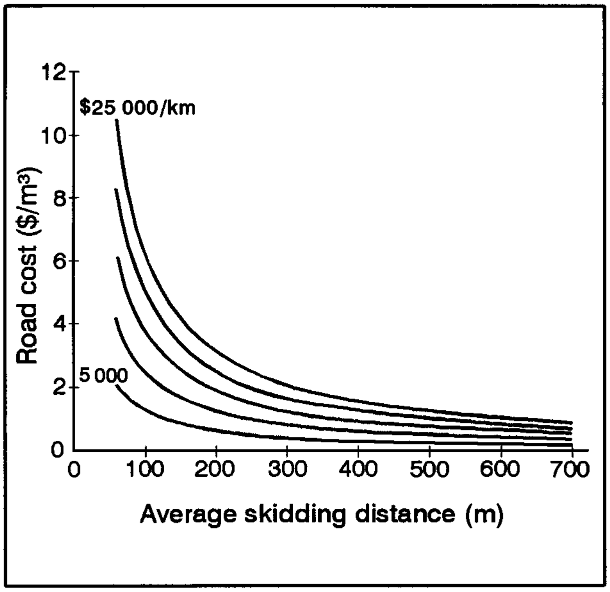

Figure 2. Road cost per cubic metre as a function of average skidding distance (volume = 100 m^3/ha).

3. The **skidding cost** ($/m^3). Four types of machines were considered: a shortwood forwarder, a cable skidder (bunch slinging), a grapple skidder, and a clambunk skidder. To establish the skidding cost for each machine, the **direct hourly operating cost** was divided by the established **productivity** as a function of skidding distance.

The **direct hourly operating cost** for each generic type of machine and the assumptions on which it is based are presented in Appendix A. This cost does not include supervision, administration or profits. The data used in these calculations were drawn from FERIC's database on the costs of forest equipment. Table 1

[2] For successive harvests spread over several years, the present discounted equivalent volume to be harvested should be calculated. As well, the road construction cost should be increased to account for road maintenance over more than one year.

presents the hourly costs calculated for each type of equipment. These costs are estimates for each type of machine, and are not specific to any particular machine make or model. Obviously, hourly costs based on different assumptions from those in Appendix A could change the results of the optimizations presented in this report.

Table 1. Hourly costs of the machines

Type of equipment	$/PMH
Clambunk skidder (150 kW)	115
Grapple skidder (110 kW)	60
Cable skidder (110 kW)	60
Shortwood forwarder (75 kW)	70

The **productivity** of skidding equipment has been the subject of numerous FERIC studies. The curves for productivity as a function of distance were developed by combining the results of all these past studies on various machine makes and models, under various operating conditions. The data comprised 51 forwarder cycles, 103 cable skidder cycles, 144 grapple skidder cycles, and 52 clambunk skidder cycles. The initial regressions of productivity on distance were able to explain significantly 10 to 40% of the variation in productivity. However, since the average travel speed of the machines tended to increase with skidding distance, the curves (Figure 3) were corrected so as to impose a speed limit that permitted more realistic extrapolations at skid distances beyond those within the sample (generally limited to about 400 m).

The productivity curves are consistent with the characteristics of the various machines. For example, the grapple skidder, with its small load capacity and very short loading and unloading times, is the most sensitive to distance, as its productivity decreases by 53% between 100 and 300 m skidding distance. Conversely, the forwarder transports a large payload but has relatively long loading and unloading times, and its productivity is thus less sensitive to distance. It should be remembered that these curves are based on numerous studies, under a wide range of terrain conditions, and thus result from a different approach than that adopted by Mellgren (1990). Productivities on sites presenting conditions more or less favorable than the average would probably be higher or lower, respectively, than those illustrated in Figure 3.

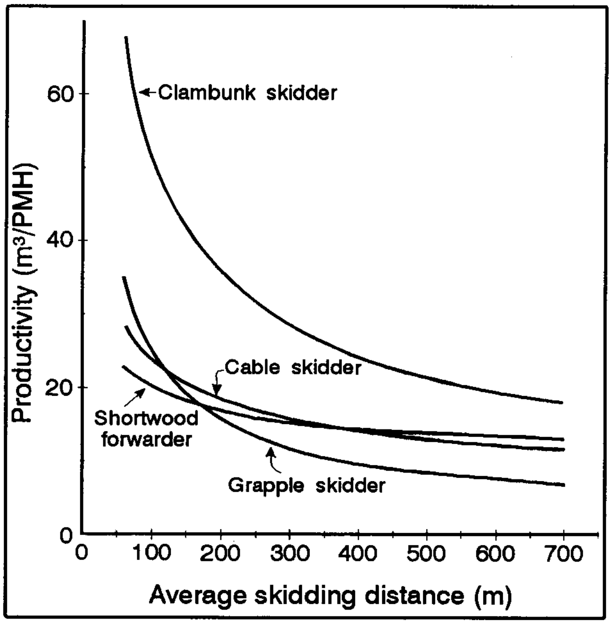

Figure 3. Skidding productivity as a function of average skidding distance.

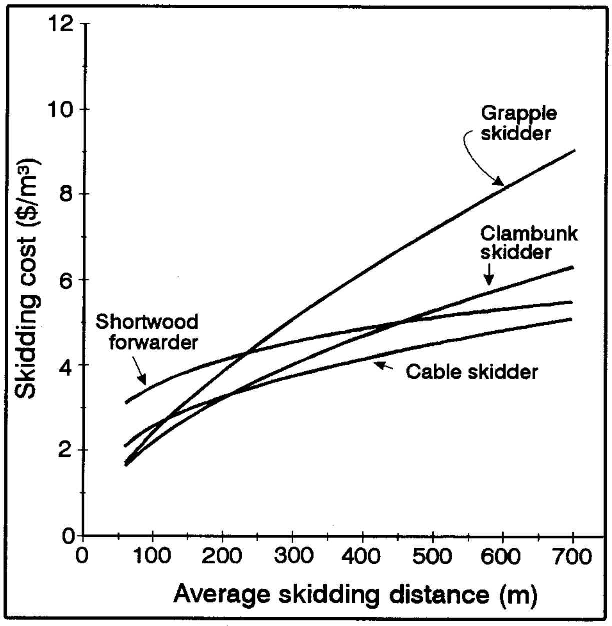

Figure 4. Skidding cost for the four types of machines.

By dividing the hourly operating cost by the corresponding productivity, the skidding cost ($/m^3) was obtained. Figure 4 presents the skidding cost by type of machine. Since this graph is based on the inverse of that in Figure 3, it is not surprising that the cost per cubic metre for grapple skidders is the one that increases most rapidly with increasing distance and that the forwarder's cost increases least rapidly.

Results of the Model

Figure 5 presents the curves for the combined cost of roads and skidding as a function of average skidding distance for each of the machines, for road-construction costs ranging from $5 000 to $25 000 per kilometre, with skidding from both sides of the road. The volume to be harvested was held constant at 100 m^3/ha. The minimum cost point on each curve is indicated by a square, and the vertical bars indicate a range of $0.05/m^3 around this minimum. The minimum can be calculated using equation B2 in Appendix B, while equation B3 permits the user to generate the combined cost curves.

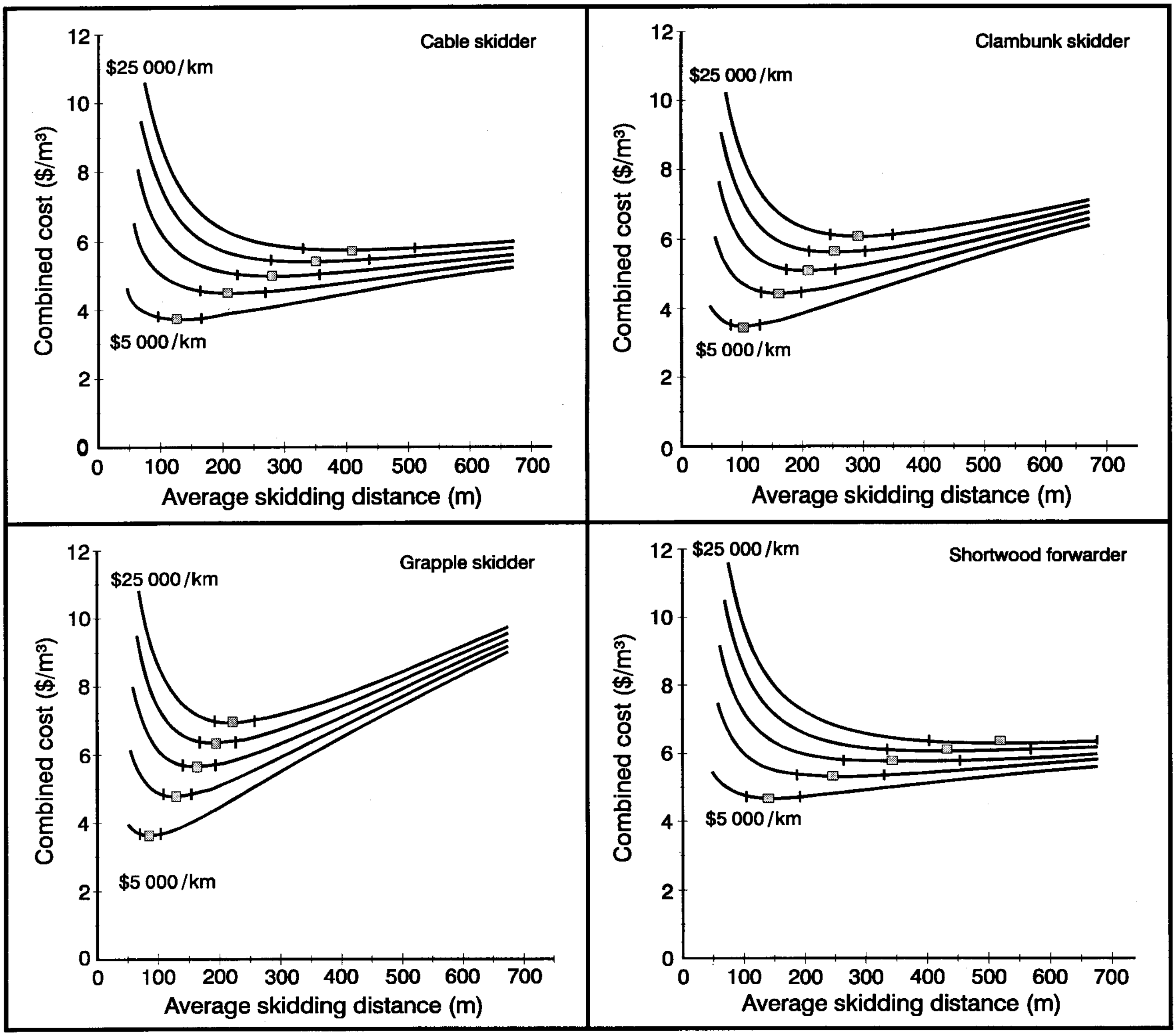

Figure 5. Combined cost of roads and skidding for the four types of machines (volume = 100 m^3/ha, squares = minimum cost, vertical bars = range of $0.05/m^3).

In absolute terms, the clambunk skidder offers the lowest combined cost for road costs of \$5 000 and \$10 000 per kilometre. The cable skidder offers the lowest combined cost for road costs of \$15 000, \$20 000, and \$25 000 per kilometre. The transition point between these two machines was calculated at \$12 000/km. Though outside the scenarios in Figure 5, the use of a grapple skidder would provide the lowest combined cost for a road cost of \$2 000/km.

A higher road cost causes an increase in the optimal cost and distance, but to different extents depending on the equipment used. An increase of 100% in road-construction cost, for example, from \$10 000 to \$20 000 per kilometre, would cause a 32% increase in the minimum combined cost of roads and skidding for a grapple skidder, the largest increase of the four machines. Conversely, for the same increase in road cost, a forwarder would experience only a 14% increase in its minimum combined cost. Note also that the change in the optimum skidding distance in response to increased road costs is most pronounced for machines such as a forwarder, whose productivity is least affected by distance, whereas it is less pronounced for a machine such as a grapple skidder, whose productivity is most sensitive to skidding distance.

Each curve has a region around the optimum that is more or less flat. Thus, moving away from this optimum does not necessarily imply a large cost increase, as indicated by the vertical bars in Figure 5. For example, a grapple skidder working at an average skidding distance of between 110 and 155 m (a range of 45 m) will have an increased combined cost of roads and skidding of no more than \$0.05/m^3 from the minimum cost for a road-construction cost of \$10 000/km. For this same road cost, the equivalent range is 65 m for a clambunk skidder, 105 m for a cable skidder, and 145 m for a forwarder, in each case for the almost negligible cost increase of \$0.05/m^3. These ranges will widen at higher road costs. However, deviating significantly from the optimum can be costly, primarily for a combination of high road-construction cost and short skidding distance. For example, a clambunk skidder working over an average distance of 100 m, with a road cost of \$20 000/km, will result in a combined cost for roads and skidding of \$7.21/m^3. Working instead at the optimal skidding distance of 250 m that was calculated for this context, the combined cost would be \$5.63/m^3, a difference of \$1.58/m^3.

Figure 6 illustrates the effect of variations in the harvested volume for a cable skidder and a road construction cost of \$10 000/km. It can be seen that a 50% decrease in the volume harvested, from 100 to 50 m^3/ha for example, will increase the minimum combined cost from \$4.49/m^3 to \$5.41/m^3. This has the same effect as increasing the road-construction cost by 100% for a harvest volume of 100 m^3/ha, which is true for all the machines.

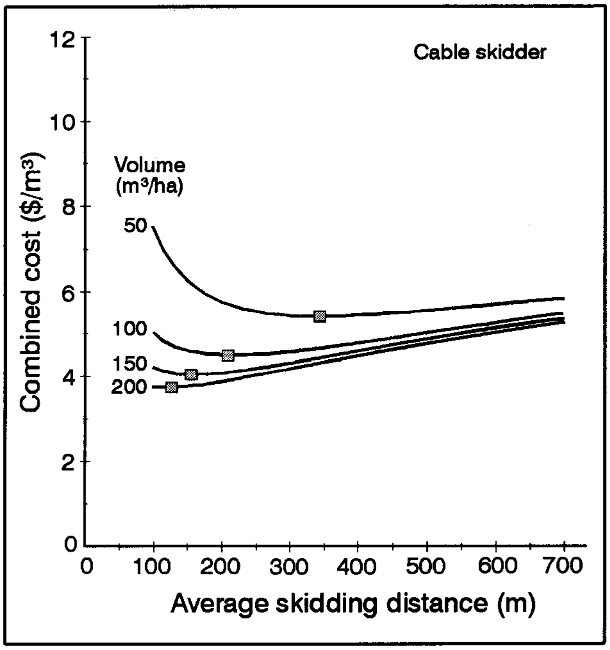

Figure 6. Combined cost of roads and skidding as a function of the harvested volume for a cable skidder (road-construction cost = \$10 000/km).

Conclusions

The model proposed in this report suggests the following general conclusions:

- The optimum skidding distance does not vary in the same manner for the four types of machines studied as a function of road construction cost or volume to be harvested. From most sensitive to least sensitive, the machines are: grapple skidders, clambunk skidders, cable skidders and forwarders.

- The calculation of an acceptable margin of tolerance will provide the manager with a range within which modification of the optimal skidding distance will have little effect on cost. Assume, for example, that the volume to be harvested is 100 m^3/ha and that the road construction cost is $10 000/km. By establishing an acceptable range of $0.10/$m^3$ around the optimum (double that assumed in Figure 5), which still remains a small increase, the average distances at which the machines could work for the lowest cost would now be:

- from 100 to 160 m for grapple skidders;
- from 120 to 220 m for clambunk skidders;
- from 150 to 300 m for cable skidders;
- from 170 to 390 m for forwarders.

- The productivity data used to establish the production functions were obtained in summer and fall. Since winter conditions may permit the use of less expensive road networks, it could be advantageous to reduce the skidding distance if skidding productivity is unchanged (Peyton 1973). If skidding productivity during the winter is below that in other seasons, it could be preferable to further reduce skidding distance. Conversely, winter conditions that lead to higher skidding productivity will offset the reduction in optimal skidding distance that results from the use of a less expensive road network (McNally 1963).

- Skidding productivities were measured in clearcutting operations. Except for strip cuts or block cuts, a partial cut cannot be simulated simply by reducing the volume to be harvested since the work techniques and the skidding speeds differ from those observed.

- The proposed model is based on the assumption of a uniformly distributed road network, which is rare in practice. The objective of the model is thus mainly to facilitate comparisons of the **relative** impacts of various operating scenarios, of using different machines, or of new harvesting regulations.

- The combined cost of roads and skidding represents only a part of the total fiber cost in a harvesting system. For example, forwarders did not provide the best combined cost in any of the scenarios presented in this report, but they are efficient in a shortwood system. The manager must evaluate the consequences of increasing or decreasing skidding distance on all other harvesting and planning costs.

- Other approaches are possible to address the question of optimal road spacing. The use of geographic information systems (GIS) would permit the calculation of skidding distances based on the actual configuration of the road network and the area's topographical constraints. A more refined analysis would thus be possible to determine one or more classes of optimal extraction distance.

References

Matthews, D.M. 1942. Cost control in the logging industry. 1st ed. McGraw-Hill, New York, N.Y. 374 p.

McNally, J.A. 1963. Mechanized logging and road requirements. Can. Pulp Paper Assoc., Woodlands Division, Montreal, Que. Rep. 2258 (B-8-b).

Mellgren, P.G. 1990. Predicting the performance of harvesting systems in different operating conditions. For. Eng. Res. Inst. Can. (FERIC), Pointe-Claire, Que. Spec. Rep. SR-67. 22 p.

Peters, P.A. 1981. Road and landing spacing models. Pages 51-68. *In*: Corcoran, T.; Jeij, W.B. Coord. Forest operations analysis - techniques for planning and control. IUFRO 3.04.01 Congress, Kyoto, Japan.

Peyton, G. 1973. An approach to proper branch road layout. Pulp Pap. Mag. Can. 74(11):49, 52, 57, 60.

Provencher, Y.; Favreau, J. (in preparation). Statistical information on forest roads. II. For. Eng. Res. Inst. Can. (FERIC), Pointe-Claire, Que. Field Note.

Appendix A
Assumptions Used in Calculating the Direct Hourly Operating Costs, by Type of Machine

	Clambunk skidder	Grapple skidder	Cable skidder	Forwarder
Economic life (years)	5	5	9[a]	5
Scheduled machine hours (SMH/yr)	3 600	3 600	1 800	3 600
Purchase price ($)	450 000	170 000	152 000	240 000
Residual value ($)	45 000	17 000	15 200	24 000
Insurance ($/yr)	22 500	8 500	7 600	12 000
Interest rate (%)	8	8	8	8
Utilization rate (%)	80	85	85	80
Lifetime repair cost (% of purchase price)	115	100	100	110
Fuel consumption (L/PMH)	25	18	16	12
Fuel cost ($/L)	0.35	0.35	0.35	0.35
Oil and lubricants ($/PMH)	1.31	0.95	0.84	0.95
Operator cost[b] ($/SMH)	20.00	20.00	20.00	20.00
Cost ($/PMH)	**115.00**	**60.00**	**60.00**	**70.00**

[a] The cable skidder works for only a single shift, which extends its economic life.

[b] Including benefits.

Appendix B
Variables and Equations Used

List of variables and symbols

P = productivity (m^3/PMH)

d = average skidding distance (m)

K = road construction cost ($/km)

VT = harvest volume (m^3/ha)

b = 1 or 2 = skidding from 1 or 2 sides of the road

C_{op} = hourly operating cost of the skidder or forwarder ($/PMH; see Table B1)

α, β = productivity coefficients (see Table B1)

C_{tot} = combined cost of roads and skidding ($/$m^3$)

C_{road} = road cost ($/km)

C_{skid} = average skidding cost ($/$m^3$)

Table B1. Productivity coefficients and hourly cost, by type of machine

Machine type	C_{op} ($/PMH)	α	β
Clambunk skidder	115	626.61	-0.54
Grapple skidder	60	573.01	-0.68
Cable skidder	60	126.93	-0.36
Forwarder	70	58.61	-0.23

Equation (B1) - Productivity (P):

$$P=\alpha\, d^{\beta}$$

Equation (B2) - Equation for the optimum average skidding distance (d_{opt}):

$$d_{opt}=\left[\frac{10\alpha K}{2b(VT)(-\beta)\,C_{op}}\right]^{\frac{1}{(1-\beta)}}$$

Equation (B3) - Combined cost of roads and skidding (C_{tot}) for a given average skidding distance:

$$C_{tot} = C_{road} + C_{skid}$$

$$C_{tot} = \left[\frac{10K}{2b(VT)\,d}\right]+\left[\frac{C_{op}}{\alpha\, d^{\beta}}\right]$$