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FOREST ROAD CONSTRUCTION IN MOUNTAINOUS TERRAIN: EVALUATING ENDHAULING OPERATIONS, CASE STUDY NO.1

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Abstract

In 1997, the Forest Engineering Research Institute of Canada (FERIC) evaluated an endhauling project at a Western Forest Products Limited forest operation on the west coast of Vancouver Island. The study was the first in a series of case studies that describe forest road construction techniques in mountainous terrain, and document productivities and costs of endhauling for a range of material types and site conditions.

Introduction

Forest road construction in mountainous terrain requires specific practices to minimize environmental impacts. One example is endhauling, the transportation of excavated material from the construction site to an embankment area or disposal site (also known as a spoil site) situated on stable terrain. A requirement under British Columbia's Forest Practices Code (FPCBC) Forest Road Regulation is to take "measures to maintain slope stability if the road will cross areas with a moderate or high likelihood of landslides as determined by a terrain stability field assessment."[1] As a result, endhauling has become a common road building practice in this type of terrain because it is considered to be an effective way to decrease the landslide hazard. It eliminates deposition of excavated material onto a slope during construction (i.e., sidecasting), a practice that can overload and over-steepen the slope, compromising its stability (Chatwin et al. 1994).

Road construction prescriptions often specify the amount of endhauling required on a road section, along with the width of the bench that must be excavated for the road base. For example, "full bench /100% endhaul" means that the entire road width must be excavated from the slope and all of the excavated material must be transported to a designated spoil site. In recent years, this prescription has been applied extensively in B.C. for road construction on slopes steeper than 60%. Wise et al. (1997) explained that in many cases, this can be an overly conservative approach and described some alternative construction techniques for reducing the volume of material that must be endhauled.

A range of construction options should be available to forest operators. This range may begin with sidecasting all excavated material in stable, benchy terrain and progress to either full bench / 100% endhaul, or reinforced soil embankments and fill retaining-structures in high hazard areas. A combination of partial benching, carefully constructed fills, and reduced endhauling is an intermediate step. Selecting the most appropriate method requires an assessment of landslide risk, a process that takes into account the hazards at the site and adjacent slope areas, as well as potential consequences to resources downslope and downstream (BCMOF 1993).

Forest operators have raised some issues around the practice of endhauling, including:

[1] BCMOF (1998), Part 2, Section 8 (g).

Keywords: Forest roads, Road construction, Mountainous terrain, Endhauling, Time study, Productivity, Costs, Coastal British Columbia.

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- Increased endhauling in recent years has contributed to a substantial increase in road construction costs for B.C. operators. To reduce costs, some operators have become skilled at modifying subgrade construction techniques to minimize the volume of material that must be endhauled, and in developing innovative ways of using spoil material to reduce trucking requirements. These techniques need to be documented and transferred to other operators.

- Productivity and cost information for endhauling operations in a range of material types may aid in determining fair cost allowances for this work under B.C.'s stumpage appraisal system.

- The "full bench / 100% endhaul" road construction prescription needs to be evaluated within a total risk management context at each site, rather than applied universally to slopes steeper than 60%.

- Judicious selection of spoil site locations is critical to minimizing endhauling costs. If site occupancy guidelines are affecting the selection process (i.e., restrictions on the forest land area that can be taken up by roads, landings, spoil sites, etc.), it is important to weigh the total construction costs when assessing alternative spoil sites.

In 1997, the Forest Engineering Research of Canada (FERIC) began a series of case studies of endhauling operations to address some of these issues. The objectives of the case studies are to describe construction techniques that can reduce costs for steep-slope operations and to document productivities and costs of endhauling for a range of material types and site conditions. This report describes the results from the first case study.

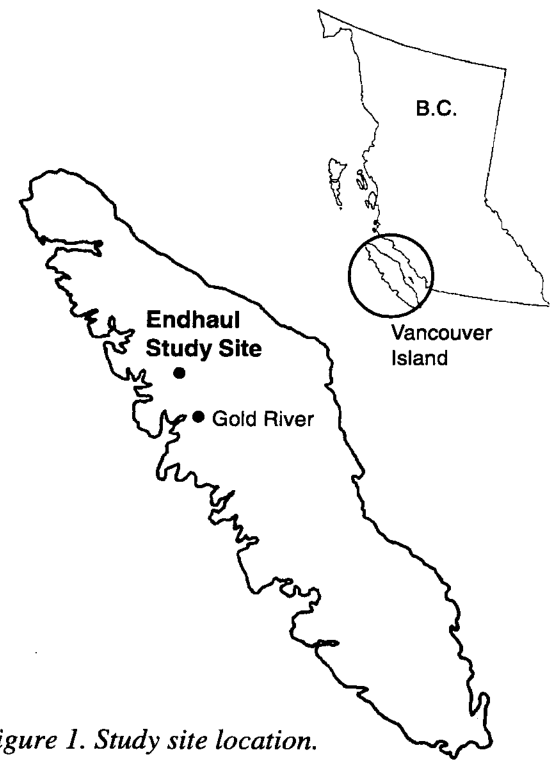

Figure 1. Study site location.

Site Description and Road Design Specifications

The study site, located 30 km west of the town of Gold River, was in Western Forest Products Limited's (WFP) Tree Farm Licence 19 on the west coast of Vancouver Island (Figure 1). The road was built by Frank Beban Logging Ltd., a logging and roadbuilding contractor for WFP.[2]

The 268-m road section examined in this case study was part of a branch road leading to a timber harvesting area (Figure 2). A 20-m clearing width was felled in the large old-growth timber along the road location. The study section was built primarily in competent volcanic rock (basalt) with one 54-m section of dense glacial till. The rock required drilling and blasting before excavation. Up to 30 cm of organic overburden covered the rock and soil. Side slopes along the road location ranged from 70 to 90%.

The road design specifications included:

- cut and fill slopes for rock of 0.25H:1V and 1H:1V, respectively

- cut and fill slopes for OM (other material) of 0.5H:1V and 1.5H:1V, respectively

- subgrade and running surface widths of 6.2 and 5.6 m, respectively

- ditch depth of 0.7 m

- favourable[3] grades of 12–20% along the study section

Road Construction Method

The machines used were a 34 000-kg hydraulic excavator (Caterpillar 330L), a pneumatic tankdrill (Finning M40), and an articulated six-wheel truck

[2] In 1998, the logging contractor's roadbuilding operation was sold to M.R. Adama Enterprises Ltd.

[3] A "favourable" grade means downhill travel for a loaded logging truck.

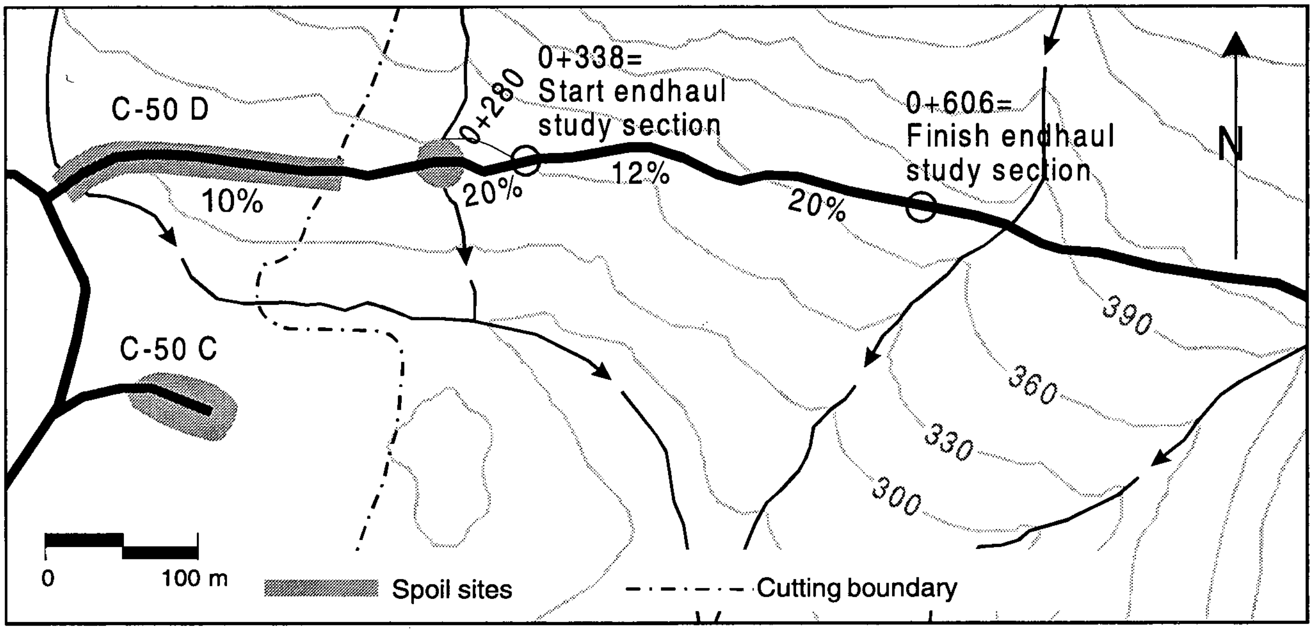

Figure 2. Layout of study road section.

(Caterpillar D250E). The truck had a 22.8-t payload capacity and a 14-m^3 heaped volume capacity. A crawler tractor (Caterpillar D8K) was parked on-site and used occasionally to spread the spoil material.

The crew consisted of an excavator operator and a driller/blaster. The driller/blaster operated the rockdrill, loaded explosives, coordinated blasting, and drove the truck when endhauling was required. (A dedicated truck driver was employed for six of the 37 shifts during the study period.) The excavator operator often helped the driller/blaster load boreholes with explosives, and occasionally drove the dump truck after loading it. The road-building operation worked seven days/week. The primary crew worked 14 days in 10-h shifts, before being replaced by a relief crew that had rotated through another of the contractor's nearby operations.

Construction activity was confined to a single road heading (i.e., only one road location was available for the crew and equipment to work on). No branch or spur roads were connected to the main road heading in the vicinity of the study site.[4]

Construction with the excavator was completed in one pass because the terrain was too steep and broken to allow pioneering of a trail ahead on the right-of-way. After each round of blasting the excavator dug the rock and loaded it into the truck (Figure 3). While the truck traveled to and from the spoil site, the excavator dug and sorted material for the next load, retrieved and decked right-of-way logs, and constructed subgrade. If the excavator completed these tasks before the round of endhauling was finished, it had to stand by until the truck returned from the spoil site.[5]

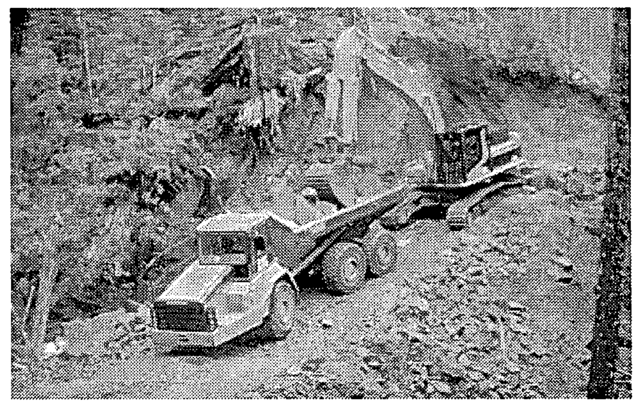

Figure 3. Excavator loading articulated truck.

During construction through the dense glacial till, the excavator was able to dig and load this material quickly, so two articulated trucks were used for 1½ shifts to speed up the endhauling process. The excavator completed the subgrade and running surface with *in situ* materials.

It was not always necessary for the truck and excavator to work together. Sometimes subgrade

[4] Road construction productivity is usually higher, and costs are lower, when the construction equipment and crews can build more than one road at the same time (i.e., multiple construction sites, or headings, are in close proximity). Equipment utilization improves because machines that must alternate their activities (e.g., rockdrills and excavators) can switch back and forth between road headings as required.

[5] In this report, "standby time" is defined as when a machine was running (idling) and waiting for work. When a machine was parked with the engine shut off, the time was recorded as "machine shutdown".

construction or ditching and finishing activities could be accomplished without endhauling excess material. On occasion the excavator operator was able to reduce the amount of material that was endhauled for a short road section by paying attention to the finer details of subgrade construction. For example, occasionally the operator was able to dig a key (or notch) below, and towards the outside edge of, the planned road grade. Boulders were then carefully placed on the key, creating a stable base to support the subgrade. In this case, the height of the support structure was usually limited to one or two boulders — a basic and common application of the technique. Using a key and placing boulders reduces the width of the bench that must be cut into a slope, and in turn reduces the volume of material to be excavated.

The rock was prepared for blasting by drilling short horizontal boreholes, aligned parallel to the road centreline, into the rockface. The driller/blaster felt that it was easier to control flyrock and spillage of rock downslope by keeping borehole length to one drill rod or less (i.e., ≤ 3.6 m). The holes, 64 mm in diameter, were loaded with emulsion-type cartridge explosives and fired with non-electric detonators and safety fuse assemblies. Controlled blasting techniques, in which individual holes are detonated in a delayed sequence, were used to help retain blasted rock on the road grade.

Where possible, logs were stacked against the standing timber along the lower edge of the clearing width as an extra precaution against rock escaping downslope during blasting and subsequent excavation. The logs formed a makeshift retaining wall that kept runaway material within reach of the excavator (Figure 4). To execute this technique, the clearing width was reduced in some places to ensure that the excavator could reach down and stack the logs against the standing trees, and subsequently retrieve any escaped rock or debris.

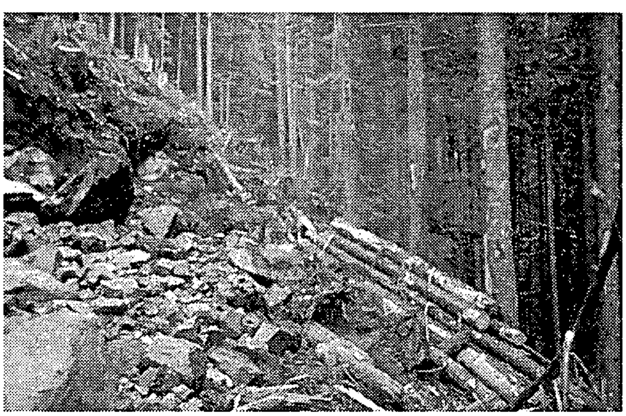

Figure 4. Makeshift retaining wall made with right-of-way logs.

Three spoil sites were used to dispose of the endhauled material. The primary site was an old landing spur, C-50C (Figure 2). Overburden, stumps, till, and some large rocks were dumped on and around the old landing, and the area was enlarged to make a service landing for future helicopter logging operations. The second spoil site consisted of the first 200 m of Branch C-50D (Figure 5). This road section was in gentle terrain where the smaller blasted rock could be deposited as fill on top of the subgrade. The third spoil site, a gully with a gently sloped base at station 0+280, was filled with clean boulders (Figure 6). The fill improved the road's vertical alignment while allowing water to drain through the clean rock fill. An overflow pipe was placed near the top of the embankment to provide an extra passage for water during periods of high flow.

Study Method

The road was built in April and May of 1997 over a 37-shift study period. Production information was collected from shift reports completed daily by machine operators for each piece of equipment at the

Figure 5. The small blasted rock was deposited on the first 200 m of Branch C-50D.

Figure 6. Forming the base for a large fill.

work site. Hourly equipment rates were developed by FERIC (Appendix I) and used with the shift-level production information to calculate unit costs for the project. (The hourly equipment rates are generic rates applicable to the makes of machines used in this study as well as other makes of the same type and weight class.) Hourly equipment rates were assigned to construction activities in the following manner:

- Total ownership and operating costs were applied to productive machine hours (PMH) and to standby time during endhauling. For the excavator, *standby (during endhauling)* was the time when no other work was done at the road heading, and the operator simply waited in the excavator until the truck returned for another load. For the dump truck, *standby (during endhauling)* was the time when the operator waited in the truck until the excavator was ready to resume loading.

- For the excavator, an additional category of standby time was identified. *Standby (operator driving truck)*, the time when the operator left the excavator to drive the truck after loading it, was charged out at the total hourly rate minus the labour cost.

- Mechanical delays and machine shutdown time were charged out at the ownership cost plus the labour cost when the operator carried out related duties (e.g., loading boreholes and blasting) or simply waited on-site. If a machine was shut down and without an operator, or the operator was assigned to another machine (e.g., driller/blaster switching to the dump truck), then only the ownership cost was applied.

Detailed drilling and blasting logs were maintained by the driller/blasters, and these were used to calculate the consumption and cost of explosives and blasting accessories. The shift-level productivity and cost summaries are the central results in this report.

The truck hauling cycle was timed and linear regression models (or means) were developed for individual cycle time elements within the trucking phase of the endhauling operation. Additional truck cycles were timed after road construction progressed beyond the study section to increase the observed range of haul distances. While the models are only valid for the specific conditions of this study, the data may be combined later with data from other case studies to provide a basis for predicting endhauling productivity and cost over a broader range of operating conditions.

Cross-sections were surveyed along the study road at intervals of approximately 10 m, before and after construction, to calculate the bank volume of excavated material. Stakes were placed at each end of the original cross-sections and used as tie-points in the post-construction survey. Volumes for the individual road segments between cross-sections were calculated by averaging the end areas.

Although much of the road was constructed on a full bench, small amounts of fill material were observed on some post-construction cross-sections. The bank volume of endhauled material was therefore calculated by subtracting the fill volume from the excavated (cut) volume for each road segment. The fill volume was converted to equivalent bank volume by assuming swell factors of 1.40 for rock and 1.25 for OM.[6]

Results and Discussion

Equipment Time Distribution

Total times for the excavator, rockdrill, and dump trucks are summarized from the daily shift reports in Tables 1, 2, and 3, respectively. Machine utilization rates were 86 and 24% for the excavator and rockdrill, respectively.[7] From Table 3, a utilization rate of 63% was calculated for the dump trucks, based on the combined total time including the primary truck and 14 PMH for a second truck. The utilization rate for the primary dump truck alone was 61%.

[6] BCMOF; BC Environment (1995), Table 6, p.28.

[7] Machine utilization = (PMH/SMH)•100. Machine availability = [(SMH-MD)/SMH]•100.

Table 1. Shift-level Time Distribution: Excavator

Activity	Total time (h)	Total time (%)
Productive machine hours (PMH)		
Grubbing and stripping	10.0	3
Subgrade construction	47.5	14
Ditching and finishing	29.3	8
Excavate and load truck(s)	207.0	60
Spoil site maintenance	4.5	1
Total productive time	298.3	86
Non-mechanical delays (NMD)		
Standby (during endhauling)	17.0	5
Standby (operator driving truck)	8.0	2
Machine shutdown (operator on-site)	20.7	6
Total non-mechanical delays	45.7	13
Mechanical delays (MD)	4.0	1
Total scheduled machine hours (SMH)	348.0	100

Table 2. Shift-level Time Distribution: Rockdrill

Activity	Total time (h)	(%)
Productive machine hours (PMH)		
Drilling boreholes	82.7	24
Non-mechanical delays (NMD)		
Machine shutdown (loading and blasting)	45.5	13
Machine shutdown (operator on-site)	48.0	14
Machine shutdown (operator driving truck)	153.8	46
Total non-mechanical delays	247.3	73
Mechanical delays (MD)	8.5	3
Total scheduled machine hours (SMH)	338.5	100

Table 3. Shift-level Time Distribution: Dump Trucks

Activity	Total time (h)	(%)
Productive machine hours (PMH)		
Load, haul and dump	221.0	63
Non-mechanical delays (NMD)		
Standby (during endhauling)	12.8	4
Machine shutdown (no operator assigned)	118.2	33
Machine shutdown (operator on-site)	0.5	0
Total non-mechanical delays	131.5	37
Mechanical delays (MD)	0.0	0
Total scheduled machine hours (SMH)	352.5	100

Machine availability, at 99, 97, and 100% for the excavator, rockdrill, and dump truck, respectively, was high during the study period, indicating that mechanical delays did not influence the productivity of the construction operation.

Approximately two-thirds of the excavator's total time was spent on endhauling-related activities: 60% was productive time and 7% comprised standby time. The machine was shut down for 6% of SMH, primarily while the operator waited for drilling and blasting to be done.

Endhauling activities also accounted for about two-thirds of the dump trucks' combined available time. For the primary truck, this included some standby time during endhauling (accounting for 4% of SMH in Table 3). This truck was parked on-site for the remaining scheduled time.

The rockdrill's work schedule was determined by the excavator's workload, and this was reflected in the drill's low utilization level. The combined activities of drilling and blasting accounted for 37% of the drill's time. For the remaining time it was shut down while the excavator prepared more rock for drilling or the driller/blaster drove the truck during endhauling.

Endhauling operations are challenging for road construction supervisors and operators because it is difficult to coordinate construction activities to achieve reasonable levels of machine utilization. All machines are likely to be shut down or on standby for significant amounts of time, especially when construction work is confined to a single road heading. In the case of rockdrills, the effect of endhauling on machine utilization rates can be estimated by comparing the current study to previous FERIC studies of rockdrills done from 1988 to 1990. In the earlier series of four rockdrill production studies (Bennett 1991), the average machine utilization rate (i.e., the measure of drilling time) and the average combined time for drilling and blasting were 37 and 57% of scheduled machine hours (SMH), respectively, compared to 24 and 37%, respectively, for this study. In the earlier studies, each rockdrill was studied for three to four months under a variety of terrain conditions, and endhauling was not done.

Productivity and Costs

Table 4 summarizes production using three units of measure: lineal metres of constructed road, total volume of material excavated, and total volume endhauled. Volume production figures exclude stumps and other woody debris. The endhauled volumes are

Table 4. Production Summary for the Study Road Section

	Lineal metres of road (m)	Excavated volume (bank-m³)	Endhauled volume (bank-m³)
Material type			
Rock	214	5391	4970
Other material	54	1168	1079
Total units	268	6559	6049
Productivity (total units/h)[a]	0.8	18.8	17.4

[a] Productivity based on total SMH for the excavator (348.0 h).

less than the total excavated volumes because some excavated material was used to build the subgrade itself, and occasionally small amounts spilled onto the slope below the road. The productivity results were calculated using the excavator's total SMH, not just time engaged in excavating and loading trucks.

Average cutslopes were 0.41H:1V and 0.51H:1V for the rock and OM sections, respectively. (These estimates were based on 20 cross-sections surveyed in the rock and seven cross-sections surveyed in the OM section.) The average volume excavated per lineal metre of road was 25.2 m^3/m for the study section, compared to 20.5 m^3/m derived from the mass haul estimates in the road design.

Average running surface width was 5.9 m. However, the top of the subgrade formed the running surface so the average subgrade width was slightly less than specified in the road design.

Table 5 presents average unit costs (for all material types combined) for the three units of production shown in Table 4. The unit costs for *excavated volume* include all the cost categories and machine activities, while the unit costs for *endhauled volume* apply to endhauling activities only. Of the volume-based unit costs, the figures for *excavated volume* are more relevant because they apply to the entire construction operation and not just to the endhauling process. Endhauling is an integral part of road construction rather than a distinct and separate phase, so it can be difficult to delimit periods where only endhauling occurs. Even within the *excavate and load truck(s)* activity as identified in this study, the excavator usually performed other activities in conjunction with endhauling to help make the finished road.

Table 5. Unit Costs for the Study Road Section

Cost category	Lineal metres of road ($/m)	Excavated volume ($/bank-$m^3$)	Endhauled volume ($/bank-$m^3$)
Excavator	202.15	8.26	6.22
Trucking	124.34	5.08	5.51
Drilling & blasting [a]	104.05	4.25	-
Explosives & accessories [a]	37.55	1.53	-
Other [b]	10.84	0.45	0.48
Total	478.93	19.57	12.21

[a] Total costs for these categories are prorated over the combined total bank volume of rock and other material. Based on the bank volume of rock only, the unit costs are $5.24/$m^3$ and $1.87/$m^3$ for drilling & blasting and explosives & accessories, respectively.
[b] Intermittent grooming of the spoil area using a crawler tractor (estimated 20 h total).

Truck Cycle Times

Table 6 identifies six time elements in the truck hauling cycle and presents means or models for each cycle element. These results are specific to six-wheel articulated trucks operating under the following conditions: soft, newly constructed subgrade; narrow (road-width) turnarounds; favourable grades ranging up to 20%; and one-way haul distances ranging from 110 to 1160 m.

The cycle elements are listed in chronological order. After being loaded, the truck traveled to the junction of Branch C-50 and Spur C-50C (see Figure 2) where it turned around and backed into the spoil site. Just before reaching the excavator on the return trip, it turned around and backed up to the machine for another load. The articulated truck worked well under conditions that were unsuitable for a conventional dump truck. It was able to negotiate the soft subgrade and gullies in the unfinished road, and could turn around and back up to the excavator without requiring specially constructed wide spots.

Table 6. Models for Cycle Element Times [a]

Cycle element	Mean or model [b] (min)	R^2	Std. Dev./Err. (min)	Observations (no.)	Haul distance (m)
Load	5.84	-	1.32	31	-
Travel loaded	0.00407•DIST + 1.54	0.91	0.55	31	110–1160
Turn loaded	1.51	-	0.22	20	-
Dump	0.64	-	0.43	31	-
Travel empty	0.00376•DIST + 1.31	0.67	1.12	31	110–1160
Turn empty	1.33	-	0.92	20	-

[a] For the observed conditions of this study. Round trip dump truck cycle time is equal to the sum of the individual cycle elements.
[b] DIST is the one-way haul distance (m) to the spoil site ($p<0.05$).

Many factors are likely to influence truck cycle time and the productivity of the whole construction process. These include the type of construction equipment, type of material, crew and equipment coordination, planning and engineering, location of spoil sites, truck turnouts and turnarounds, road grades, and rolling resistance. Therefore, the results of this study should be used with caution when making predictions about truck cycle times, and endhauling productivity and cost for other construction situations.

Other Observations

The two-person construction crew was well organized and appeared to use the equipment efficiently, given the constraints on the operation. Because construction was restricted to a single road heading, the crew had to plan activities carefully to minimize standby time for the excavator and rockdrill. Whenever possible, work was organized to allow both machines to work concurrently. For example, the excavator would concentrate on preparing the rock so the drill could return as soon as possible to begin the next round of drilling. Sometimes this was accomplished by stockpiling material along the inside edge of the road rather than loading it directly onto the truck for immediate endhauling (Figure 7). The stockpiled material was subsequently loaded and endhauled while the drill worked on the heading. Similarly, any drilling that was not essential to maintaining the excavator's forward progress was saved for the rockdrill's spare time. Work such as drilling ditchline and widening the subgrade was done while the excavator moved ahead with grubbing and stripping, and subgrade finishing activities.

Because the gully at station 0+280 was not identified as a spoil site until construction had started, the road-building crew was forced to stockpile large rock along the outside edge of the road until approval to use the gully site was obtained from government agencies (Figure 8). This situation slowed the road-building operation, creating an obstacle for travel on the road and a potential landslide hazard. In any road-building operation unforeseen circumstances will require last-minute changes in plans. Where endhauling is prescribed, however, it is important to identify all potential spoil sites when the road location is being engineered, well in advance of construction operations, to minimize changes to plans and inefficiencies during construction.

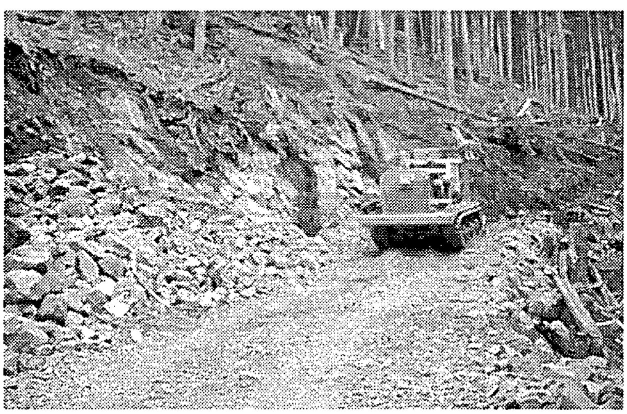

Figure 7. Stockpiling material allowed the rockdrill to resume work promptly.

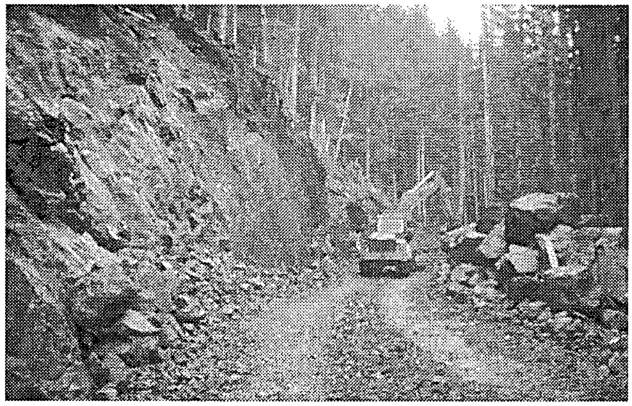

Figure 8. Boulders stockpiled prior to endhauling.

Conclusion

This report is the first in a series of case studies designed to provide information on productivities, costs, and construction techniques used in endhauling operations. Endhauling is an expensive road construction practice. Unit costs for the 268-m road section in this study were estimated at $478.93/m and $19.57/m^3 for lineal metres of road and excavated volume, respectively. Over a larger development unit, planners must weigh the high cost of building difficult endhaul sections with the lower cost of construction on benches and in gentle terrain to determine if an acceptable average cost/km can be achieved.

The challenge for supervisors and operators is to coordinate equipment activities to minimize standby and downtime during endhauling. There are fewer opportunities to separate machines and work them concurrently, especially when construction is confined to a single road heading. In this case, the negative impact of equipment standby and downtime on costs was partially mitigated by utilizing the small, two-person crew efficiently. The operators could run several different types of equipment and usually switched to another machine when their primary machine was temporarily out of work.

Thorough engineering and planning are critical to achieving an efficient operation. It is important to identify all potential spoil sites when the road is engineered in the field, well in advance of construction. Innovative uses of spoil material and construction techniques that reduce the endhaul volume will help reduce costs.

Endhauling is a practice often used for building forest roads in steep terrain and it is an integral part of the operation, rather than a distinct phase of construction. Site conditions dictate how and to what extent this practice must be applied. For example, it is not always necessary to build a full bench road and endhaul 100% of the excavated volume. Other options such as excavating a partial bench and carefully building up the fill portion of the subgrade, in conjunction with some endhauling, may also be feasible and more cost-effective.

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Disclaimer

Appendix I

Hourly Costs for Road Construction Equipment [a]

	Excavator 30-35 000 kg	Rockdrill pneumatic tankdrill	Articulated truck 22.8 t payload	Crawler-tractor 20-25 000 kg
OWNERSHIP COSTS				
Purchase price (P) $	500 000	385 000	450 000	575 000
Ownership period (D) y	8	9	10	10
Scheduled hours per year (h)	1 200	1 200	1 200	1 200
Salvage value as % of P (s) %	33	25	30	30
Interest rate (Int) %	10.0	10.0	10.0	10.0
Insurance rate (Ins) %	2.5	2.5	2.5	2.5
Salvage value (S) = (P•s/100) $	165 000	96 250	135 000	172 500
Average investment (AVI) = ((P+S)/2) $	332 500	240 625	292 500	373 750
Loss in resale value ((P-S)/(D•h)) $/h	34.90	26.74	26.25	33.54
Interest = ((Int•AVI)/h) $/h	27.71	20.05	24.38	31.15
Insurance = ((Ins•AVI)/h) $/h	6.92	5.01	6.09	7.78
Total ownership costs (OW) $/h	69.53	51.80	56.72	72.47
OPERATING AND REPAIR COSTS				
Fuel consumption (F) L/h	40	25	20	30
Fuel cost (fc) $/L	0.48	0.48	0.48	0.48
Lube and oil cost as % fuel cost (fp) %	10	10	10	10
Track & undercarriage life (h)	4 800	5 400	-	6 000
Track & undercarriage replacement cost (Tr) $	32 000	25 000	-	35 000
Tire life (h)	-	-	3 500	-
Tire replacement cost (Ti) $	-	-	2 000	-
Annual operating supply cost (Op) [b] $	5 000	9 000	2 000	4 000
Annual repair and maintenance cost (Rp) $	25 000	20 000	8 000	15 000
Wages (W) $/h				
Machine operator base rate	24.12	23.46	21.99	22.40
Machine servicing allowance [c]	3.02	2.93	2.74	2.79
Blasting ticket allowance	-	0.20	-	-
Total machine operator rate	27.14	26.59	24.73	25.19
Driller's assistant [d]	-	-	-	-
Wage benefit loading (WBL) %	40	40	40	40
Fuel cost (F•fc) $/h	19.20	12.00	9.60	14.40
Lube and oil cost ((fp/100)•(F•fc)) $/h	1.92	1.20	0.96	1.44
Track & undercarriage cost (Tr/h) $/h	6.67	4.63	-	5.83
Tire cost ((Ti/h)• no. of tires) $/h	-	-	3.43	-
Operating supply cost (Op/h) $/h	4.17	7.50	1.67	3.33
Repair and maintenance cost (Rp/h) $/h	20.83	16.67	6.67	12.50
Labour cost (W•(1+WBL/100)) $/h	37.99	37.22	34.63	35.27
Total operating and repair costs (OP) $/h	90.78	79.22	56.95	72.78
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	160.31	131.02	113.67	145.25

[a] These figures are based on FERIC's standard costing methodology for determining machine ownership and operating costs, and do not include such costs as crew transportation, supervision, profit and office overhead. IWA labour rates effective June 15/98 have been used.

[b] For rockdrills, annual operating supply cost includes the cost of striker bars, drill steel, couplings, and button bits.

[c] The servicing allowance for machine operators is 2/3 of 1 hour at the overtime rate. It is prorated over an 8-hr shift length for this analysis.

[d] A driller's assistant was not used during this study. Standard costing formats often include this cost, which in this case would be $21.03/h. Total ownership and operating cost for the rockdrill would be $160.45/h if the driller's assistant was included.