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Contents

Forest road construction in mountainous terrain: evaluating endhauling operations, case study no. 2

Abstract

In 1997, the Forest Engineering Research Institute of Canada (FERIC) evaluated an endhauling project at a forest operation on the east coast of Vancouver Island. The study was the second 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.

Keywords

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

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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 (BCFPC) Forest Road Regulation is to take "…measures to maintain slope stability if a 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 to decrease the landslide hazard because it reduces or eliminates the amount of excavated material placed on a slope during construction. This placement of material, also known as "sidecasting", can decrease stability by overloading and/or oversteepening the slope (Chatwin et al. 1994).

Road construction prescriptions often specify the amount of endhauling required along a road section, as well as 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 into the slope and all 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) suggested that, in many cases, this can be an overly conservative approach and described some alternative construction techniques for reducing the volume of material to be endhauled.

A range of construction options should be available to forest operators working in mountainous terrain. This range begins with sidecasting all excavated material on stable, benchy sites and progresses to more expensive options in high hazard areas such as "full bench/100% endhaul", reinforced soil embankments, and fill-retaining structures. A combination of partial benching and carefully constructed fills accompanied by

[1] Forest Practices Code of B.C., Forest Road Regulation, Part 2, Sec. 8 (g), 1998.

some endhauling is an intermediate step. Selecting the most appropriate method requires an assessment of landslide risk, a combination of the expected post-construction landslide hazard and potential consequences to resources downslope and downstream (BCMOF 1993).

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

- The increased reliance on endhauling in recent years has contributed to a substantial increase in road construction costs for B.C. operators. To reduce costs, some roadbuilders have modified subgrade construction techniques to minimize the volume of material that must be endhauled, and developed 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 help determine 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 minimize endhauling costs. An overly stringent interpretation of site occupancy guidelines[2], at the cutblock level, could prohibit the use of a spoil site that is ideal in terms of stability, capacity and proximity to the construction area. When site occupancy objectives are applied to the larger watershed or forest development planning area, there should be enough flexibility to take advantage of prime spoil site locations.

In 1997, 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 document productivities and costs of endhauling for a range of material types and site conditions. This report describes the results from the second case study.

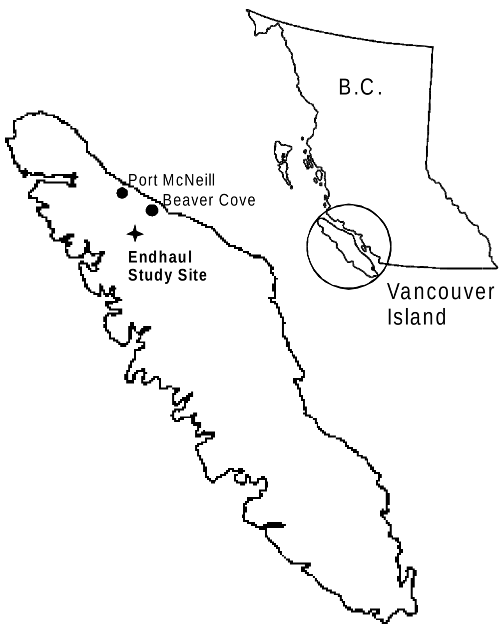

Figure 1. Study site location.

Site description and road design specifications

The study site, 34 km southeast of Port McNeill on Vancouver Island's east coast, is on public land within TimberWest Forest Corp.'s Tree Farm Licence 47. Operations were based at Beaver Cove (Figure 1). Most of the road construction and harvesting is done by the company's own crews with company-owned equipment. Several

[2] Site occupancy guidelines—restrictions on the forest land area that can be taken up by roads, landings, and other permanent access structures—are discussed in the Soil Conservation Guidebook, published by BCMOF/B.C. Environment, April 1995.

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road-building and harvesting sites were usually active at the same time throughout the Beaver Cove operation.

The 147-m endhaul section in this study was part of Branch 27 (Figure 2). The road traversed a slope within a timber harvesting unit (Figure 3). Prior to the study, construction was temporarily halted at the beginning of the endhaul section (i.e., sta. 0+727) and a portion of the the slope was subsequently harvested using a cable system. The road location was then re-established through the cutover area, and construction of the endhaul section resumed several months after logging.

The study section was built in highly weathered and fractured limestone. The layer of overburden was thin, with less than 30 cm of organic material overlying the bedrock. The slope gradient along the road location ranged from 70 to 95%.

The road construction prescription for the study section recommended "full bench/100% endhaul". Road design specifications included:

- cut slopes in rock of 0.25H:1V
- road subgrade and running surface widths of 5.9 and 5.2 m, respectively
- ditch depth of 0.9 m
- favourable grades[3] ranging from 17 to 23%

Road construction method

A 45 000-kg hydraulic excavator (John Deere 992D LC) and a rubber-tired hydraulic rockdrill (Tamrock Logmatic) were used to build the subgrade (Figures 4 and 5). Most of the endhauling was done with a three-axle, rigid-frame dump truck. A Hayes HDX logging truck tractor, retrofitted with a semi-circular body with struck capacity of 18.2 m^3, was the primary dump truck used on the project (Figure 6). The balance of the hauling requirements were met with a conventional three-axle dump truck with 12.4-m^3 box. A crawler tractor (Caterpillar D8K) or a front-end loader (Caterpillar 966D) was parked at the spoil site and used occasionally to level piles of endhauled material.

The construction crew consisted of an excavator operator, driller/blaster and driller's assistant. The dump trucks had their own dedicated drivers. Any crew member with spare time would operate the crawler tractor or front-end loader to groom the spoil site as required. The crews worked a standard eight-hour shift, five days per week.

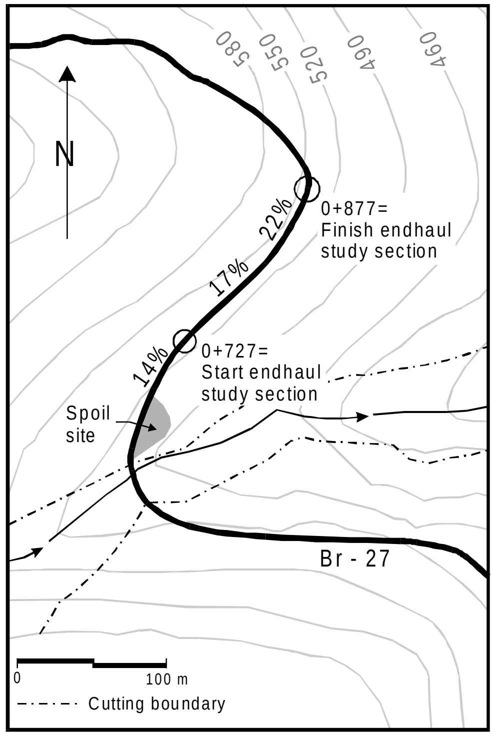

Figure 2. Layout of endhaul study section.

Figure 3. Endhaul section traverses the cutover slope.

Figure 4. Excavator ripping rock with bucket.

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

Figure 5. Rockdrill at work while excavator loads truck.

Figure 6. Hayes HDX tractor retrofitted with 18.2 m^3 body.

The crew and equipment at the study site were part of an integrated logging and roadbuilding operation, which meant that the construction supervisor often had more than one option for assigning equipment and crews to work sites. For example, a dump truck could be sent to the study site when endhauling was required, and then redirected to another job in another part of the operation when it was no longer needed. Similarly, the rubber-tired rockdrill could travel to other nearby work sites when drilling and blasting were not needed at the study site. The proximity of Port McNeill also created some flexibility for selecting and scheduling equipment. If the company-owned dump trucks were not available for endhauling, a contract truck from the town could be dispatched to the site.

Construction activity was confined to a single road heading on Branch 27 (i.e., only one road location was available for the crew and equipment to work on). No spur roads were connected to the main road heading in the vicinity of the study site.[4]

Construction was completed in one pass with the excavator because the terrain was too steep and broken to allow the excavator to pioneer a trail ahead on the right-of-way. The excavator dug out the stumps and scattered them in the cutover area below the road. The operator did not have to deal with very much overburden, and any that was stripped from the bedrock was also scattered below the road. Because the site had been logged, no right-of-way logs were handled.

The excavator could rip much of the weathered and fractured rock with its bucket. Excavation often left an irregular-shaped rock face because hard points of rock were exposed on the inside portion of the road bench, while the outside layers of more weathered rock could be excavated further along the road location. This meant that the driller/blaster had to drill an irregular borehole pattern using a combination of downholes and horizontal boreholes. The overriding construction strategy focused on getting the drill back to work at the heading as soon as possible. Following each blast, the excavator would ramp over the broken rock to form a rough access trail for the rockdrill, excavating and endhauling the minimum amount of blasted rock needed to create the trail. When the rockdrill could resume work at the heading, the excavator would move back and load the excess material still heaped on the subgrade.

The driller/blaster kept borehole lengths to one drill rod or less (i.e., ≤3.0 m), but blasting usually loosened more rock than was actually drilled. After each round of drilling and blasting, the excavator often ripped up to twice the length of the drilled round before encountering solid rock. Both emulsion-type and water gel cartridge explosives were used during the project, and fired with non-electric detonators and safety fuse assemblies. Controlled blasting techniques, with individual holes detonated in a delayed sequence, were used to help retain blasted rock on the road

[4] Road construction productivity is usually higher, and costs are lower, when the construction equipment and crews can build more than one road location 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.

grade. Occasionally the rockdrill and crew were not needed for two to three days, and travelled to other work sites while the excavator continued work at the road heading.

The excavated rock was loaded into a truck for endhauling. Only one truck was required because haul distances were short. While the truck travelled to and from the spoil site, the excavator dug material for the next load, scaled the cutslope, and constructed the subgrade. Often the excavator would simply stand by until the truck returned for another load.[5] The excavator had to deal with some large boulders but most of the excavated and endhauled material was small broken rock.

The spoil site was located on Branch 27 (Figure 7), approximately 80 m from the start of the study section; the haul distance ranged from 80 to 230 m. The base of the spoil site was on a bench below the road, where a slight ridge separated it from a nearby stream. The site's low base elevation relative to the road surface made it possible to store a large volume of rock while occupying a relatively small site area. The material was piled up against the slope until it reached the road level. This rock was subsequently retrieved and used as base course material on a section of Branch 27 beyond the study site.

Along some parts of the study section, the top of the roadcut was 2–3 m beyond the reach of the excavator. The excavator climbed up a ramp, formed from excavated rock, to scale these sections of the cutslope. Because the rock was loose and prone to ravelling, thorough scaling was crucial to stabilize the slope and minimize the rockfall hazard to the crew and equipment. Scaling must be planned and monitored carefully to ensure that it is done adequately before the excavator cuts down to final grade level.

As a final step, the excavator used the smaller shot rock to create a smooth subgrade and compacted the material with its tracks to create the finished running surface. It was not necessary to import aggregate for the running surface.

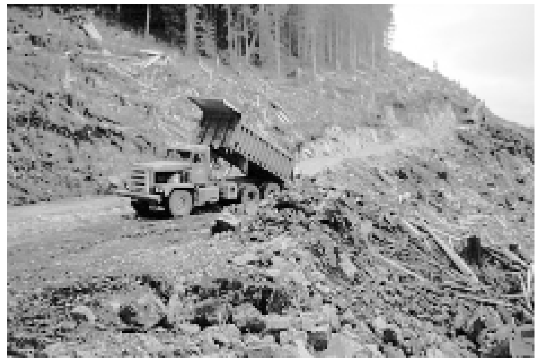

Figure 7. Conventional rigid-frame truck dumping at spoil site.

Study method

The study road section was built in May and June of 1997 over a 29-shift study period. Production information was collected from shift reports, completed daily by machine operators. Hourly rates for equipment based on machine type and weight class were developed by FERIC (Appendix I) and used with the shift-level production information to calculate unit costs for the project. These rates were assigned to construction activities in the following manner:

- Total hourly 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 trucks, standby (during endhauling) was the time when the operator waited in the truck until the excavator was ready to resume loading.
- Mechanical delays and machine shutdown time were charged out at an hourly rate that included ownership and labour costs. In these situations, the operators (or operator plus assistant for the rockdrill) carried out other duties (e.g., loading boreholes and blasting) or simply waited on site.

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

A detailed drilling and blasting log, maintained by the driller/blaster, was 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.

Cross-sections were surveyed, before and after construction, along the study road at intervals of approximately 9 m 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. Bank volume of endhauled material was 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 a swell factor of 1.30 for rippable rock.[6]

The truck hauling cycle was timed to produce descriptive statistics for individual cycle time elements within the trucking phase of the endhauling operation. Two trucks were timed and mean cycle element times were compared (each truck had a constant, but slightly different, haul distance during timing). Although the statistics only apply to 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.

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 80 and 79% for the excavator and rockdrill, respectively.[7] An overall utilization rate of 85% was calculated for the two dump trucks.

Machine availability, at 96, 100, and 99% for the excavator, rockdrill, and dump trucks, 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 8% was standby time. The machine was shut down for 8% of SMH, primarily while the operator waited for drilling and blasting to be done.

Endhauling-related activities accounted for 95% of the dump trucks' combined scheduled time: 85% was productive time and 10% was standby time. The large-capacity HDX truck was used about three-quarters of the time, with the conventional truck making up most of the balance (a contractor-owned truck was also used, but only for 2.5 hours).

High utilization rates for excavators should be attained because they are the primary machines for subgrade construction in mountainous terrain. It is essential to keep these machines occupied and advancing on the right-of-way to achieve acceptable road costs. Construction activities can usually be coordinated so that if the excavator cannot bypass rock requiring drilling, it can retreat and do other necessary work saved for such occurrences, e.g., loading stockpiled material, installing drainage structures, ditching, widening the subgrade, scaling cutslopes, or subgrade finishing.

On the other hand, it can be more difficult to achieve high utilization rates for rockdrills and dump trucks. The availability of work for these machines often depends on the excavator's workload, so relatively large proportions of delay time can occur. For example, in a series of four production

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6 Source: Soil and rock swell and shrinkage factors, FPCBC Forest Road Engineering Guidebook, Sept. 1995, p.28.

7 Machine utilization = PMH/SMH • 100

Machine availability = (SMH-MD)/SMH • 100

where SMH = scheduled machine hours

MD = mechanical delays.

Table 1. Shift-level time distribution for the excavator

Activity	Total time (h)	Total time (%)
Productive machine hours		
Grubbing and stripping	25.0	11
Subgrade construction	14.5	7
Ditching and finishing	4.0	2
Excavate and load truck	127.0	59
Spoil site maintenance	3.0	1
Subtotal	173.5	80
Non-mechanical delays		
Standby (during endhauling)	17.0	8
Machine shutdown (operator on site)	16.5	8
Subtotal	33.5	16
Mechanical delays	8.5	4
Total scheduled machine hours	215.5	100

Table 2. Shift-level time distribution for the rockdrill

Activity	Total time (h)	Total time (%)
Productive machine hours		
Drilling boreholes	57.0	79
Non-mechanical delays		
Machine shutdown (loading and blasting)	9.8	13
Machine shutdown (crew on site)	5.5	8
Subtotal	15.3	21
Mechanical delays	0.3	0
Total scheduled machine hours	72.6	100

Table 3. Shift-level time distribution for the dump trucks

Activity	Total time (h)	Total time (%)
Productive machine hours		
Load, haul and dump	125.4	85
Non-mechanical delays		
Standby (during endhauling)	14.0	10
Machine shutdown (operator on site)	6.0	4
Subtotal	20.0	14
Mechanical delays	2.0	1
Total scheduled machine hours	147.4	100

studies done from 1988 to 1990, rockdrill utilization ranged from 31 to 47% (Bennett 1991), and another endhauling case study showed utilization rates of 24 and 63% for the rockdrill and dump trucks, respectively (Bennett 1999). When the excavator is busy at the road heading, secondary tasks can be done by a rockdrill (e.g., drilling ditchline, culvert catch basins, or narrow spots on the road). However, opportunities for alternative work are usually limited unless the drill has access to another nearby road heading.

By comparison, the utilization rates achieved for the rockdrill and dump trucks in this study were quite high, because they were directed to other work sites when they were not needed at the study site. As a result, the construction supervisor reduced the amount of non-productive time chargeable to the project. The rockdrill's rubber-tired carrier was a benefit because it could move quickly to other work sites several kilometres away.

Productivity and costs

Table 4 presents road construction production using three units of measurement: lineal metres of road, total volume of material excavated, and total volume endhauled. The endhauled volume is less than the total excavated volume 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 the time that the machine was engaged in excavating and loading trucks.

The average cutslope along the study section was 0.41H:1V, based on 17 cross-sections surveyed. The average volume excavated per lineal metre of road was 46.1 m^3/m compared to the 29.7 m^3/m derived from the mass haul estimates in the

Table 4. Production and productivity summary for the study road section

	Production	Productivity (units/h)[a]
Lineal metres of road (m)	147	0.7
Excavated volume (bank-m^3)	6775	31.4
Endhauled volume (bank-m^3)	6548	30.4

[a] Productivity based on total SMH for the excavator (215.5 h).

road design. One obvious factor contributing to the larger-than-planned excavated volume was the material type. Because the rock was loose and prone to ravelling, cutslopes had to be less steep than planned. In fact, the loosest bedrock was encountered along a 60-m road section where the cutslope was highest. These cutslopes, ranging from 0.5 to 0.7H:1V, resulted in considerable excess volume.

The mean subgrade width was 7.0 m. Part of the discrepancy between the planned and final subgrade widths can be attributed to the fact that, although the ditch was eliminated on portions of the endhaul section, the road prism width was not reduced by the corresponding amount. The loose material sloughed continuously during construction, making it difficult to control and maintain a precise road width. Also, the large excavator used on this project influenced the minimum achievable road width.

Table 5 presents average unit costs for the three units of production shown in Table 4. The unit costs based on excavated volume include all the cost categories and machine activities. The unit costs based on endhauled volume cover only the specific machine activities related to endhauling. Of these two 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" activity as identified in this study, the excavator usually performed other activities in conjunction with endhauling to help make the finished road.

The unit cost per lineal metre of road ($/m) found in this study was similar to the results of FERIC's first endhauling case study, also conducted at a coastal B.C. site where the construction material was predominantly rock. However, the unit costs for excavated volume were very different ($10.35/m^3 in this study compared to $19.57/m^3 for the first study). One of many factors that likely contributed to this cost difference was the difference in the unit volumes excavated (46.1 m^3/m compared to 25.2 m^3/m in the first study).

Truck cycle times

Table 6 presents mean times for the elements of the hauling cycle. These results are specific to the two rigid-frame trucks travelling on a firm subgrade with favourable grades of 17 to 23%. The modified HDX

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	263.25	5.71	4.21
Trucking	68.78	1.49	1.54
Drilling & blasting [a]	102.08	2.21	-
Explosives [a]	28.30	0.61	-
Other [b]	14.83	0.33	0.33
Total	477.24	10.35	-

[a] Total costs for these categories are prorated over the bank volume of excavated rock, including the volume ripped by the excavator.
[b] Intermittent grooming of the spoil area using a crawler tractor or front-end loader (estimated 15 h total).

Table 6. Mean cycle element times for two dump trucks used in the study [a]

Truck box volume (m^3)	18.2	12.4	
Haul distance (m)	170	190	
No. of cycles observed	13	12	
Cycle elements (min)			
Load	8.3 (1.5)	6.6 (0.9)	*
Travel loaded	1.3 (0.1)	1.5 (0.2)	*
Dump	1.2 (0.5)	1.4 (0.3)	NS
Travel empty	1.6 (0.1)	3.0 (0.3)	*
Total cycle	12.4 (1.8)	12.6 (1.1)	NS

[a] Standard deviation shown in parentheses. NS indicates means are not significantly different and * indicates means are significantly different, at the 0.05 level.

and conventional trucks were timed, on separate occasions, over constant haul distances of 170 and 190 m, respectively.

The cycle elements are listed in chronological order. After being loaded, a truck travelled to the spoil site where it stopped and backed in to dump its load. The trucks did not turn around during the hauling cycle; on the return trip they backed up to the excavator.

The time to load the larger 18.2 m^3 truck was 25% greater than the time needed for the conventional 12.4 m^3 truck, but as expected, their dump times were not significantly different. Travel loaded time was slightly greater for the conventional truck, and this was most likely attributable to its 20-m longer haul distance. However, on average, the conventional truck took almost twice as long to travel empty back to the excavator. This truck often lost traction on the return trip and sometimes took several attempts to reach the loading position. (On some trips, the box was raised to shift more weight onto the rear wheels in an attempt to improve traction.) Loss of traction usually occurred just before the loading position was reached, when the truck was backing onto the temporary ramp of rock created by the excavator. The modified HDX truck had no problem backing up the steep pitches.

Finally, the difference in total cycle time between the two trucks was not significantly different. If the difference in travel loaded times is attributable to the difference in haul distance, then the modified HDX was a more productive truck because of its larger payload and better traction. Its productivity (volume transported per unit of time) was approximately 50% greater than the conventional dump truck in this study.

Other observations

Working within an integrated forest operation provided some flexibility in assigning road crews and equipment to work sites and helped reduce non-productive time on this endhauling project. However, the influence of the larger operation also meant that roadbuilding activities were subject to the priorities of the harvesting phases. For example, the excavator operator was qualified to operate other types of logging equipment, and occasionally the endhauling operation was shut down if he was needed to run a machine that was essential to daily log production. (The operator had two years of road construction experience on the excavator at the time of the study, but had many years of experience on several types of logging equipment.) Also, the dump truck was not always available for endhauling at the optimum time. This slowed the endhauling operation because the excavator had to temporarily stockpile boulders on the outside edge of the road and smaller rock against the cutbank. Overall, the effect of the integrated operation was probably beneficial, outweighing the cost of disruptions to roadbuilding. If the study had been done at an isolated site, additional standby and shutdown time for the rockdrill and dump truck would have been expected. This in turn would have resulted in a substantial increase in equipment ownership and labour charges.

Use of the larger 45 000-kg excavator contradicts an established trend in B.C. of using smaller excavators in forest road construction. Depending on the region and site conditions, excavators in the 30 000 to 35 000-kg or 25 000 to 30 000-kg class are common. (At the Beaver Cove operation, most road construction is done with excavators in the 30 000 to 35 000-kg class—the 45 000-kg machine was the operation's oldest excavator.) In this project, the large machine's long reach was useful for scaling the high cutslopes, and its substantial power output enabled much of the rock to be ripped. However, greater tail swing radius, undercarriage width, and operating weight make it more difficult to minimize road width with this class of excavator. Other factors to consider when matching machine size to the job are the capital cost, hourly operating costs, and the speed at which the various excavating functions can be performed — factors that also usually favour the smaller late-model excavators.

The spoiled rock was subsequently retrieved and used for base course material on another section of Branch 27 beyond the endhaul study site. Although this practice did not affect the cost of the endhaul section, it likely reduced the overall cost of new construction on Branch 27 because a new quarry was not needed. Another benefit is that when the spoil material is thoroughly recovered, the spoil site area can be returned to productive forest land.

Conclusion and Implementation

This report is the second 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 147-m road section in this study were estimated at \$477.24/m and \$10.35/m^3 for lineal metres of road and excavated volume, respectively. Over a larger development area, 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 per kilometre can be achieved.

The study pointed to several factors that can contribute to the successful implementation of an endhauling project:

- **Coordinate equipment activities to minimize standby and downtime.** This is a challenge for supervisors and operators because there are usually fewer opportunities to separate machines and work them concurrently during an endhauling project. The problem is exacerbated when construction is confined to a single road heading. In the study, the construction site was part of an integrated forest operation with several logging and roadbuilding sites active at the same time. The construction supervisor took advantage of opportunities to minimize equipment standby and downtime by redirecting the rockdrill and dump truck to other work locations when they were not needed at the endhauling site.
- **Emphasize thorough engineering.** A high standard of forest engineering is needed to achieve an efficient operation. It is important to identify all potential spoil sites during the reconnaissance and road layout phases. The spoil sites must be incorporated into the road design. Any required agency approvals for sites should be obtained well in advance to avoid construction delays. In this study, the spoil site location was ideal. Haul distances were short, requiring only one truck.
- **Match equipment type to site conditions.** The study showed the benefit of using a locally modified HDX dump truck to haul spoil material. In this case, a firm road with a relatively even, favourable grade suited the use of rigid-frame dump

trucks. The HDX truck performed well. Its large-capacity body and good traction made it 50% more productive compared to the conventional rigid-frame truck also used during the study. The hourly cost for the HDX was estimated to be similar to conventional rigid-frame trucks, thus making it the more cost-effective alternative for this operation. The benefit of altering an operation's equipment complement must be weighed on a site-specific basis. For example, for small projects in isolated operations, the cost of transporting machinery to the site and the cost of parking existing equipment in favour of the alternative may be prohibitive.

- Consider alternative construction techniques to minimize endhaul volumes. Endhauling is a practice often used for building forest roads in steep terrain and 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. Innovative uses of spoil material and construction techniques that reduce the endhaul volume will help reduce costs. It may not always be necessary to build a full bench road and endhaul all 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, should also be considered. After this study was completed, the spoil material was retrieved and used for the base course on the same road, beyond the endhaul section. This helped to control the overall cost of the new road.
Adoption of alternative construction techniques should be done in conjunction with an assessment of the associated risks. This means assessing the landslide hazard and the potential consequences to resources downslope and downstream from the construction site.

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Appendix I

Hourly costs for road construction equipment [a]

	Excavator (45 000–50 000 kg)	Rockdrill (rubber-tired, hydraulic)	Dump truck [b] (modified 18 m^3)	Dump truck (conventional 12 m^3)	Crawler tractor (20 000–25 000 kg)
OWNERSHIP COSTS					
Purchase price (P) $	575 000	575 000	150 000	165 000	575 000
Ownership period (D) y	8	7	12	12	10
Scheduled hours per year (h)	1 200	1 200	1 200	1 200	1 200
Salvage value as % of P (s) %	30	30	30	30	30
Interest rate (Int) %	10.0	10.0	10.0	10.0	10.0
Insurance rate (Ins) %	2.5	2.5	2.5	2.5	2.5
Salvage value (S)=(P•s/100) $	172 500	172 500	45 000	49 500	172 500
Average investment (AVI)=((P+S)/2) $	373 750	373 750	97 500	107 250	373 750
Loss in resale value ((P-S)/D•h) $/h	41.93	47.92	7.29	8.02	33.54
Interest=((Int•AVI)/h) $/h	31.15	31.15	8.13	8.94	31.15
Insurance=((Ins•AVI)/h) $/h	7.78	7.78	2.03	2.23	7.78
Total ownership costs (OW) $/h	80.86	86.85	17.45	19.19	72.47
OPERATING AND REPAIR COSTS					
Fuel consumption (F) L/h	50	30	18	18	30
Fuel cost (fc) $/L	0.48	0.48	0.48	0.48	0.48
Lube and oil cost as % fuel cost (fp) %	10	10	10	10	10
Track & undercarriage life (hr)	4 800	-	-	-	6 000
Track & undercarriage replacement cost (Tr) $	43 000	-	-	-	35 000
Tire life (hr)	-	4 000	3 000	3 000	-
Tire replacement cost (Ti) $	-	2 800	500	500	-
Annual operating supply cost (Op) [c] $	5 000	9 000	2 000	2 000	4 000
Annual repair and maintenance cost (Rp) $	35 000	50 000	5 000	5 000	15 000
Wages (W) $/hr					
Machine operator base rate	24.12	23.46	21.99	21.99	22.40
Machine servicing allowance [d]	3.02	2.93	2.74	2.74	2.79
Blasting ticket allowance	-	0.20	-	-	-
Total machine operator rate	27.14	26.59	24.73	24.73	25.19
Driller's assistant	-	21.03	-	-	-
Wage benefit loading (WBL) %	40	40	40	40	40
Fuel cost (F•fc) $/h	24.00	14.40	8.64	8.64	14.40
Lube and oil cost ((fp/100)•(F•fc)) $/h	2.40	1.44	0.86	0.86	1.44
Track & undercarriage cost (Tr/h) $/h	8.96	-	-	-	5.83
Tire cost (Ti/h•no. tires) $/h	-	2.80	1.67	1.67	-
Operating supply cost (Op/h) $/h	4.17	7.50	1.67	1.67	3.33
Repair and maintenance cost (Rp/h) $/h	29.17	41.67	4.17	4.17	12.50
Labour cost (W•(1+WBL/100)) $/h	37.99	66.66	34.63	34.63	35.27
Total operating and repair costs (OP) $/h	106.68	134.46	51.63	51.63	72.78
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	187.54	221.31	69.08	70.82	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 were used.

[b] A used off-highway logging truck tractor retrofitted with a large semi-circular box. Purchase price estimated as the tractor salvage value plus the cost of modifications.

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

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