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Contents

Evaluating forest road construction techniques: Redding Creek case study

Abstract

FPInnovations studied a forest road construction operation in the southern interior of British Columbia in order to provide forest managers with current information about planning and costing. A limited comparison of an alternative construction technique in similar terrain was also conducted. This report presents the second in a series of case studies about evaluating forest road construction techniques in interior British Columbia.

Keywords:

Forest roads, Road construction, Cost analysis, Cost comparison, Harvesting, Time distribution, Productivity, Costs, Utilization, Interior British Columbia.

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Introduction

Forest road construction is typically divided into two distinct activities—harvesting the right-of-way and roadbed construction—each of which is composed of various phases. Typically, forest roads are built in stages. The interactions between harvesting the right-of-way and construction of the roadbed often lead to inefficiencies, reduced productivity, and increased overall cost. Therefore, many forest companies have identified road construction research as a priority and are interested in exploring alternative construction strategies. Little current information is available about the productivity and costs associated with forest road construction. To address this gap, FPInnovations initiated a series of case studies to evaluate common construction techniques. This report presents the results of the second of these studies, which we conducted in the fall of 2006 at the Redding Creek site of Tembec Industries' Cranbrook Division in the southern interior of British Columbia.

Objectives

The objectives of this study were to:

- Document selected right-of-way harvesting and roadbed construction techniques.
- Evaluate time distribution, machine productivities, and costs.
- Determine the interactions between road construction phases and the effects of these interactions on productivity and cost.
- Observe and compare alternative construction techniques.
- Recommend improvements to increase operational efficiency.

Study methods

All right-of-way harvesting and roadbed construction activities at the Redding Creek study area were performed from June to November 2006.

Shift-level data collection

All machines used to harvest the right-of-way and to construct the roadbed were equipped with MultiDAT electronic dataloggers. The dataloggers monitored machine functions (including electrical power), motion, and sources of mechanical and non-mechanical delays, and they recorded global positioning system (GPS) data. Information from the dataloggers was supplemented by daily shift reports that included descriptions of machine downtime and unforeseen conditions encountered during construction.

FPInnovations researchers downloaded data from the dataloggers, collected shift reports, observed the road construction process, and discussed the operation with the crews.

Post-construction field surveys

Post-construction field surveys were carried out with laser survey instruments and GPS technology. Tree diameters and heights were sampled along the road right-of-way and used to calculate average stem volume. Road cross-sections were sampled along the newly constructed road to calculate the average ground slope. This slope was determined for a transect extending from the top of the cutbank to the bottom of the fill slope.

Equipment time distribution

Total scheduled machine hours were summarized for each machine. Scheduled machine hours comprised productive machine hours, mechanical delays, and non-mechanical delays.

Productivities were determined by the length of completed road (m) and by the volume (m^3) of stems processed. Wood volume, as determined at the weigh scale, was used to calculate productivity. Machine productivity was calculated on a weighted average if more than one machine was included in the phase.

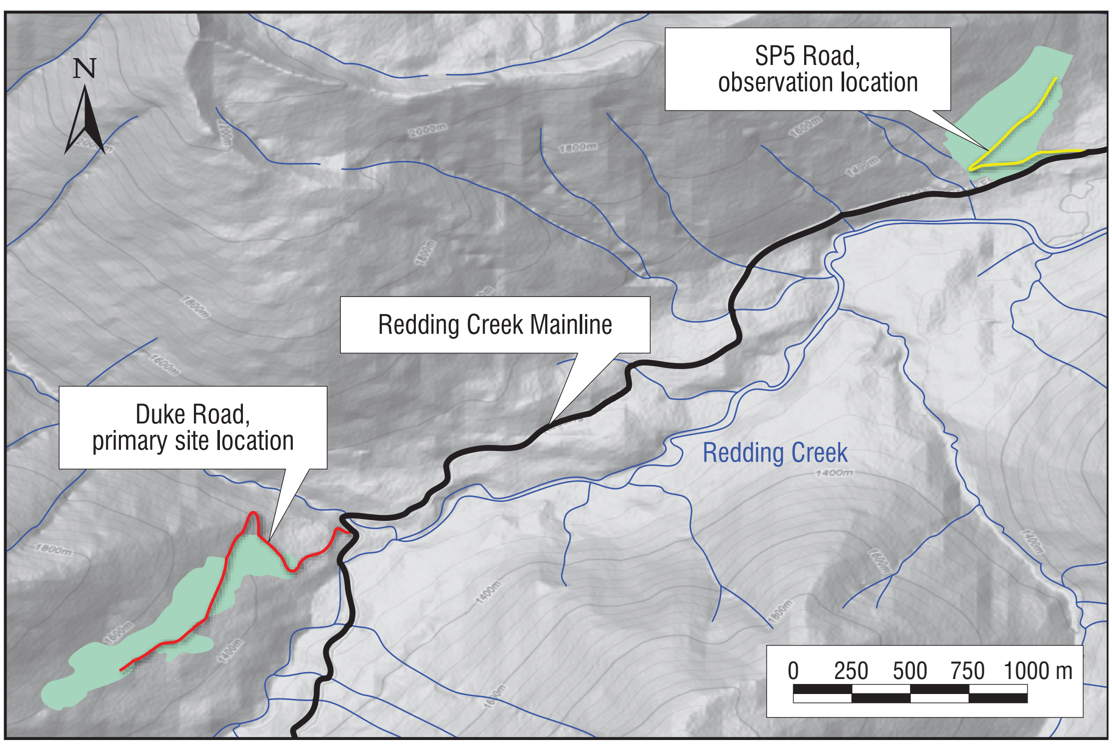


Figure 1. Road network, and the primary (Duke Road) and observation (SP5 Road) study locations.

An hourly rate for each machine was calculated using FPInnovations' standard costing methodology. Costs for each machine used in the study were calculated based on data for machines in comparable weight classes. Shift-level time and production information were applied to the hourly machine rates to determine the unit costs.

Investigation of a variation in the construction technique

Before the crew and equipment arrived at the primary study location, FPInnovations had an opportunity to study a variation of the construction technique at a nearby observation location. We compiled this site's shift-level information from a combination of timesheet records and MultiDAT data. After construction was complete, a field survey was conducted to collect road attribute information, i.e., total length, slope, and other characteristics. The survey results confirmed that field conditions for the primary and secondary study locations were similar. Productivity comparisons between the two locations were made on the basis of scheduled machine hours.

Study site

Redding Creek is 75 km northwest of Cranbrook in the southern interior of British Columbia. The primary study location (Duke Road) and the observation location (SP5 Road) are about 4.7 km apart along the Redding Creek Mainline. Figure 1 illustrates the associated harvesting units and road network. Figure 2 shows a typical length of constructed road at the study site.

Duke Road was built on slopes that ranged from 0 to 61% with an overall average of 31% over the entire length.

Lodgepole pine was the dominant tree species, with western larch, Douglas-fir, trembling aspen, white spruce, western red cedar, and western hemlock also present. The site was in the early stages of a mountain pine beetle infestation. The average volume was 0.46 m^3/stem.

The soil material conditions consisted of a shallow overburden overtopping deep glacial tills. The soil texture was a silty loam above schist bedrock. The parent material at this site was comprised of a rippable schist

Figure 2. A typical length of road constructed during the study.

throughout the site. The road was not capped with imported materials because the available material was suitable for maintaining the finished grade. The soil conditions allowed the use of standard excavation and rock-ripping practices. To complete the roadbed construction, approximately 10% (229 m) of the new road required ripping. Multiple ripping shanks mounted on the crawler-tractor and ripping teeth on the excavator's bucket were used for this task.

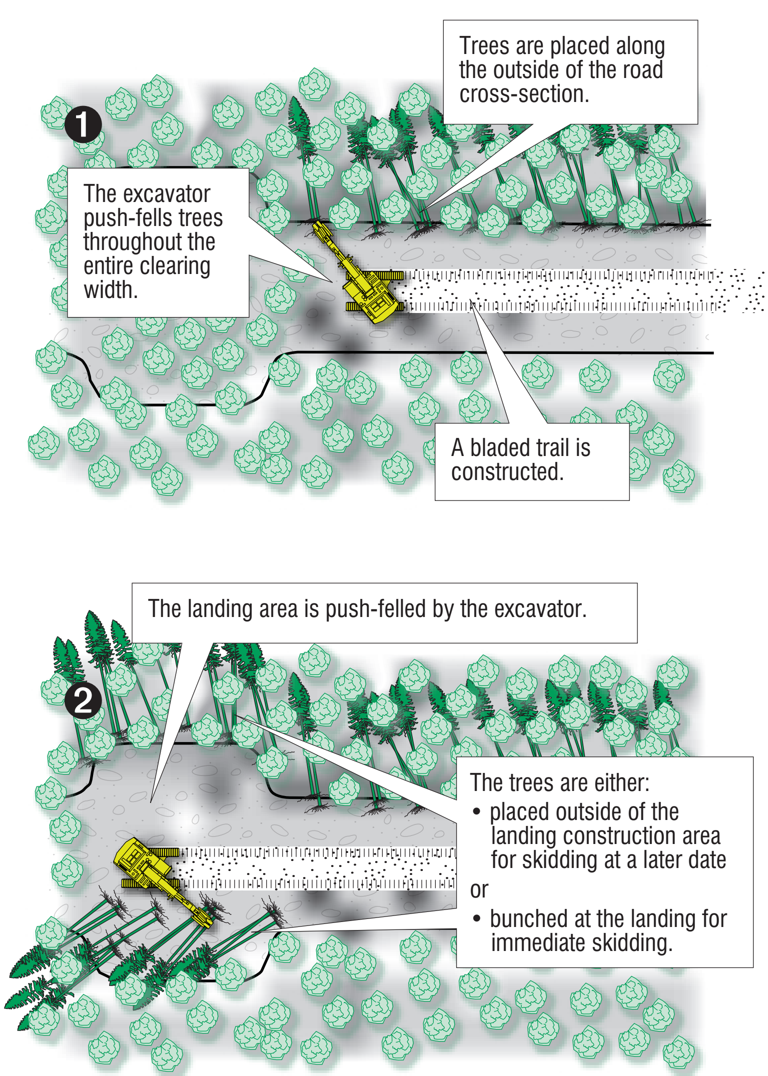
The roads at both locations were considered "in-block roads" with the potential for future extension to develop additional timber. Features included: ditches, culverts, a roadbed free of organic material, and landings to accommodate the harvesting operation.

Road construction techniques

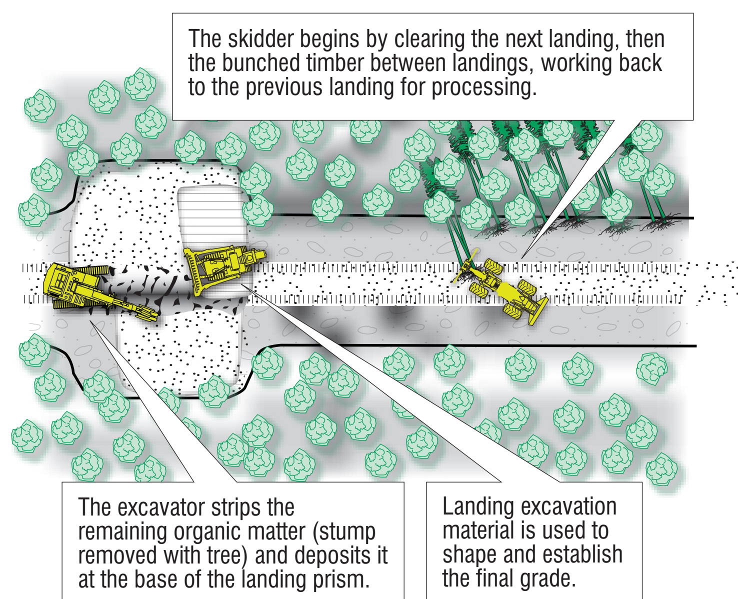
At the Duke Road location, harvesting of the right-of-way and roadbed construction were carried out using a fully mechanized operation (i.e., no manual felling was performed to clear the right-of-way).

- An excavator push-felled trees and built a pilot trail along the entire road right-of-way, placing the trees outside the right-of-way construction area or bunching them in a location where they would be accessible for immediate skidding.
- A grapple skidder extracted the felled trees to landings.

Trail-construction and tree-felling phase



Landing construction and skidding phases



Harvesting of the right-of-way timber was fully mechanized; here a skidder and processor are working at a landing.

- Stems were mechanically processed and decked at the landings prior to road transportation.
- An excavator grubbed and stripped the overburden, and a crawler-tractor shaped the landings and the final roadbed cross-section.

Harvesting of the right-of-way comprised three phases: tree felling phase (including pilot trail construction), skidding, and processing at a landing. The roadbed construction phases comprised construction of the roadbed and landings.

Figure 3 illustrates the work phases and the overall interaction between the right-of-way harvesting and the road construction activities at the Duke Road location of the Redding Creek site.

The entire harvesting phase involved the use of the push-felling technique, performed by an excavator. In this stand, push-felling offered many advantages from both productivity and safety perspectives. The shallow root network of the pine trees and the small stem size allowed for the push felling of the stems, so a dedicated harvester such as a feller-buncher was not needed; this had the additional advantage of removing the stumps along with the trees, eliminating the need for stump-removal during roadbed construction. Push-felling eliminates the exposure of manual fallers to the hazards of the snags and dead limbs that are often found in

Processing and roadbed construction phases

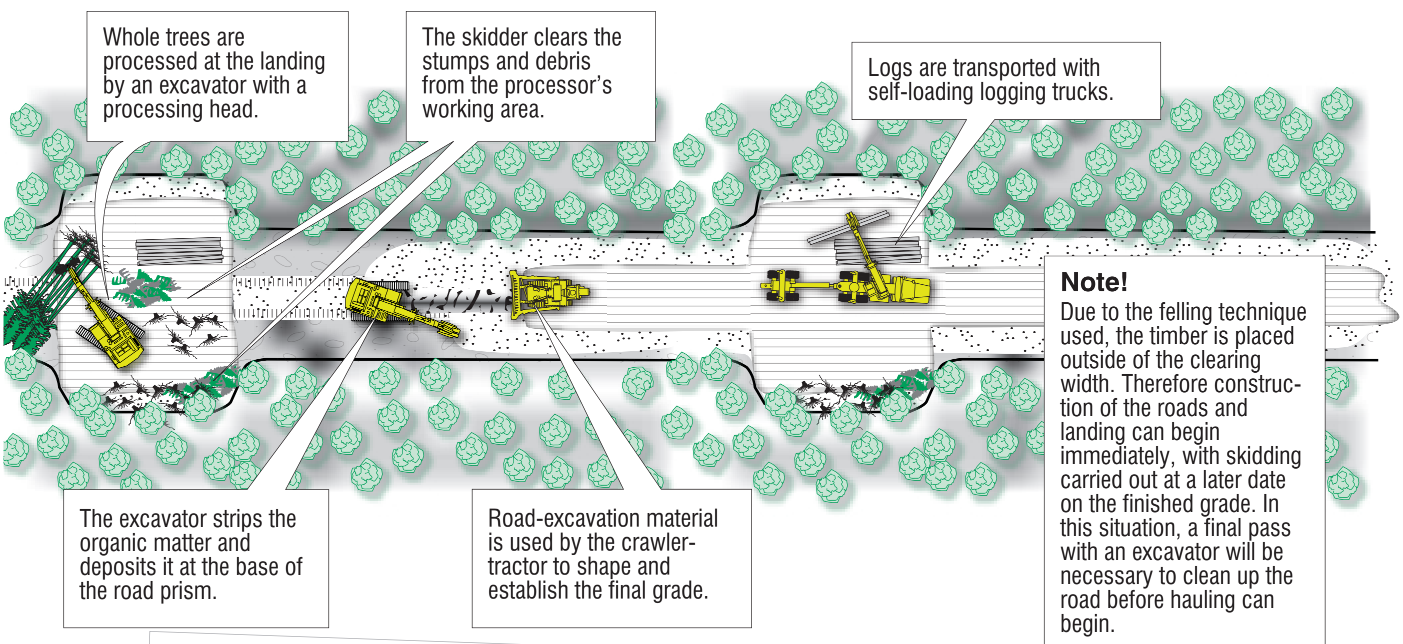


Figure 3. The work phases of the harvesting and road construction activities and how they interact.

An excavator and a crawler-tractor were used for roadbed and landing construction.

Figure 4. Skidding on the finished road grade was one variation in the construction technique used at the SP5 Road location.

beetle-infested stands, and it eliminates their exposure to the risks associated with creating an initial opening from which to begin the felling. In some instances, the brushing of felled treed on adjacent standing trees can create additional hazards which would potentially require hazard assessment of the remaining trees in areas where follow-up harvesting is not planned. In some jurisdictions, 40-m-wide right-of-ways have been implemented in mountain pine beetle–infested areas to reduce hazards adjacent to roadways.

The push-felling technique also presented some disadvantages. When the whole tree is skidded from the right-of-way and processed at designated landings, stumps accumulate at the landing. To solve this problem, stumps and roots are piled with the slash for burning after the processing is complete. Although piling increases the skidder and processor costs, it probably decreases road construction costs by a roughly equal amount by eliminating the need to de-stump during roadbed construction. This approach also eliminates the safety hazards created by roadside debris and improves the quality of the roadbed construction by removing the roots from the fill materials.

Differences between the two techniques

FPInnovations observed the following differences between the technique used at the primary study location (Duke Road) and the variation of the technique employed at the observation location (SP5 Road):

- At the SP5 Road location, the trail-construction/felling phase, and the roadbed and landing construction phases, were completed two months before the skidding and processing phases.
- At the Duke Road location, the skidding was conducted directly from the pilot trail created by the excavator. Because roadbed construction was completed at the SP5 Road location before skidding began, the skidding/processing phases were conducted on a finished road grade.
- Prior to skidding being conducted at the SP5 Road location, whole trees were pulled down the cutslope and bunched by the excavator that was used in roadbed construction (Figure 4).
- After the harvesting activities were complete at the SP5 Road location, an excavator conducted maintenance work to prepare the road for future activities.

Results and discussion

Time distribution

Table 1 summarizes the total scheduled machine hours in each phase. Roughly 75% of the total time was spent on roadbed construction activities, and 25% was spent on the harvesting activities.

The overall machine utilization rate during this study was 76%, which is typical for a fully mechanized operation. The bulk of the mechanical delays were attributed

Table 1. Time distribution, productivities, and costs: Duke Road location

Time distribution	Roadbed and landing construction [a]	Trail construction and felling [a]	Skidding	Processing
Productive machine hours (PMH)	390.4	21.6	51.8	54.5
Mechanical delays (MD, h)	47.1	1.1	4.6	9.0
Non-mechanical delays (NMD, h)	77.9	2.2	14.0	4.1
Scheduled machine hours (SMH)	515.4	24.9	70.4	67.6
Availability ([SMH-MD]/SMH) (%)	91	96	93	87
Utilization (PMH/SMH) (%)	76	87	74	81
Productivity				
m^3 of right-of-way wood/PMH	8.6 [b]	76.8 [b]	16.0	15.2
Road length (lineal m/PMH)	22.8 [b]	204.0 [b]	42.6	40.5
m^3 of right-of-way wood/SMH	6.0 [b]	66.6 [b]	11.8	12.3
Road length (lineal m/SMH)	16.0 [b]	176.9 [b]	31.3	32.6
Costs				
Machine cost ($/h)	808.86 [c]	359.44 [d]	122.25	171.83
Unit cost ($/$m^3$ of right-of-way wood)	101.10	5.40	9.20	12.50
Unit cost ($/lineal m of road)	38.00	2.00	3.50	4.70

[a] Time distribution is total of multiple machines combined, i.e., excavators, crawler-tractors, rock truck, and grader.
[b] Productivity is the weighted average of both crawler-tractor/excavator (road) and excavator/excavator (trailing/felling).
[c] Crawler-tractor = $216.51/h. Excavator = $179.72/h + second machine at same rate. Rock truck = $124.77/h. Grader = $108.14/h.
[d] Excavator = $179.72/h + second machine at same rate.

to major breakdowns of the excavator used for roadbed construction. During this project, several different workers operated the crawler-tractor. Therefore, delays were incurred while each new worker became oriented with the project, thus contributing to increased non-mechanical delays (i.e., planning time) for this machine.

Productivity

At the Duke Road location, 2204 lineal metres of a 6.1-m-wide road (running surface) were constructed and 829 m^3 of wood were extracted from the 20-m-wide right-of-way, representing approximately 380 m^3/km. When multiple machines worked together within a phase, the time attributed to the principal machine was used to calculate productivity for that phase.

The productivities for the roadbed construction phase, trail construction/felling phase, and skidding phase varied widely, at 16.0, 176.9, and 31.3 m/SMH, respectively (Table 1). This suggests that these phases were operating independently—an observation that we confirmed in the field. Phase productivities for skidding and processing were similar because of the link between these phases; that is, the productivity of one phase depended on that of the other phase.

Costs

For the Duke Road location the unit cost for roadbed and landing construction totaled \$101.10/m^3, or \$38/lineal m. The unit cost for the right-of-way harvesting activities (trail construction/felling, skidding, and processing) totaled \$27.10/m^3, or \$10.20/lineal m.

Table 1 indicates that 79% of the project's cost was attributed to roadbed construction activities. This illustrates the importance of roadbed construction activities in determining overall road construction costs. Ditch construction and culvert installation are included in these costs.

Table 2. Time distribution, productivities, and costs: SP5 Road location

Time distribution	Roadbed and landing construction	Trail construction and felling	Skidding	Processing
Scheduled machine hours (SMH)	189.0	25.0	23.5	20.3
Productivity				
m^3 /SMH	6.8	17.1	18.2	21
lineal m/SMH	21.8	54.9	58.4	67.5
Unit cost				
\$/m^3	79.18	10.52	6.16	8.10
\$/lineal m	24.65	3.27	1.92	2.52

Supervision, planning/engineering, and costs to mobilize equipment to and from the site are not included. Timber values, terrain features, soil material conditions, and the construction technique all influence these costs.

Observations of the technique used at the SP5 Road location

Our study showed that productivity was greater at the SP5 Road location than at the Duke Road location. Thus operational costs were lower here than at the Duke Road location (see Table 2).

Productivity at the SP5 Road location was higher in all phases except the trail-construction/felling phase. However, FPInnovations did not observe this phase directly; because some of the work was completed by road construction crew, some costs may have been incorporated with roadbed and landing construction. This explains the lower productivity in the trail-construction/felling phase at the SP5 Road location compared to that at Duke Road. The largest increase in productivity at the SP5 Road location occurred in the skidding and processing phases, which resulted in an overall cost reduction in the harvesting activity at the observation location of $2.32/m³ (Figure 5). This can be largely attributed to skidding on the finished grade and the lack of any interference from road construction equipment at the SP5 Road location.

A complete separation of the skidding and processing phases occurred at the SP5 Road location. In contrast, interactions between the road construction and harvesting activities occurred for 7 of the 25 days at the Duke Road location. During this time, the road crew constructed the landings, i.e., just prior to being used for harvesting activities. After harvesting activities were complete, the road crew finished constructing the road between landings. The increased productivity at the SP5 Road location decreased the overall cost of right-of-way harvesting and construction by $15.84/lineal m. Also, due to the trailing/felling phase being conducted by the road crew, only minimal delays in roadbed construction were incurred, avoiding any interaction or standby time with the skidding and processing phases.

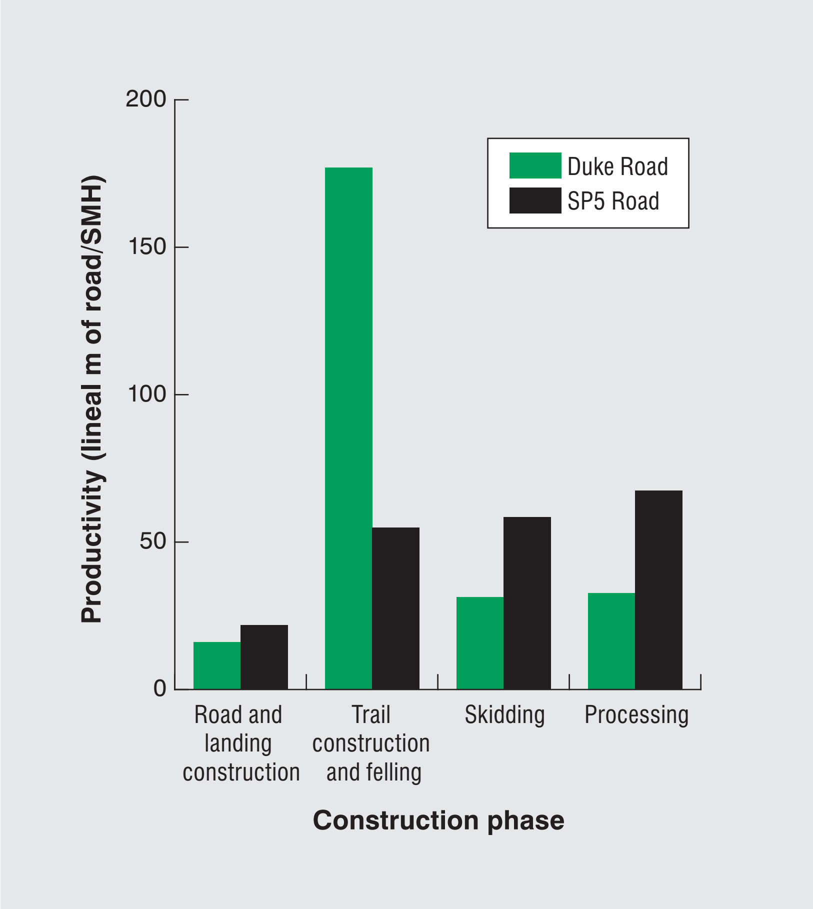


Figure 5. Comparison of productivity at the Duke Road and SP5 Road locations.

Variations in the construction technique

Within each construction technique, variations were occasionally required based on logistics and site conditions. The techniques that were unique to this project included the skidding of push-felled whole trees and skidding on a finished roadbed (at the SP5 location).

Skidding of push-felled whole trees offered a potential decrease in roadbed construction costs (because no de-stumping was required during roadbed construction and roots were removed from the fill), the ability to defer skidding and processing until after roadbed construction was complete, and the potential to recover all biomass from the site. The disadvantages are that during skidding the roots occasionally tangle in the tires of the grapple skidder, and the presence of the roots, stumps, and branches reduced the potential load size per turn (to between 3 and 7 trees, versus 10 to 14 trees). However, some compensation was offered by faster travel times on the finished road and the fact that the excavator bunched the trees to facilitate load assembly by the skidder. Having to transport the extra biomass could also be seen as a disadvantage; no biomass harvesting program was in place at the time of the study.

Skidding on the finished road surface offered several advantages: faster skidder travel, reduced turn durations, some delimbing of the trees during skidding, immediate extraction (no grader was required), compaction of the green road surface by skidder traffic (thereby strengthening the roadbed), and scattering of debris along the cutslopes (which facilitated vegetation establishment and erosion control). Disadvantages included the risk of damage to the road under wet conditions; scattering of debris in ditches, which subsequently had to be removed; increased risk of embedding rocks in the logs; and increased dirt on the logs (which would reduce the processor's saw chain life).

During skidding and processing, the extraction distance was modified by the operator based on the processor's productivity. The operator generally tried to accumulate a small pile of stems so that the processor would not run out of wood.

Some equipment changes could improve the efficiency and reduce the overall costs of the roadbed construction operation. A compactor could be used to increase soil strength and bearing capacity and thereby reduce settling of the roadbed (Légère 2002). Compaction would also reduce the volume of gravel required for surfacing the road.

Conclusions and implementation

The road construction technique used at the primary study location and the observation location was based on the harvesting and roadbed construction activities being functionally independent. As a result, the productivities differed among the phases, ranging from 16.0 to 176.9 lineal m/SMH. The total unit cost for the project's primary location, including harvesting the right-of-way and roadbed construction, was $48.20/ lineal m of road.

There were two important points to note about these techniques. First, the fully mechanized aspects of this operation increased individual machine utilization rates while decreasing workers' exposure to safety hazards. Second, the harvesting and roadbed construction activities operated independently of each other, which is in contrast to a previous case study near Radium, B.C. (Matthewson 2008). These points had several effects on the operation:

- Separation of and independent functioning of the phases allowed for efficient utilization of machines with different productivity levels. This allowed managers to choose machines with greater differences in productivity than would be possible in an integrated operation. This reduced inefficient interaction between resources and allowed for greater operational flexibility.
- Because of this independence, roadbed construction moved forward continually without any logistical delays related to harvesting of the right-of-way (e.g., delays related to the availability and operational capability of a feller-buncher). The excavator's use of push-felling in mountain pine beetle-killed and pine-dominant stands during construction of the right-of-way increased productivity, worker safety, and roadbed quality. Push-felling also eliminated the need for a high-cost feller-buncher in right-of-way situations and is often a liability in certain seasonal circumstances (fire season). Forest biomass demand is increasing; utilization of the stumps resulting from the whole-tree harvesting technique used in this right-of-way construction process should be maximized.
- Worker safety in operations such as this one increases dramatically compared to systems in which workers are more exposed (e.g., fellers equipped with chainsaws). Nevertheless, hazards that may result from push-felling would need to be assessed before commencing subsequent forestry activities.
- Planning the operation such that the various phases could function independently increased overall machine utilization by reducing waiting time. Where independence was not possible, good communication and planning between crew leaders and company staff were critical to the project's success. Any delay in the decision-making process caused a ripple effect within the operation, reducing overall machine utilization rates. The machines and crew were selected to match the site conditions and to strike a balance between the equipment's capital cost and its versatility and productivity. Overall, the high level of operator skill and teamwork resulted in good coordination of road construction activities.

The technique used at the SP5 location, which involved conducting skidding operations on the finished road grade, led to a decrease in overall costs. When conditions are favourable, significant cost savings can be achieved by using operational techniques in which the roadbed receives compaction exposure, or by using road compacting equipment. This will assist in setting up the road for harvesting activities and increase road accessibility in the fringe or wet seasons.

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