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Forest Road Construction Techniques: Evaluating Right-of-Way Logging and Roadbed Construction Activities

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ABSTRACT

In British Columbia's Interior region, the conventional forest road construction process is comprised of several phases. Typically the roads are built in stages and conflicts between right-of-way logging activity and road bed construction often cause inefficiencies and poor equipment utilization. To provide better information for planning and costing road building operations, FERIC initiated a series of case studies to evaluate construction techniques. This paper describes the construction techniques used at two sites in southeastern B.C. Productivity and cost results for the two projects are presented.

KEYWORDS

Forest roads, construction techniques, right-of-way logging, time study, machine productivity, costs, utilization, Interior British Columbia

INTRODUCTION

In British Columbia's Interior region, many variations in the forest road construction process exist, but typically the roads are built in stages. Road building is comprised of several phases including pilot trail construction, right-of-way felling, right-of-way skidding, log processing, log loading and hauling, and road and landing construction. The equipment used for each phase continually switches position along the right-of-way. The interaction between road construction and right-of-way logging activities causes inefficiencies, reduces equipment productivity, and increases the overall cost of the operation. As a result, many forest companies in the Interior would like to investigate alternative construction strategies. Currently, there is little information available on the productivity and costs of alternatives, so FERIC initiated a series of case studies to:

- Document selected road building techniques.
- Evaluate equipment time distribution levels, productivities and costs by phase.
- Determine how the interaction between road building phases affects productivity and cost.
- Recommend improvements to increase operational efficiency.

Field work for two case studies in southeastern British Columbia was completed in 2006. This paper introduces the study series and presents some preliminary results. It describes the construction technique used at each site and presents the productivity and cost information for road building operations.

STUDY METHODS

A case study approach was used to evaluate road construction productivity and costs for selected construction techniques. FERIC conducted two types of production studies, known as shift-level and detailed-timing studies. The two methods were complementary and were carried out concurrently. Major divisions in productive time were captured in the shift-level data. However, to distinguish between the finer points of some phases detailed-timing methods were also used. This paper focuses on the results from the shift-level studies.

Shift-level study methods

All machines used for right-of-way logging and road construction were equipped with MultiDAT electronic dataloggers to continuously monitor machine function. MultiDATs have four channels for electronic inputs, a channel to record machine vibration, and Global Positioning System tracking capability. The MultiDATs were installed in the machine cabs and were accessible to the operators. The dataloggers were programmed to accept operator inputs identifying machine activity and sources of delays. The MultiDAT units accumulated shift-level information about productive time, and mechanical and non-mechanical delays for each piece of equipment.

The MultiDAT units were programmed to collect global positioning information for each machine at specified time intervals. The GPS information was used to investigate equipment productivities for selected zones within the study sites. The time information from the dataloggers was supplemented with daily shift reports. The shift reports were used to gather additional information about equipment function and the road building process that would not be recorded by the MultiDATs alone. For example, descriptions of equipment downtime or unforeseen conditions encountered during construction were noted on the forms.

FERIC researchers visited the site regularly to download data from the MultiDATs, collect shift reports, observe the construction process, and discuss the operation with the crews. Digital photographs and video were also taken during these site visits to further document the road building system.

Post construction field survey

Post construction field surveys were conducted at each site. Information about timber type, ground slope and construction material was collected. Laser survey instrumentation and Global Positioning System (GPS) technology were used in the field surveys. Timber diameters and heights were sampled systematically along the road right-of-way and used to calculate average stem volumes at each site. Road cross-sections were sampled systematically along the newly constructed road and an average value for ground slope was calculated. Ground slope was determined for a transect spanning the top of the cut bank to the bottom of the fill slope.

Equipment time distribution, productivity and costs

Total scheduled time, known as scheduled machine hours (SMH), was summarized for each piece of equipment used in the project. Scheduled machine hours are the sum of productive machine hours (PMH), non-mechanical delays (NMD), and mechanical delays (MD). The following formulas were used to calculate machine utilization and availability:

Machine utilization $= \frac{PMH}{SMH} * 100$ Machine availability $= \frac{(SMH - MD)}{SMH} * 100$

Road construction production was measured according to lineal-metres of completed road. For the right-of-way logging phases, the volume (m^3) of timber processed was also measured. Phase productivities were calculated by dividing the measures of production by the time spent on right-of-way logging and subgrade construction.

Hourly equipment rates, comprised of ownership and operating costs, were developed by FERIC for each machine. The rates were generic rates applicable to the makes of machines used in the study as well as to other makes of the same type and weight class. Shift-level time and production information was applied to the hourly equipment rates to determine the unit costs for the project. The scheduled machine hours were segregated into three categories for the purposes of assigning costs to the activities within each project (see Table 1). Unit costs, in terms of $/lineal-metre of road constructed and $\$/m^3$ of right-of-way timber extracted, are presented for all phases of the project.

Table 1: Assignment of hourly machine costs to scheduled time.

Scheduled Machine Hours	Assignment of Hourly Equipment Costs
Productive Machine Hours Machine in motion Short delays (<15 min.) Mechanical Delays Service and Warm up Non-Mechanical Delays Planning, Move and Standby	Full ownership and operating costs
Mechanical Delays Repairs Non-Mechanical Delays Machine available/No Operator – Operator off site or operating another machine	Ownership costs only
Non-Mechanical Delays Machine available/Operator conducting manual duties – Falling, landing bucking snag falling etc.	Ownership and labour costs

STUDY SITE DESCRIPTIONS

Both study sites were located on public land. The first road construction study was the Ravenshead project, located 50 km east of Radium Hot Springs in the Interior of British Columbia (Figure 1). The second study was the Duke Road project, located 75 km northwest of Cranbrook, B.C.

Figure 1: Study site locations.

Hereafter, the Ravenshead and Duke Road projects will be referred to as Site 1 and Site 2, respectively. The following is a brief summary by site of the timber type, ground slope and construction material encountered at the two sites.

Site 1

Timber type. Within the right-of-way area Lodgepole pine was the dominant tree species with components of Douglas-fir, White spruce, Western Red Cedar and Western larch. The site was in the early stages of mountain pine beetle infestation. Average whole tree volume was 0.52 m^3/stem.

Ground slope. Slope conditions varied from flat to undulating. On average, roads were built on slopes of 18 %.

Construction material. The material conditions consisted of a shallow organic overburden layer overtopping deep tills. Soil texture was predominately a silty clay loam overtopping limestone bedrock. The parent material at this site contained several small sections of highly fractured limestone rock with the occasional hard limestone deposit.

Site 2

Timber type. Within the right-of-way area Lodgepole pine was the dominant tree species with components of Western larch, Douglas-fir, Trembling aspen, White spruce, Western Red Cedar and. Western hemlock. The site was in the early stages of mountain pine beetle infestation. Average whole tree volume was 0.46 m^3/stem.

Ground slope. Slope conditions varied from flat to steep terrain. On average, roads were built on slopes of 31%.

Construction material. The material conditions consisted of a shallow organic overburden layer overtopping deep tills. Soil texture was predominately a silty loams over a schist parent material. A rippable schist rock-type was scattered across the site.

The arrangement of the cutting units and their associated road systems are illustrated in Figures 2 and 3. Figures 4 and 5 provide examples of typical roads built and conditions at the two sites.

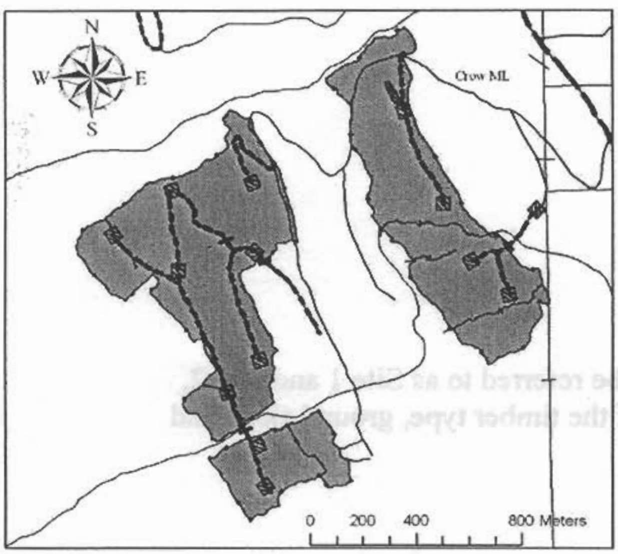

Figure 2: Road network at Site 1

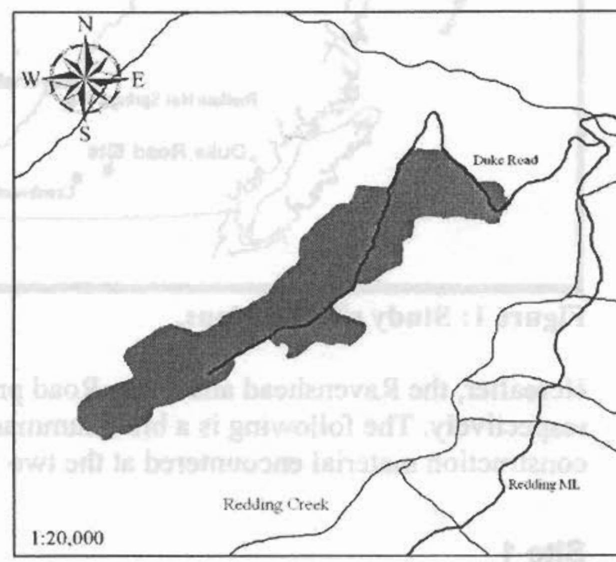

Figure 3: Road network at Site 2

Figure 4: New road at Site 1

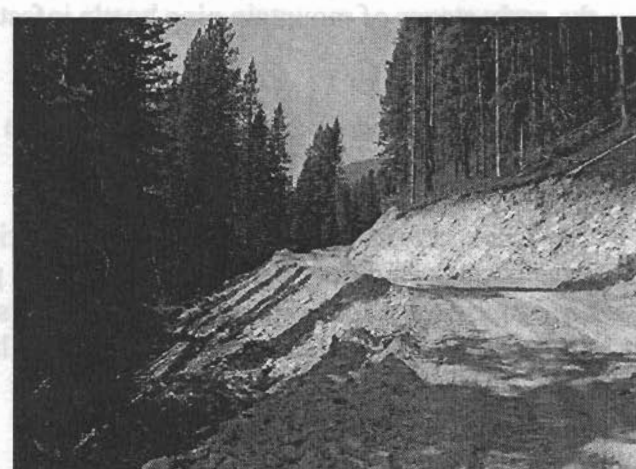

Figure 5: New road at Site 2

DESCRIPTION OF CONSTRUCTION TECHNIQUES

At each site, right-of-way logging and construction activities were carried out by a multi-phase contractor working for a major forest company. Site 1 had a combination of mechanized and manual operations while Site 2 was entirely mechanized. The crew complement for both projects consisted of five operators; each had a principal job function but in some cases an operator was skilled in more than one job function.

In this paper, right-of-way logging and construction activities are broken down into phases. For example, right-of-way logging is comprised of the trailing/falling, skidding, processing, loading, and hauling phases. Construction of the roadbed is comprised of the road and landing construction phases. Table 2 lists the type of equipment used on the projects by phase. The overall process is illustrated in Figure 6. A description of how these phases were conducted at each site follows.

Table 2: Equipment used by project and phase

Phase	Equipment used	
	Ravenshead	Redding Creek
Trailing/falling	Caterpillar 320C LU (22 000 kg) excavator	Caterpillar 330BL (35 000 kg) excavator OR Caterpillar RB300B (35 000 kg) excavator
Skidding	Caterpillar 518 cable skidders (90 kW)	Caterpillar 535B Grapple skidder (150kW)
Processing	Caterpillar 315 (16 000 kg) excavator	John Deere 230 LC (22 300 kg) excavator under carriage with Waratah HTH 20T felling head attachment
Loading and hauling	Western Star self-loading tridem drive with tridem pole trailer	Kenworth self-loading tridem drive with tridem pole trailer with CTI (Central Tire Inflation)
Road and landing construction	John Deere 3554 (39 000 kg) excavator Caterpillar D7R XR (26 000 kg) bulldozer	Caterpillar 330BL (35 100 kg) excavator Caterpillar D9H (42 600 kg) bulldozer

Site 1

Trailing/falling phase. A 22 000 kg excavator initiated pilot trail construction. The machine push-felled the trees in its path and constructed a narrow, 3-m-wide, stump-free skid trail within the lower half of the clearing width. This machine worked closely with a hand faller, and in some cases the operator had dual responsibilities as operator and faller. The faller's job was to manually fell the upper half of the clearing width and to cut off stumps from the push-felled timber placed along the trail.

Skidding phase. The skidding phase was completed using one, and sometimes two, 90 kW cable skidders. Tree-length stems were skidded along the newly constructed trail to the nearest finished landing for processing.

Processing phase. The processing phase was completed with a combination of manual and mechanized methods. The landing operator manually bucked and delimbed stems to their required specifications and also used a 16 000 kg excavator to pile the stems and debris.

Loading and hauling phase. Logs were transported with self-loading tridem drive with tridem pole-trailer logging trucks. This phase was carried out concurrently with all right-of-way logging activities.

Road and landing construction phases. These phases were completed using a 39 000 kg excavator in conjunction with a 26 000 kg crawler tractor. In both the road and landing construction phases, the excavator pioneered ahead near the road centerline, but above the previously constructed pilot trail. Stumps and debris were placed on the outer edge of the subgrade fill. While moving forward, the excavator placed a windrow of material for the bulldozer to spread along the road centerline. The bulldozer shaped the material and established the finished grade level. The majority of the limestone rock was fractured and rippable with an excavator or crawler tractor. There were also some sections of very hard deposits that could not be ripped and these sections were avoided by the road construction crew.

Site 2

Trailing/falling phase. The trailing/falling phase was initiated by a 35 000 kg excavator. The excavator push-felled the trees in its path and concurrently constructed a narrow, 3-m-wide, stump-free skid trail within the lower half of the clearing width. The entire right-of-way width was push-felled by the excavator into the adjacent timber. The stems complete with stumps were later retrieved and presented on the trail or finished road for subsequent skidding.

Skidding phase. A single 150 kW grapple skidder was used. The skidder dragged whole tree stems along a trail, or the finished road, to the nearest landing for processing.

Processing phase. Whole trees were processed at landings using a 22 000 kg excavator equipped with a feller processor attachment. Stumps and other debris, after some handling by the processor, were cleared from the working area by a skidder.

Loading and hauling phase. Logs were transported with self-loading tridem drive with tridem pole-trailer logging trucks. This phase was carried out concurrently with all right-of-way logging activities.

Road and landing construction phases. A 35 000 kg excavator was teamed with a large 42 600 kg crawler tractor to construct roads and landings. The process of excavating and shaping the roadbed was similar to the process implemented at Site 1. A rippable schist rock-type, encountered intermittently at Site 2, was typically ripped by the excavator or crawler tractor.

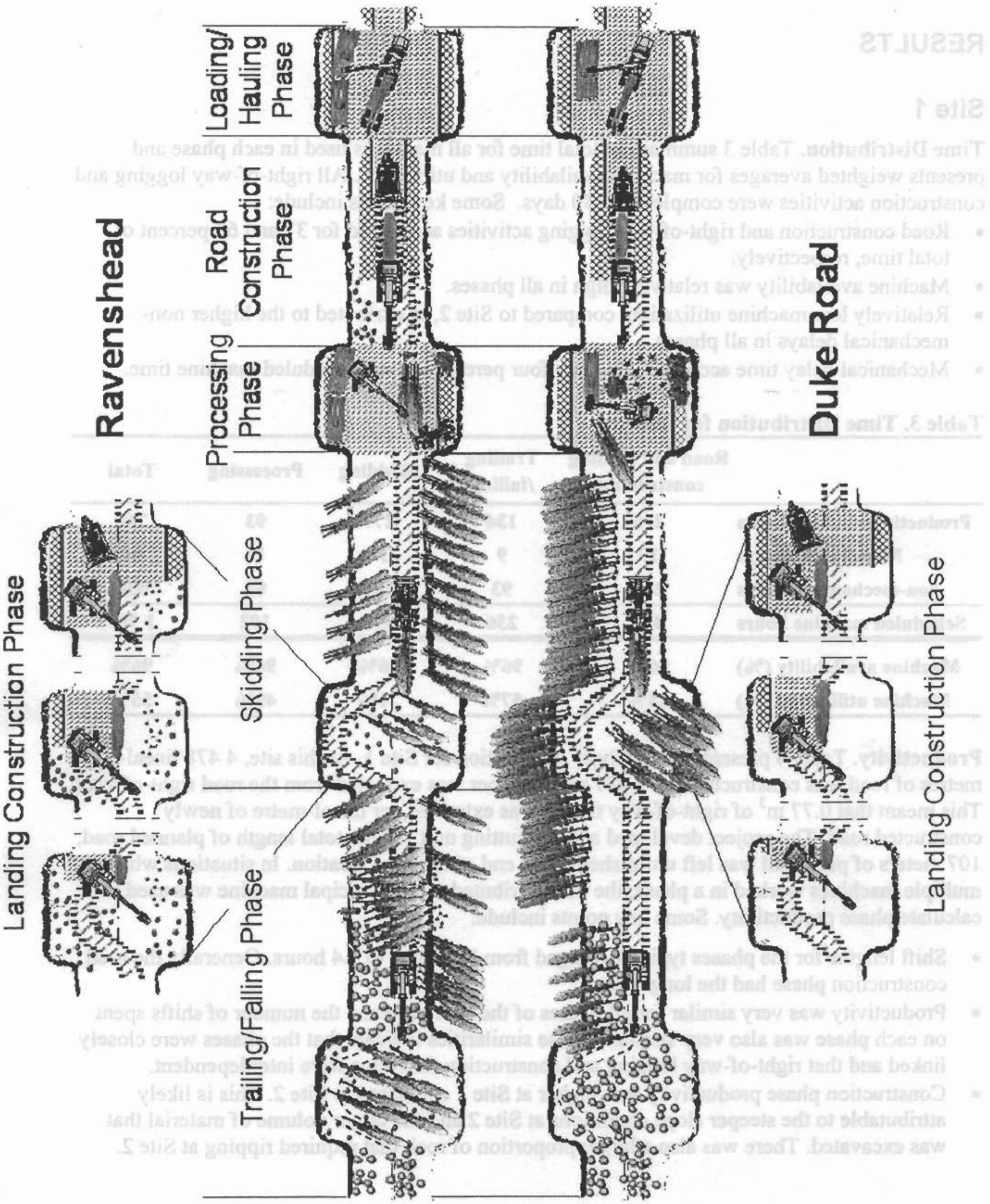

Figure 6: Road construction techniques

RESULTS

Site 1

Time Distribution. Table 3 summarizes total time for all machines used in each phase and presents weighted averages for machine availability and utilization. All right-of-way logging and construction activities were completed in 30 days. Some key points include:

- Road construction and right-of-way logging activities accounted for 37 and 63 percent of total time, respectively.
- Machine availability was relatively high in all phases.
- Relatively low machine utilization, compared to Site 2, is attributed to the higher non-mechanical delays in all phases.
- Mechanical delay time accounted for only four percent of total scheduled machine time.

Table 3. Time Distribution for Site 1.

	Road and landing construction	Trailing /falling	Skidding	Processing	Total
Productive machine hours	215	134	277	93	719
Mechanical delays	19	9	14	11	53
Non-mechanical delays	252	93	101	88	534
Scheduled machine hours	485	236	392	192	1 305
Machine availability (%)	96%	96%	96%	94%	96%
Machine utilization (%)	44%	57%	71%	49%	55%

Productivity. Table 4 presents productivity information for Site 1. At this site, 4 478 lineal-metres of road was constructed and 3 487 m^3 of timber was extracted from the road right-of-way. This meant that 0.77 m^3 of right-of-way timber was extracted per lineal-metre of newly constructed road. The project developed a 98 ha cutting unit. Of the total length of planned road, 107 meters of pilot trail was left unfinished at the end of the road location. In situations where multiple machines worked in a phase, the time attributed to the principal machine was used to calculate phase productivity. Some key points include:

- Shift lengths for the phases typically ranged from 7.4 hours to 9.4 hours. Generally the road construction phase had the longer days.
- Productivity was very similar for all phases of the operation and the number of shifts spent on each phase was also very similar. These similarities indicate that the phases were closely linked and that right-of-way logging and construction functions were interdependent.
- Construction phase productivity was higher at Site 1 compared to Site 2. This is likely attributable to the steeper slope conditions at Site 2 and the larger volume of material that was excavated. There was also a larger proportion of rock that required ripping at Site 2.

Table 4. Productivity for Site 1.

	Road and landing construction	Trailing /falling	Skidding	Processing
Right of way timber volume (m^3)	3 487	3 487	3 487	3 487
Road constructed (Lineal-metres)	4 478	4 585	4 478	4 478
Average shift length (hrs)	9.4	7.9	7.4	7.4
Lineal-metres/hour	18	19	23	23
Lineal-metres/shift	172	153	173	171
No. of shifts	26	30	26	26

Costs. Total project costs and two unit cost measures are shown in Table 5 by phase. Unit costs are presented in terms of $/m^3 of right-of-way timber and $/lineal-metre of constructed road. Some key points include:

- Road and landing construction accounted for 42% of the total project cost. The unit costs for construction are much less at Site 1 compared to Site 2. The difference of $25/lineal-metre between the two sites is likely attributable to the differences in terrain conditions.
- The combined unit costs for right-of-way logging activities, including trailing/falling, skidding and processing, were 22 $/m^3 and 16 $/lineal-m based on the volume of right-of-way timber and the length of finished road, respectively.

Table 5. Costs for Site 1.

	Road and landing construction	Trailing /falling	Skidding	Processing	Total
Total project cost ($)	57 568	28 019	28 124	20 586	134 297
Unit cost ($/m^3 of right-of-way timber)	16.5	8.0	8.1	5.9	38.5
Unit Cost ($/Lineal-metre of road)	12.9	6.1	6.3	4.6	29.8

Site 2

Time Distribution. Table 6 summarizes total time for all machines used in each phase and presents weighted averages for machine availability and utilization. All right-of-way logging and construction activities were completed in 23 days. Some key points include:

- Road construction and right-of-way logging activities accounted for 75 and 25 percent of total time, respectively
- Machine availability was relatively high in all phases.

- Machine utilization was relatively high at Site 2 compared to Site 1.
- Mechanical delay time accounted for nine percent of total scheduled machine time.

Table 6. Time distribution for Site 2.

	Road and landing construction	Trailing /falling	Skidding	Processing	Total
Productive machine hours	390	22	52	54	518
Mechanical delays	47	1	5	9	62
Non mechanical delays	78	2	14	4	98
Scheduled machine hours	515	25	70	68	678
Availability	91%	96%	93%	87%	92%
Utilization	76%	87%	74%	81%	79%

Productivity. Table 7 presents productivity information. At Site 2, 2 204 lineal-metres of road was constructed and 829 m^3 of timber was extracted from the road right-of-way. This meant that 0.37 m^3 of right-of-way timber was extracted per lineal-metre of new constructed road. Some key points include:

- Phase productivities for skidding and processing were closely matched. This shows that skidding and processing phases were linked, meaning that the production of one phase depended on the other.
- The productivities for the road construction, trailing/falling and skidding phases varied widely at 104, 1030, and 276 lineal-m/shift, respectively. This shows that these phases were operating independently from each other, an observation confirmed by FERIC in the field.

Table 7. Productivity for Site 2.

	Road and landing construction	Trailing /falling	Skidding	Processing
Right of way timber volume (m^3)	829	829	829	829
Road constructed (Lineal-metres)	2 204	2 204	2 204	2 204
Average shift length (hrs)	9.2	9.2	8.8	8.4
Lineal-metres/hour	11	112	31	33
Lineal-metres/shift	104	1030	276	274
No. of shifts	21	2	8	8

Costs. Total project costs and two unit cost measures are shown in Table 8 by phase. Some key points include:

- Road and landing construction accounted for 78% of the total project cost and resulted in a unit cost of $38/lineal-m.
- The combined unit costs for right-of-way logging activities, including trailing/falling, skidding and processing, were 27 $/m^3 and 10 $/lineal-m based on the volume of right-of-way timber and the length of finished road, respectively.

Table 8. Costs for Site 2.

	Road and landing construction	Trailing /falling	Skidding	Processing	Total
Total project cost ($)	83 837	4 478	7 624	10 392	106 331
Unit cost ($/m^3 of right-of-way timber)	101.1	5.4	9.2	12.5	128.2
Unit Cost ($/Lineal-metre of road)	38.0	2.0	3.5	4.7	48.2

DISCUSSION

Several aspects of the road building operations likely influenced productivity and costs. FERIC made the following observations about the road building strategies adopted at each project and the influence of site conditions.

Crew Complement

The skill and versatility of the operators allowed for flexibility in planning and scheduling right-of-way logging and construction activities. Leadership and decision-making responsibilities were generally shared by the lead excavator operator and the logging crew leader. At Site 1, a person known as a utility operator would switch to any piece of equipment within any phase as needed. The utility operator was a key individual for this operation because the productivities of the phases were interdependent. The utility operator would be directed to a phase that was lagging behind to help boost overall production.

Push Falling and Separation of Phases

Push falling trees with an excavator was a technique used to varying degrees at both study sites. At Site 1, the pilot trail and much of the lower portion of the right-of-way was push-felled and the remainder was felled manually. At Site 2, the entire right-of-way was push-felled. The excavator would then push the downed stems complete with root balls to the outside edges of, and sometimes beyond, the clearing width. The latter method has some advantages. With the timber out-of-the-way subgrade construction can progress unimpeded by the felled timber and any subsequent skidding activity. This means that the logging and construction phases can be separated. Separating phases reduces the interaction and congestion between right-of-way logging and construction equipment and improves phase productivities.

Handling of stumps

One of the differences between the techniques at the two sites was in the handling of stumps. At Site 1, stumps remained along the road because the trees were felled manually on the upper half of the right-of-way. On the bottom portion of the right-of-way where trees had been push-felled, the root balls were cut off manually. At Site 2, whole trees complete with roots were skidded to a landing where the root balls were cut off by the processor. The roots were then piled for burning. There are advantages and disadvantages with both systems. Leaving stumps along the right-of-way eliminates the debris disposal problem at a landing, and should improve skidding and processing productivity. However, removing stumps from the right-of-way makes subgrade construction easier and eliminates the possibility of stumps getting mixed into the road fill. Further, removing stumps can improve worker safety for manual fallers or choker setters in subsequent harvesting operations because the risk of stumps rolling into the adjacent cutting unit is reduced when they are concentrated at the landings.

Site Conditions

The right-of-way timber volume per unit length and the average piece for processed timber were different at the two study sites. On average, there were 0.77 and 0.37 m^3 of timber per lineal-m of road at Site 1 and Site 2, respectively. The average piece size was 0.52 and 0.46 m^3/piece for Site 1 and 2, respectively. It is likely that the timber type influenced the productivity and costs for the right-of-way logging phases, which include trailing/falling, skidding and processing. But the data suggest that the technique used to carry out these phases may have had a greater influence on productivity and costs than the timber characteristics themselves.

For example, the combined unit cost, in terms of $/$m^3$, for right-of-way logging was approximately 19% lower at Site 1 compared to Site 2, reflecting the larger unit timber volumes and piece sizes at Site 1. However, the combined unit cost for right-of-way logging activities, in terms of $/lineal-m of road, was 66% greater at Site 1 compared to Site2. It was the much higher phase productivities at Site 2 that resulted in this lineal-m cost differential, and the higher productivities can be attributed to the technique used. At Site 2 the phases were separated and could carry on their work independently.

The productivity of the construction phase was higher at Site 1 compared to Site 2. This is likely attributable to the steeper slope conditions at Site 2 and the larger volume of material that was excavated. There was also a larger proportion of rock that required ripping at Site 2.

Implications for Operations Affected by Mountain Pine Beetle

Both study sites were in the early stages of Mountain Pine Beetle infestation. The push-falling technique is well suited to pine stands because root balls are smaller making push-felled pine stems more amenable to skidding compared to other species. Other advantages of the technique not previously noted include:

- Manual fallers are not exposed to the hazardous snags and dead limbs often found in beetle-affected stands.
- The relatively small size and shallow root network of pine trees can be handled easily and productively by an excavator.

- The need for additional falling equipment such as feller bunchers is eliminated.
- Timely access to deteriorating beetle-killed stands is needed. Forest operators have very little time to allow roads to "set up" before harvesting and log hauling commence. The push falling technique allows phases to be separated and road construction to be completed sooner.
- Right-of-way timber can be skidded and hauled on a finished road rather than a pilot trail. Skidding on a finished road helps to compact the subgrade and improves the bearing capacity of the roadbed.

SUMMARY

This paper provides preliminary results for two case studies of road building techniques in B.C.'s Interior region. Productivity and costs were influenced by the technique and the level of interaction between the right-of-way logging and construction activities. Many variations of systems are possible and selection of an appropriate technique will depend on the type of equipment available and conditions at the site. Additional studies are planned in different regions of Western Canada to further investigate relationships between roadbuilding productivity and site conditions. The studies will provide needed data on road building operations to assist managers in making decisions about applying alternative techniques, and to improve their assessments of operating costs.

ACKNOWLEDGMENTS

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