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END-HAULING FOR FOREST ROAD CONSTRUCTION

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Figure 1 - End-haul road construction in Lee Valley, Nelson

ABSTRACT

Midslope roads constructed in steep terrain can have an adverse impact on the environment. Steep unconsolidated fill slopes are prone to surface erosion and mass movement during periods of intense rainfall. End-haul is a method of construction where the sidecast material is carted away rather than thrown over the side. An excavator forms the road and loads the excavated material on to a truck for transporting to a dump site.

Truck and excavator cycle times were measured during the construction of a midslope road located in Nelson. A spreadsheet model was developed for estimating earthwork costs. The spreadsheet model calculates the time required for each truck to complete a round trip for all the trips required to complete the earthworks. End-haul road

construction is expensive, typically from $40,000 to $100,000 per kilometre for a single lane road (excluding road metal). The costs can be minimised by: optimising the number of trucks, minimising the total cut volume, using 15 m^3 dump trucks, minimising dump site distance, and providing passing bays.

INTRODUCTION

Studies have shown that roads, tracks, and landings can contribute significantly to erosion (O'Loughlin, 1979; Vaughan, 1984). Harvesting on steep terrain (exceeding approximately 20^{o}) often requires the establishment of roads, tracks, and landings by sidecasting (Figure 2). This can result in increased areas of soil exposure, changes to the existing drainage pattern, and decreased soil strength producing significant sources of sediment. In periods of prolonged or intense rainfall, sidecast slopes are particularly prone to mass erosion (Coker and Fahey, 1993).

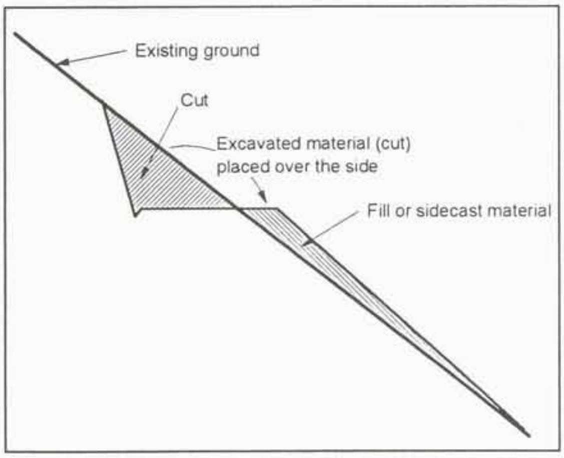

Figure 2 - Sidecast construction

End-haul is a method of construction where the excess material is carted away rather than placed over the side. This eliminates the sidecast or fill slope (Figure 3).

End-hauling is typically two to four, and occasionally as high as ten times, the cost of conventional sidecast construction. Since end-haul is expensive, an accurate cost estimate is required to determine the best logging and transport system. Alternatives for harvesting, such as aerial cableway and two staging, may be considered if road construction costs are high.

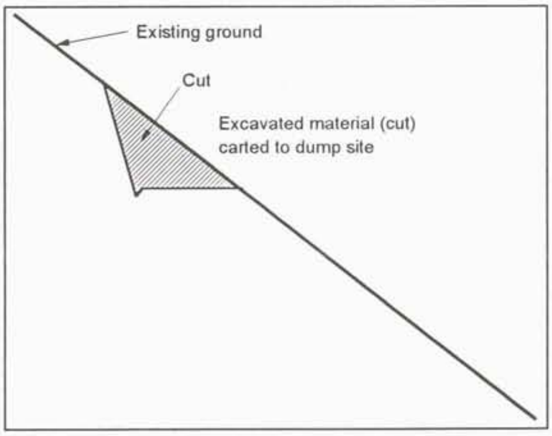

Figure 3 - End-haul construction

To provide a reasonable estimate of end-haul costs using the one pass method, a spreadsheet model was developed. This model uses inputs on truck and excavator performances to calculate and sum all the truck cycle times required to complete the earthworks. End-haul in Lee Valley, Nelson was studied to measure excavator and truck performance for input into the spreadsheet model.

This report discusses methods of end-haul road construction, the development of the spreadsheet model, and how to minimise costs.

END-HAUL CONSTRUCTION METHODS

End-haul construction typically involves an excavator forming the road, either in one or two passes and at least two trucks carting the excavated material to the dump site. The roadline can be logged using a skidder prior to road construction, if a small track is constructed below the road grade. Alternatively, the roadline can be logged during construction.

One Pass Method

The one pass method is suited to construction of narrow one-lane roads in steep terrain. An excavator clears trees, and forms the road in one pass. The trees are pushed to one side for later extraction. Every bucket load of excavated material is loaded on to a truck for carting to the dump site.

Two Pass Method

A small pioneer track is constructed first by sidecasting using an excavator. The excavator then constructs the main road and loads trucks, while backing along the pioneer track (Figure 4). The original sidecast material is also recovered and placed on a truck for transport.

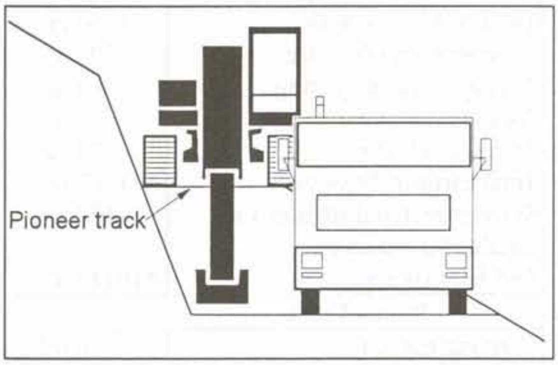

Figure 4 - The two pass method

Truck loading time is reduced as the swing time (and distance) between excavating a bucket of material and then loading it on to a truck is less than the one pass method. The two pass method is only suitable if the excavated material can remain safely on the side of the hill until loaded on to a truck.

TRUCK AND EXCAVATOR PERFORMANCE

The one pass method of end-haul in Lee Valley, Nelson was studied to determine truck and excavator performances for inputs into the spreadsheet model. Ground slope was in excess of 70% (35°) and the soil type was predominantly clayey-gravel with pockets of rock. Two or three eight wheeler trucks with a capacity of 8 m^3 each, and a 20-tonne excavator were used to construct this road.

The proposed road and dump site were surveyed using a cloth tape, clinometer and compass to measure cross-sections at regular intervals. This survey data was entered into Lumberjack™ to design the road and estimate the volume of earthworks. The total cut was 8,500 m^3 for a 750 m long road. Cumulative distances were calculated in Lumberjack™ for each survey station located from the dump site (0 m) to the start of the road (186 m) and then to the end of the road (938 m). The trees were clearly marked with station numbers to enable the truck cycle times and speeds to be determined. The results are summarised in Table 1.

The variables in Table 1 are defined as follows (position numbers refer to those labelled in Figure 5):

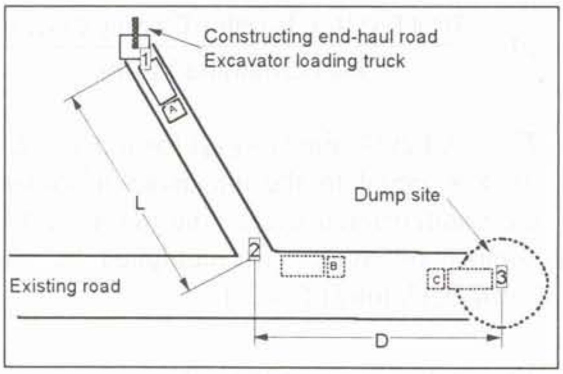

Figure 5 - Typical end-haul scenario

Reversing Speed, V_{Rev} = the unloaded reversing truck speed from position 2 to 1.
Loaded Speed, V_{Load} = the loaded truck speed from position 1 to 3.
Unloaded Speed, V_{Empty} = the unloaded forward truck speed from position 3 to 2.

The speeds and times calculated in Table 1 showed very little variation. This validated the assumption used in the spreadsheet model that the inputs did not change markedly during construction.

Table 1 - Measured truck and excavator performances

Element	Symbol	No.	Mean ± 95% CI
Loading Time (s)	T_{Load}	54	**122** ± 9
Dump Time (s)	T_{Dump}	51	**104** ± 12
Turning Time (s)	T_{Turn}	39	**36** ± 3
Reversing Speed (km/hr)	V_{Rev}	53	**4.9** ± 0.3
Loaded Speed (km/hr)	V_{Load}	54	**9.9** ± 0.6
Unloaded Speed (km/hr)	V_{Empty}	39	**9.3** ± 0.3

MODELLING

Figure 5 shows a typical end-haul operation that was modelled in a spreadsheet. The model uses the inputs in Table 2 to calculate and sum all the truck cycle times required to complete earthworks.

The procedure used to estimate one cycle time is outlined below. It should be noted that each cycle time is different as after every truck load the length of road constructed increases linearly by ΔL:

$$\Delta L = \frac{\text{Total End Haul Length} \times \text{Carrying Capacity}}{\text{Total Earthworks Volume}}$$

The total cycle time (T_{Total}) for a particular truck is equal to the maximum of either: the uninterrupted cycle time (T_{Un}); or the number of trucks (n) multiplied by the bottle neck time ($T_{Btlneck}$) :

$$T_{Total} = \max(T_{Un}, n \times T_{Btlneck})$$

where:

T_{Un} = the total time for a particular truck to be loaded, dump the load and then return to the excavator ready to be loaded while uninterrupted (excludes waiting time).

$T_{Btlneck}$ = the total time from when a truck enters the newly constructed one lane road and then leaves after being loaded. This is the time when no other truck can enter the newly constructed road until the truck has left this road.

Table 2 - Variables required for the spreadsheet model. Excavator and truck performances are those measured, while studying end-haul construction in Lee Valley, Nelson. (End-haul volume is calculated assuming a 10% wastage).*

End Haul Road Construction Inputs	
Road Description	
Total end-haul length	1000 m
Average dump distance	500 m
Average turnout spacing	200 m
Formation width	4 m
Average side slope	80 %
Total earthworks volume	*11267 m^3
Sidecast material (that is, rock suitable for sidecast)	*1127 m^3
End-haul volume	*10140 m^3
Dump Truck	
Carrying capacity	8 m^3
Number	3
Truck loaded speed	2.74 m/s
Loading time	122 s
Dumping time	104 s
Turn in preparation for reversing	36 s
Truck empty speed	2.57 m/s
Truck reverse speed	1.36 m/s
Hours paid per day	9.5 hrs
Productive hours per day	8 hrs
Hourly rate	66 \$/hr
Excavator	
Bucket capacity	1.14 m^3
Loading time per bucket	17.47 s
Hours paid per day	9 hrs
Productive hours per day	8 hrs
Hourly rate	100 \$/hr

The bottleneck and uninterrupted time can be calculated as shown (the numbers refer to the positions labelled in Figure 5):

$$T_{Btlneck} = T_{2\text{-}1} + T_{Load} + T_{1\text{-}2}$$
$$T_{Un} = T_{Load} + T_{1\text{-}3} + T_{Dump} + T_{3\text{-}2} + T_{Turn} + T_{2\text{-}1}$$

where:
T_{1-3} = travel time from position 1 to 3
T_{3-2} = travel time from position 3 to 2
T_{2-1} = travel time from position 2 to 1
T_{Load} = the total time a truck is required to wait before fully loaded at position 1
T_{Turn} = the time required for the truck to turn around at position 2 ready for reversing to the excavator (position 1)
T_{Dump} = the total time from when the truck arrives at the dump site (position 3), turns around, dumps the spoil and then ready to leave.

Using the inputs from Table 2 and the formulae in a spreadsheet, the production and efficiency of the operation (Nelson case study) was calculated (Table 3).

Table 3 - Productive hours (per machine) required and cost to complete job for the variables shown in Table 2

	Excavator	Trucks
Number	1	3
Productive Hours	42	136
Waiting Hours	96	2
Total Hours	138	138
Cost ($)	$15,536	$32,471
Total Cost ($)	$48,008	

By varying any of the inputs in Table 2, the efficiency and total cost of the operation can be quickly calculated. This allows the number of trucks used, turnout spacing and dump site distances to be varied for comparison. Table 3 shows a large amount of waiting time for the excavator. This time could be reduced by increasing the number of trucks.

FACTORS TO CONSIDER

The spreadsheet model used in this study was limited to a one-lane road using the one pass method for end-haul.

Accurate Inputs

To obtain accurate results, accurate inputs are required. The current inputs are for those measured during end-haul in Lee Valley, Nelson and are likely to be different for end-haul construction of roads in other districts. In particular, it is more common to use a 30-tonne excavator in combination with two 15 m^3 all-wheel drive dump trucks. The performance for these machines will be different than the machines observed in the study (20-tonne excavator and eight wheeler gravel trucks). Therefore the inputs for the model (Table 2) should be changed to values applicable to the machinery used and the conditions encountered.

Passing Bays

Passing bays at regular intervals within the one-lane road being constructed increases production, as there is less time for the excavator to wait for the next truck for loading. This reduces the bottleneck time ($T_{Btlneck}$).

$T_{Btlneck}$ was approximated by calculating the time the truck was travelling between the passing bays.

Truck Speeds and Excavator Loading Times

The spreadsheet model assumes that the truck's speed and excavator loading times do not change over the whole job. This was the case for the cycles measured in Lee Valley, Nelson. However, hard rock can be encountered which slows the excavator production considerably. In addition, the dump site could change which could result in different truck speeds. If the inputs are expected to change, then the road should be broken into segments with similar characteristics and costed separately.

Additional Costs

Any costs in addition to the earthworks are not included in the model. These include the optional use of a bulldozer to level and compact the fill on the dump site. Metalling, blasting, logging and any other costs will need to be calculated and added separately.

HOW TO MINIMISE COSTS

End-hauling is expensive and there are various ways to minimise the total costs.

Optimum Truck Number

The optimum number of trucks is the number of trucks needed to cart material to the dump site that will minimise the total costs. The optimum number of trucks is influenced by a combination of many different variables: truck speed, loading time, road length, turnout spacing and dump site distance. The optimum number of trucks can be estimated using the spreadsheet model, by simply increasing or reducing the number of trucks until the lowest total cost is obtained.

However, since working conditions can change on a daily basis, it is more economical to have flexibility with the number of trucks employed. A minimum of two trucks should be used full time, with additional trucks on standby for use as needed. If it appears that there is a long wait time for the excavator, then hire an additional truck. If the trucks are waiting, then lay off a truck. This ensures that as the site conditions change from day-to-day, the maximum production is achieved with the optimum number of trucks for the least total cost.

Minimising Earthworks

Every bucket load of material that is loaded on to a truck for dumping costs approximately $5 and by minimising the total number of bucket loads, the total costs can be reduced. Pegs can be placed to show the top of the cut batter (Figure 6) to ensure the correct formation is constructed.

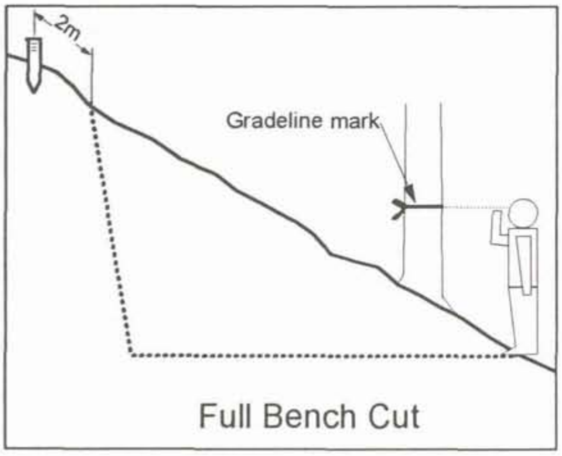

Figure 6 - Set-out of cut batter peg

Truck Size

Specialised dump trucks, such as the 6x6 Bell (Figure 7) are designed specifically for moving large quantities of earth. The tray has a capacity of 15 m^3, and the all-wheel drive and large tyres allow the vehicle to travel quickly over rough terrain. This also enables the trucks to drive on soft and wet ground, without the need for metalling. Metal can then be more efficiently applied to the whole road when the formation is complete.

Figure 7 - 6x6 dump truck (15m^3 capacity)

Cycle times have not been measured for a 6x6 Bell dump truck, but it is expected to be substantially faster than the standard gravel trucks that were measured in the study.

Assuming the speeds are the same for the 6x6 dump truck, the costs shown in Table 4 were calculated. Even though the hourly rate of the dump trucks is more, it is shown the total cost to complete the end- haul is less. The reduction in cost will be greater if the average speed of the 6x6 dump truck was increased from 10 km/hr to a more realistic 20 km/hr. Further cost savings can be obtained as a bulldozer is not required at the dump site; the dump trucks can spread the fill evenly over the site.

Table 4 - Effect of using 6x6 dump trucks on end-haul costs

Road Length = 1000m; Turnout Spacing = 200m; Dump Distance = 500m		
	Gravel Truck	6x6 Dump
Capacity (m^3)	8	15
Number	3	2
Hourly Rate ($/hr)	66	105
Time per truck (hrs)	138	117
Unit Cost ($/$m^3$)	4.86	4.30
Total Cost ($)	**$48,000**	**$42,500**

The effect on end-haul cost using other types of machinery can also be evaluated using the spreadsheet model.

Dump Site Distance

Dump site distance (D) has the largest influence on costs. As would be expected, if the dump site distance is increased, the cost increases. The optimum number of trucks increases also, as it takes longer for trucks to return to the loading position. Figure 8 shows the effect of increasing dump site distance on cost.

A careful inspection of the area is required to determine the closest possible dump sites. These dump sites need to be flat areas, and could be abandoned landings or roads. More than one dump site may be required and it is important to plan its location to avoid delays during construction.

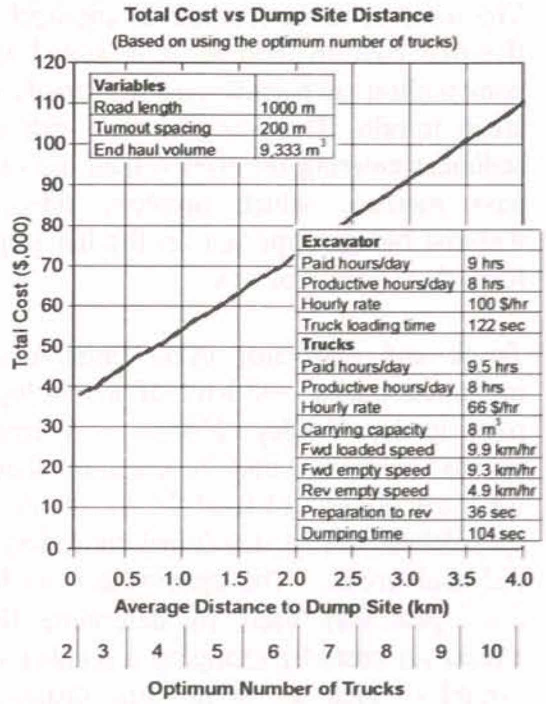

Figure 8 - Dump site distance effect on cost

Turnout Spacing

Sufficient passing bays are required to reduce the waiting time for the excavator. Usually passing bays can be constructed at naturally occurring areas where the terrain is flatter with little extra effort. Even if there are no flatter areas, a passing bay should still be constructed, so that the maximum turnout spacing does not exceed 300 m. The spreadsheet model accounts for the additional earthworks required and can be used to compare different turnout spacings. If the number of trucks used is less than the optimum, then the passing bays constructed will be under-utilised and the savings will not be realised.

SUMMARY

The only sure way to prevent fill material entering waterways is to use end-haul construction. This involves full bench construction, where the excavated material is transported away to a safe dumping area (flat and away from waterways).

The most common method of end-haul is the one pass method as it is suited for construction of narrow one-lane roads in steep terrain. There is also less risk of sediment entering the stream than the two pass method, which involves sidecast material being supported on the hill slope for a short period of time.

Truck and excavator cycle times were measured during end-haul of a midslope road in Lee Valley, Nelson. Average speeds, dumping and turnaround times were calculated and used for input into a spreadsheet model developed to estimate end-haul costs. The spreadsheet model developed was used to determine the effects on costs by changing a number of variables, such as dump site distance, turnout spacing and machinery. This spreadsheet model can be purchased from LIRO.

ACKNOWLEDGMENTS

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