RIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

Productivity and Cost of Four Subgrade Construction Machines

Technical Report No. TR-28
December 1978

M.M. NAGY

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Foreword

Help was received from many sources during the course of this cooperative study. The author wishes to thank the following for providing opportunities to set up the four case studies on their operations:

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Michael M. Nagy joined FERIC in 1976 to carry out research in coastal logging and road construction. A Registered Professional Forester and member of the Canadian Institute of Forestry, he has spent sixteen years in private industry, both as an industrial consulting forester and as a forest engineer specializing in harvesting, logging layout and road construction. He received his B.S.F. from the University of British Columbia in 1960.

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ABSTRACT

This report gives the results of a series of continuous time studies on the work performance of basic machinery used to build subgrade in British Columbia: the backhoe, the bulldozer, the line shovel, and the hydraulic shovel. By establishing and comparing each machine's unit costs for earth-moving, right-of-way logging, and stumping, FERIC produced costing methods, tables, and sample estimates to help the reader develop a formula for determining subgrade quality and cost. The report lists the advantages and disadvantages of each equipment type and makes recommendations for the utilization of these machines and for improvements in their design and in road-building techniques.

RÉSUMÉ

Ce rapport donne les résultats d'une série de chronométrages continus, portant sur le rendement au travail de l'équipement de base qui sert, en Colombie-Britannique, à la construction de l'encaissement d'une chaussée: la pelle rétrocaveuse, le bulldozer, la pelle à benne traînante et la pelle hydraulique. En établissant pour chaque engin les coûts unitaires de terrassement, de coupe des arbres sur l'emprise de route et d'essouchement, et en comparant ces coûts entre eux, FERIC fournit des méthodes d'établissement du prix de revient, des tableaux et des exemples d'évaluations, qui aideront le lecteur à développer une formule lui permettant de déterminer comment, dans le cas de sa propre exploitation, la qualité de l'encaissement peut influer sur les coûts d'empierrement et l'entretien futur de la route. Le rapport donne une liste des avantages et des inconvénients que présente chaque type d'équipement, et fait des recommandations relatives à l'utilisation de ces engins et aux possibilités d'améliorer la façon dont ils sont conçus de même que les techniques de construction de routes.

INTRODUCTION

The aim of this report is to give companies better data for measuring the cost efficiency of their own road construction operations. The steady climb in road-building costs can be attributed in part to working on steeper ground with more rock, to lower timber volumes per mile (kilometre) of road built, and to more complex environmental regulations. Other factors also affect cost, and in an effort to understand these relationships, FERIC undertook this study of the performance of the backhoe, bulldozer, line shovel, and hydraulic shovel, four common types of machines used to build subgrade in British Columbia.

During evaluation, FERIC measured productivity, cycle times, and subgrade quality, and noted factors which affected the efficiency of the operation.

These measurements and observations were used as a basis to compare the unit costs and production rates between the machines. Earth moving, right-of-way logging, stumping, and subgrade quality were analyzed and suggestions made to improve operational techniques. The advantages and disadvantages of each machine are listed and recommendations made to improve its effectiveness on the job.

Two costing methods were compared and illustrated with the data collected. These are the station-per-shift method and the unit-cost method. The problems with each method are discussed and we have suggested some solutions and general applications.

Finally, FERIC noted the role of the operator in subgrade construction.

TEST CONDITIONS AND STUDY METHODS

Site choice played an important part in setting uniform conditions for the operation of the four machines; the only sites considered were those with a variation of ten percent or less in favorable or adverse grades. A side slope of about thirty percent composed of gravel soil cemented with clay gave the machines enough flotation, yet required maximum performance. The soil was moist but never exceeded the saturation point. Road sections chosen for the study were nearly rock-free; at most it was necessary only to clear surface rock.

The machines were old enough to be characteristic of their type yet in good enough mechanical condition to avoid abnormal breakdowns. Each of the four operators had more than a year of experience with the machine type used during the study, and each had a background in logging-road construction.

The field work consisted of a continuous time study.

The centerline was traversed with a staff compass to establish stations every 50 feet (15.24 m). Survey points (stations) throughout this report are marked showing the footage as 200, 250, 300, etc. instead of the usual stationage mark of 2 + 00, 2 + 50, 3 + 00, etc. Each of the stations was levelled with an Abney hand level and a levelling rod.

The cross-sections were established at every survey station once the centerline was levelled. On each side of the centerline a point was marked at 20, 30, and 50 feet (6.10, 9.14 and 15.24 m). These points were also levelled with an Abney hand level and a levelling rod.

Prism plots for measuring timber volumes were marked every 200-300 feet (60-90 m) on the centerline. All the survey points were re-established after the timber was felled.

Each phase of construction was timed with a stopwatch, and these times were entered under four major headings: logging, stumping, excavation and delay.

The logging time elements break down into four groups: moving logs by sizes, pushing logs and organizing log piles, falling trees, and machine movement. During stumping, timing was kept by species, estimated stump sizes, and moving time.

During excavation, we timed clearing and moving; stripping (removing topsoil) and moving; excavating mineral soil and moving; and excavating rock and moving.

Time element definitions are contained in Appendix I. For the purposes of this study, time-distribution charts, production tables and graphs are limited to productive time and machine delays. Time for out-of-shift repair or maintenance was not recorded or used for calculations. During the timing period, observations relating to the machine's productivity problems and subgrade quality were recorded in a field book. Soil samples were taken for later laboratory analysis (Appendix II). After each phase of excavation, a new survey was carried out, re-establishing the cross-sections to calculate the excavated earth volumes.

Once the machine finished construction of the test site, the centerline was levelled at 10-foot (3.05 m) intervals to calculate the Roughness Indicator (Appendix III). The Roughness Indicator is the area in ft^2 or m^2 which requires cut or fill to form a straight line between two points 20 feet (6.10 m) apart in the longitudinal cross-section of a station length of road at the centerline.

When shovel mats were in use, the subgrade was checked over a length of 4½ feet (1.37 m) at random intervals to calculate the extra ballasting material needed to compensate for the uneven surface. As soon as the subgrade was completed, the last step in field work was the machine's Working Speed Test (Appendix IV). Earth-volume computations and calculations for charts and tables were made in the office after field work was finished.

CASE STUDY I

CATERPILLAR 235 HYDRAULIC BACKHOE

EQUIPMENT DESCRIPTION

Manufacturer's Specifications

Engine:	Caterpillar Model 3306, 6 cylinders Flywheel horsepower: 195 at 2,000 rpm
Bucket Size:	Bite size width: 42 in. (1.07 m) Capacity: 1¼ yd^3 (0.96 m^3) struck 2½ yd^3 (1.91 m^3) heaped
Tracks:	Shoe width 36 in. (0.91 m) Ground contact area 9,936 $in.^2$ (6.41 m^2)
Stick Length:	12 ft (3.66 m)
Ground Clearance:	21 in. (0.53 m)
Working Range:	Level reach: 39 ft 1 in. (11.91 m) Maximum depth: 26 ft 6 in. (8.08 m) Travel speed: maximum 2.3 mph (3.7 km/h)
Controls:	— Two joysticks control movement of the boom, stick, bucket and swing — Two travel pedals, forward and reverse — One steering lever
Hydraulic System:	A low-pressure (1,000 psi (68.9 bar) at 2,000 rpm) hydraulic system operates the working circuits to power the boom, stick, bucket, swing and travel.

Backhoe Characteristics for Road Building

Reach: Prepares high cutbanks, removes overhang from the cutbank, and places material almost anywhere on the fill slope, excavates and moves material well below the grade level.

Bucket design: Sorts material well, produces a smooth subgrade and cutbank finish, ditches well and digs hard material; the bucket's only disadvantage is its small capacity.

Flotation: Has the best capability (of the four machines studied) for working on soft ground without shovel mats. Under low load-bearing ground-capacity conditions, its flotation[1] can be increased by using brush matting and burying small logs under the surface.

Speed: Has a high working and travelling speed (2.3 mph) (3.7 km/h), enabling it to travel back and forth compacting the subgrade; it is easily moved for machine and road maintenance or for loading gravel trucks.

Working Speed Test: 0.63 minutes (Appendix IV).

Rock preparation: Prepares rock for blasting.

Operator comfort: Has a comfortable seat but poor ventilation and heating.

Visibility: Has the best field of vision of the four cases studied because the bucket faces the operator where he can see the actual work area.

Ease of operation: Has the simplest controls of the four machines; a beginner can quickly learn to operate it.

Maintenance: Easy to service.

[1]The ground pressures of all the machines are given in Table DC-1.

Boom design: Manufactured for trenching and could not withstand twisting stress; the boom cracked at the top.

Condition of machine: The machine studied was one year old, in excellent condition, and it had been modified to protect the operator and equipment by putting heavy plating on the underside and by installing screens around the machine and cab. To help pinch the logs during logging, knobs were welded on the inside of the bucket stick.

Operator and Crew

The operator was paid an hourly rate with no incentive pay. Supervisors and operators were satisfied with overall machine performance.

Effect of Right-of-Way Falling on Subgrading

The right-of-way was about 70 feet (21 m) wide, with the road location line at the center. The right-of-way here could be no wider because the fill would bury the logs. Trees were felled parallel to the centerline and bucked to 40-foot (12.2-m) lengths, so right-of-way falling did not slow down production and had no adverse effect on machine performance. Although the toe of the fill was against the standing timber in many places, this would not have obstructed falling the rest of the timber.

Three-Pass Subgrading System

The backhoe moved most of the logs and stumps in the pioneering phase (Figure 1-a) by building a tote road in about 200 feet (60 m).

Figure 1-a. Logs being moved in pioneering stage

It finished stripping by working backward and removing all the waste material and dumping it below the tote road. The machine then scraped the topsoil off the hard gravel subsoil, starting at the top of the planned cutbank and finishing with the removal of the tote road itself. This topsoil was used to cover the waste material and stumps on the fill side (Figure 1-b).

Once the stripping was completed, the machine moved ahead again, excavating the mineral soil and shaping the cutbank and subgrade--both at the side and in front--as well as digging the ditch (Figure 1-c).

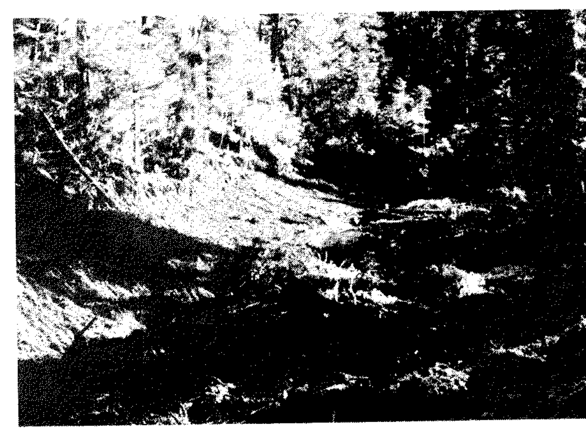


Figure 1-b. Waste material to be covered with subsoil to form the subgrade

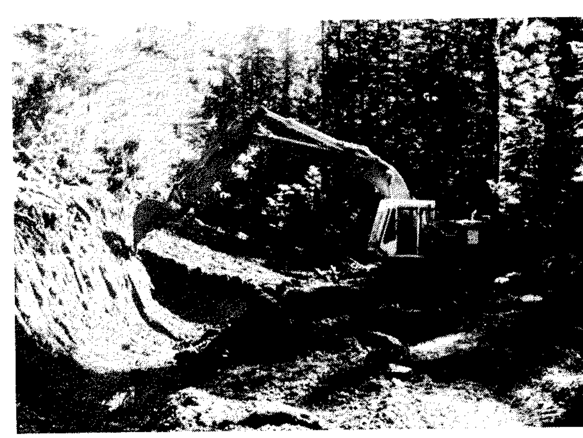


Figure 1-c. Backhoe digging ditch

Table 1-1 shows running averages of the three adjoining sections of the subgrade.

LOGGING

The backhoe utilized the curling action of the bucket to pinch the logs, but without loading tongs or chokers the machine could not handle logs oriented radially about the pivotal pin of the

Table 1-1. Logging Productivity: Hydraulic Backhoe

Section*	No. of Logs	Av. Log Size (ft³)	(m³)	Logging Time (hours)	Production Rate (logs/hr)
0- 50					
50-100	11.3	50.6	1.43	0.20	57.1
100-150	9.0	39.0	1.10	0.16	54.9
150-200	9.7	37.8	1.07	0.22	44.7
200-250	10.0	69.7	1.97	0.30	33.5
250-300	11.7	69.7	1.97	0.34	34.0
300-350	11.0	79.0	2.24	0.36	30.9
350-400	8.3	59.3	1.68	0.25	33.1
400-450	6.3	62.2	1.76	0.19	33.6
450-500	7.7	55.3	1.57	0.18	41.7
500-550	8.3	56.2	1.59	0.21	40.1
550-600	9.3	56.1	1.59	0.22	41.7
600-650					
Average	9.2	58.5	1.66	0.23	40.3

*Survey points or station marks are shown in this report as the distance in feet from the beginning of the survey (0) e.g., 300, 350, 400 etc. Sections are the 50-foot distances between two survey points on the centerline.

boom. To lift such a log, the operator first had to turn it on the ground until it was in some degree perpendicular to the boom. He used the machine's bucket teeth to pull logs closer before positioning them and once a log was in position, he pinched it close to the balance point with the bucket against the stick. At this stage he could move the log around and put it anywhere within reach or he could sidecast it. The logs were usually decked on the side or behind the machine.

The backhoe moved only those logs within its reach; for more careful handling of valuable logs, a set of loading tongs or chokers could be used. Although the log-handling ability of the backhoe was good, the machine had difficulty closing the bucket on large logs and could not pinch small ones because the bucket could not close up far enough against the stick. The result was that large logs had to be moved one end at a time, and small ones had to be balanced on the curled-up bucket. By using the back of the bucket, the operator was able to push log piles over without any breaking or scarring (Figure 1-d).

Table 1-1 indicates the relationship between the number of logs and the time needed to remove them. The backhoe required an average of 0.02 hours, or 1.49 minutes per log.

The sections are 50 ft (15.24 m). During timing it was difficult to tell the exact moment when the machine completed a section and progressed into another one. To eliminate error as much as possible, we show the figures as running averages of the three adjoining sections. For example, the figures for section 300-350 are the averages of section 250-300, 300-350 and 350-400.

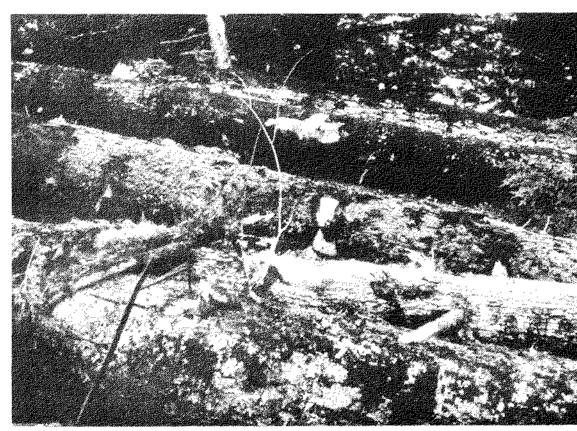


Figure 1-d. Log pile showing minimum damage

STUMPING

The backhoe was the only one of the four machines able to cut roots all around the stump. It moved large flat-rooted stumps by digging out one side and then rotating the stump to break off the rest of the root system. Then the machine put the bucket under the stump, pinched it against the boom, and moved or sidecast it (Figure 1-e). The backhoe operator could also move larger stumps in sections after splitting them with the bucket. The backhoe's reach was useful for discarding stumps, positioning them on the fill bank and covering them with dirt.

Table 1-2. Stumping Productivity: Hydraulic Backhoe

Section	No. of Stumps	Av. Diameter (in.)	Av. Diameter (cm)	Removal Time (hours)	Production Rate (stumps/hr)
0- 50					
50-100	11.0	18.4	46.7	0.22	50.7
100-150	11.7	18.7	47.5	0.25	47.1
150-200	10.3	18.6	47.2	0.23	45.5
200-250	7.0	20.0	50.8	0.22	31.5
250-300	5.7	20.3	51.6	0.18	31.2
300-350	5.0	21.3	54.1	0.22	23.0
350-400	4.3	20.3	51.6	0.18	23.3
400-450	4.7	20.9	53.1	0.22	21.1
450-500	4.3	19.5	49.5	0.18	23.7
500-550	5.3	20.6	52.3	0.20	27.1
550-600	6.0	21.4	54.4	0.17	36.3
600-650					
Average	7.1	20.1	51.0	0.20	34.7

The figures in Table 1-2 are running averages of the three adjoining sections showing stumping productivity. The backhoe required an average of 0.029 hours or 1.7 minutes to remove a stump.

Figure 1-e. Backhoe sidecasts stump.

EXCAVATION

Excavating with the backhoe has been described in the section Three-Pass Subgrading System.

Table 1-3. Excavation Productivity: Caterpillar 235 Hydraulic Backhoe (Imperial Units)

Section	Clearing Rate (ac/hr)	Stripping			Shaping & Ditching		
		Excavation (bank yd^3)	Excavation Time (hour)	Production Rate (bank yd^3/hr)	Excavation (bank yd^3)	Excavation Time (hour)	Production Rate (bank yd^3/hr)
0- 50							
50-100	0.27	209.6	1.32	158.7	157.1	0.63	251.1
100-150	0.22	237.3	1.43	166.2	144.1	0.53	271.2
150-200	0.24	229.0	1.37	167.5	164.1	0.52	316.8
200-250	0.15	239.8	1.66	144.6	180.1	0.72	249.3
250-300	0.18	266.0	1.63	162.7	165.6	0.68	243.9
300-350	0.18	248.1	1.71	144.7	139.4	0.86	162.1
350-400	0.26	189.1	1.15	165.0	147.3	0.60	247.0
400-450	0.26	147.4	1.15	128.6	160.3	0.78	206.1
450-500	0.29	149.4	0.84	178.2	139.7	0.61	228.2
500-550	0.43	165.4	0.67	245.4	89.2	0.47	187.8
550-600	0.54	167.9	0.72	231.9	161.3	1.19	135.5
600-650							
Average	0.24	198.9	1.19	166.8	136.7	0.60	227.8

Average 4,362.6 yd^3/23.3 hr = 187.2 yd^3/hr
Average cut cross-section: 178.2 ft^2

Table 1.3. Excavation Productivity: Caterpillar 235 Hydraulic Backhoe (SI Units)

Section	Clearing Rate (ha/h)	Stripping Excavation (bank m³)	Stripping Excavation Time (hour)	Stripping Production Rate (bank m³/h)	Shaping & Ditching Excavation (bank m³)	Shaping & Ditching Excavation Time (hour)	Shaping & Ditching Production Rate (bank m³/h)
0- 50							
50-100	0.11	160.2	1.32	121.3	120.1	0.63	192.0
100-150	0.09	181.4	1.43	127.1	110.2	0.53	207.3
150-200	0.10	175.1	1.37	128.1	125.5	0.52	242.2
200-250	0.06	183.3	1.66	110.6	137.7	0.72	190.6
250-300	0.07	203.4	1.63	124.4	126.6	0.68	186.5
300-350	0.07	189.7	1.71	110.6	106.6	0.86	123.9
350-400	0.10	144.6	1.15	126.2	112.6	0.60	188.8
400-450	0.10	112.7	1.15	98.3	122.6	0.78	157.6
450-500	0.12	114.2	0.84	136.2	106.8	0.61	174.5
500-550	0.17	126.5	0.67	187.6	68.2	0.47	143.6
550-600	0.22	128.4	0.72	177.3	123.3	1.19	103.6
600-650							
Average	0.10	152.1	1.19	127.5	104.5	0.60	174.2

Average 3 335.5 m^3/23.3 h = 143.1 m^3/h
Average cut cross-section: 16.56 m^2

DITCHING

Most of the material from the ditch was placed behind the machine to form the finished subgrade and as it went along, the machine padded and smoothed the surface with its bucket. The size of the ditch was dictated by the amount of material needed to complete the subgrade, and the remaining mineral soil was used to give the machine flotation and to smooth the surface. Table 1-3 shows excavation productivity figures for the backhoe.

DISTRIBUTION OF SCHEDULED TIME - HYDRAULIC BACKHOE

The data for time distribution were obtained during full-time observation of eight separate shifts in October 1976.

Figure 1-f shows the scheduled time distribution.

Figure 1-f illustrates the machine's capability for handling logs and removing stumps. Only a small percentage of the total productive time was spent on clearing the right-of-way (logging, stumping and clearing). More time was spent on stripping and shaping the subgrade. Delays (8.3%) are personnel-oriented and not related to the machine. The 12.4% Repair and Maintenance operational-time loss was due mainly to repairing the hydraulic systems and welding the boom.

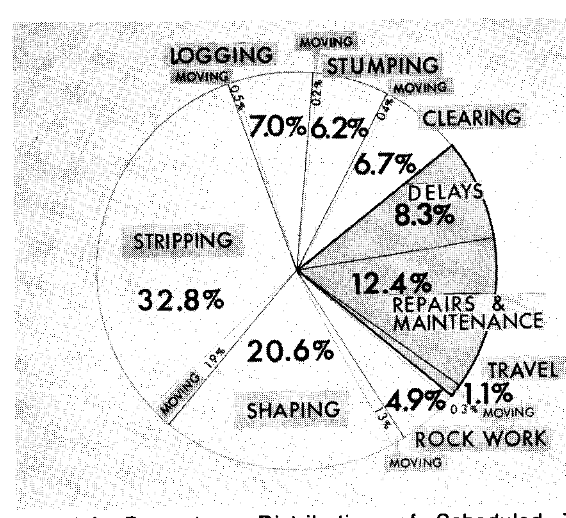


Figure 1-f. Percentage Distribution of Scheduled Time: Caterpillar 235 Backhoe

QUALITY OF COMPLETED SUBGRADE

Clean mineral soil covered with sandy gravel from the ditch covered most of the subgrade, forming a good base for the ballast material.

The Roughness Indicator (Appendix III) for this machine was 5.85 ft^2/sta (1.78 m^2/100 m), indicating the need for a small amount of ballasting material to even out the roughness of the subgrade surface.

Ditching was well done, with a clean, smooth surface, a steady even slope, and a good size. (In fact, in many cases, the ditch was larger than necessary for drainage–see Figure 1-g.)

SUBGRADING TECHNIQUE IMPROVEMENT

When extra flotation is required to support the machine on soft or muddy ground, organic debris can be buried in the subgrade under the road surface. The necessity for excavating oversized ditches (Figure 1-g) might also be questioned because such ditches can be a safety hazard under adverse conditions–especially when the road is also used by the public.

The machine operator spent time removing all organic material and making the subgrade smooth during the stripping phase. This can be a substantial moneysaver if there is not enough high-quality material to build a good subgrade. However, when material of good quality is within reach the time would be better spent on building a heavier and more solid subgrade.

The log-handling ability of the backhoe is good, utilizing the curling action of the bucket and moving most logs smoothly. Large logs which are difficult to pinch with the bucket should be moved with chokers to save time and machine wear and to prevent scarring damage. Logs lying at the outer edge of the machine's reach could also be better handled with a set of tongs or chokers.

MACHINE IMPROVEMENT

A larger and wider boom-end design with the stick-mounting points further apart to accommodate a longer stickpin would distribute the forces better and prevent cracking the mounting points.

Removable windows on the right side and back of the cab would be useful in case of an accident. The windshield as it is stored now could become an obstruction to trap the operator if the machine were lying on the ground in a cabside-down position.

We would recommend a better defogging system for the windshield and side windows, supported by a fan for air circulation. The screens should be placed to allow easy access for cleaning the windshield and the machine should have a good built-in windshield washer and wiper.

We think the cab should have a larger canopy to protect the operator from rain and sun. The cab on the backhoe could be modified to have a large roof area shading a small floor, similar to the cab presently used on Caterpillar road-graders.

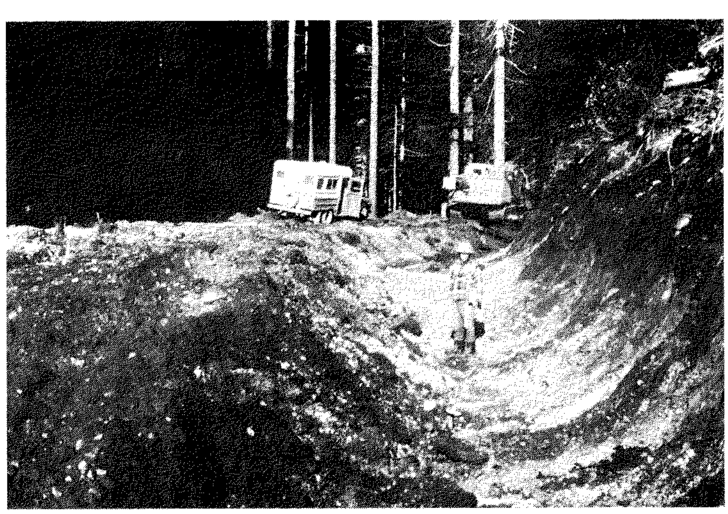


Figure 1-g. Example of an oversize ditch

CASE STUDY 2

CATERPILLAR D8H BULLDOZER

EQUIPMENT DESCRIPTION

Manufacturer's Specifications

Engine:	Caterpillar Model D342, 6 cylinders 4-cycle diesel Flywheel horsepower: 270 at 1,280 rpm
Tracks:	Shoe width 24 in. (0.61 m) Ground contact area: 6,059 in.^{2} (3.91 m^2)
Ground Clearance:	20 in. (0.51 m)
Working Range:	Travel speed, maximum forward 6.5 mph (10.5 km/h) maximum reverse 8.1 mph (13.0 km/h)
Bulldozer Blade:	Straight blade Length: 13 ft 1 in. (3.99 m) Height: 53.5 in. (1.36 m) Maximum drop below ground: 18.4 in. (0.47 m)
Winch:	Hyster Model D896C towing winch Line speed: 32 to 65 fpm (9.75 to 19.8 m/min) at maximum pull Maximum pull: 113,000 lb (51 256 kg) with 1 1/8 in. (28.6 mm) cable Cable capacity: 239 ft (72.85 m) using 1 1/8 in. (28.6 mm) cable

Bulldozer Characteristics for Road Building

Reach: Not limited by reach and could move fill material long distances (unlike the other three machines). Cannot work on steep fill slopes and has difficulty widening a subgrade when the cutbank is already high.

Flotation: Uses machine weight to doze downhill; it can use the winch to move uphill or to free itself when stuck. Machine weight becomes a disadvantage when it has to support its own weight as it works.

Speed: Has a high moving/working speed, works on long road sections and its high mobility is useful in correcting road alignment.

Working Speed Test: 0.83 minutes (Appendix IV)

Operator comfort: Cab has a comfortable seat and simple controls; there is no protection from the elements and heating is provided by engine heat with its accompanying exhaust fumes.

Visibility: The operator's vision is blocked by the engine and blade.

Ease of operation: Easy to operate. One disadvantage is the use of the winch for logging--a two-man operation with long delays while the operator waits for the swamper.

Maintenance: Easy to service.

Condition of machine: The machine studied was nine years old and had been recently rebuilt. It is a track-type tractor equipped with a three-speed forward and reverse power shift transmission, and a straight hydraulically-controlled dozer blade with adjustable pitch angle. One hydraulic cylinder in the right tilting arm tilted the blade, and the left arm was manually operated to increase or decrease the pitch of the blade. The bulldozer arms were heavily fish-plated on the outside, partly for protection and partly to increase their strength.

Operator and Crew

The machine was kept in good operating condition by the operator, who was paid by stationage production. The operation was considered to be good for subgrading by all involved and the crew was satisfied with the machine and its performance.

Effect of Right-of-Way Falling on Subgrading

The right-of-way was felled 70 to 100 ft (20 to 30 m) wide with the timber parallel to the centerline. Trees on the upper half of the right-of-way tended to fall toward the center. Bucking was poor. The skidder doing the logging had difficulty freeing the long logs and required assistance from the bulldozer.

Multipass Subgrading System

The bulldozer constructed a 50 ft (15 m)-long path in the pioneering phase by moving the logs and tree tops to the side and flattening the ground.

A Timberjack Skidder Model No. 404 worked with the bulldozer much of the time to skid the right-of-way logs. The skidder piled the logs on landings to facilitate truck loading and to allow the bulldozer to spend more time moving earth. In the road section studied the skidder was not fully utilized. When the skidder logged, the bulldozer idled. When the bulldozer worked, the skidder was shut down or waited for the bulldozer to open up another section of the right-of-way for logging.

LOGGING

The skidder hauled the logs to the log decks from a distance of 200 to 500 ft (60 to 150 m) (Figure 2-a). While the skidder logged, the bulldozer usually stood by and was nonproductive.

The logging operation often required two men. Although many of the turns were hooked up to the skidder by the skidder operator himself, at other times he needed the help of the bulldozer operator who could substitute as chokerman for the skidder. When the bulldozer logged, the skidder operator acted as swamper.

Figure 2-a. Timberjack 404 skidder yarding logs on the right-of-way

The crew was careful not to damage the logs and to salvage every valuable piece. Logs lying diagonally between stumps were first freed one by one before the load was hooked up to the machines for yarding.

The bulldozer also used its blade for moving logs out of the way. Chokers were fastened to the dozer blade and the logs pulled a shorter distance or they were simply pushed with the blade. Pushing the logs around did result in some surface damage and breakage but this technique was used only to move logs a very short distance.

The skidder had difficulty piling the logs high on the log deck and the bulldozer built many of the piles (Figure 2-b). Because the skidder did most of the logging, we could not get enough data to indicate the logging productivity of the bulldozer.

Figure 2-b. Bulldozer preparing a log deck

STUMPING

The bulldozer had more difficulty stumping than the other three machines. It was the one machine which could not lift stumps; it could only push them.

Stumping was simple on level ground. The operator usually cut or tore the roots off two sides of the stump with the corner of the blade and then cut under it until he was able to bulldoze it out. Before he could bulldoze some of the large stumps, most of the major roots had to be ripped off. After the stumps were pulled from the ground the bulldozer could easily push them any distance (with the exception of very large stumps). Small stumps with a diameter of a foot (30.5 cm) or under were removed with the topsoil during the stripping process by cutting the dirt from under them. Stumps left for anchors in case the machine became stuck in a mud-hole or between logs or stumps were usually removed after the stripping phase of subgrade construction (Figure 2-c).

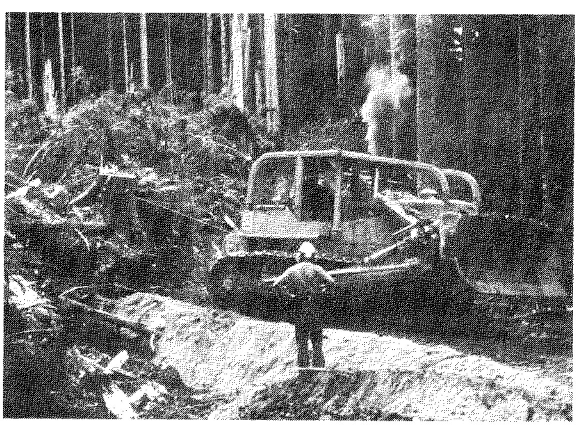


Figure 2-c.Bulldozer removes an anchor stump

Table 2-1 fails to show the machine's difficulty approaching the stump root system, or the distance the stump had to be moved--and these factors contributed to the variation reflected in the production figures. Because of the difficulty in handling very large stumps the operator tried to move them the shortest possible distance, while small stumps were freely moved to the best location. For this reason the machine sometimes spent more time moving a small stump than moving some of the large ones.

EXCAVATION

Starting at the center of the road a light cut was made just big enough for the machine. The excavation on this section was continued by widening and lowering to the subgrade level, and the operator was careful to remove all organic material to the side and to keep the road from getting muddy. The waste material was used to build large flat areas for the log decks and in fact some sections of the road were double width, either because the log decks were close to each other or because the operator had an excessive amount of excavation material to waste (Figure 2-b).

After the subgrade was shaped, it was smoothed out and covered with more good quality mineral soil from the cutbank (Figure 2-d). In this pass the operator utilized the pockets of sand found in the cutbank.

DITCHING

The last phase of subgrading was ditching (Figure 2-e). By angling and tilting the bulldozer blade, the operator built a ditch about two feet (0.6 m) deep and five feet (1.5 m) wide. The blade acted like a giant plow, cutting the material out of

Table 2-1. Stumping Productivity: Bulldozer

Section	No. of Stumps	Av. Diameter (in.)	(cm)	Removal Time (hours)	Production Rate (stumps/hr)
1000-950					
950-900	6.3	26.8	68.1	0.30	20.8
900-850	7.0	26.4	67.1	0.26	26.5
850-800	6.0	25.9	65.8	0.24	24.6
800-750	6.7	28.3	71.9	0.25	26.5
750-700	3.7	28.9	73.4	0.15	24.9
700-650	2.7	32.7	83.1	0.10	26.1
650-600	2.0	27.0	68.6	0.09	22.7
600-550	3.7	25.8	65.5	0.13	29.3
550-500	6.3	27.7	70.4	0.24	25.8
500-450					
Average	5.4	27.8	70.6	0.22	24.3

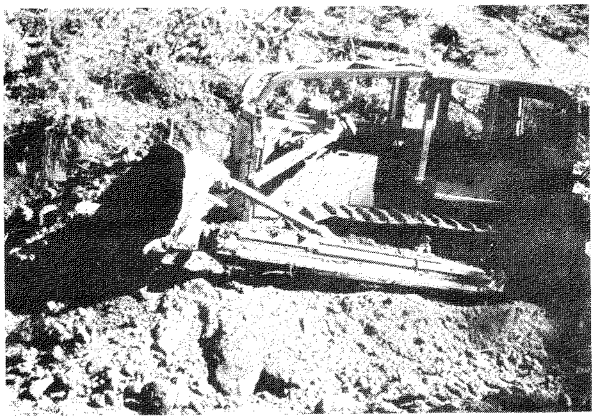


Figure 2-d. Bulldozer excavates soil from cutbank.

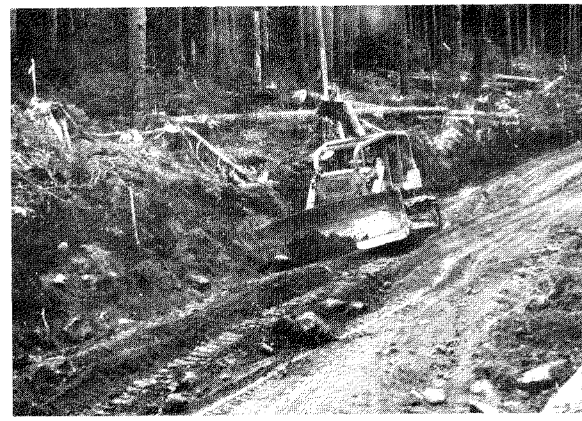


Figure 2-e. Bulldozer prepares ditch.

the ditch and placing it on the subgrade crown. As a final touch to each completed section, the operator shaped the subgrade, back-bladed and compacted the road by walking it down. After completion, the road surface was hard enough to support a loaded pickup truck.

Table 2-2 gives excavation productivity figures for the bulldozer.

One of the reasons for the production fluctuation is the distance the machine moved the material, which varied from a few feet to over 200 ft (60 m).

In sections where the machine sidecast most of the material, the production was around 300 yd^3/hr ($230 m^3/h$) and where the machine had to carry a few loads up to 200 ft (60 m) in distance the production dropped to around 100 yd^3/hr (76 m^3/h).

Excavation productivity was also influenced by the location of the pioneering tote road. When the subgrade was excavated down close to the desired elevation, the machine had difficulty in widening it into the cutbank to improve the alignment.

Table 2-2. Excavation Productivity: Caterpillar D8H Bulldozer (Imperial Units)

Section	Clearing Rate (ac/hr)	Excavation (bank yd^3)	Excavation Time (hours)	Production Rate (bank yd^3/hr)
1000-950				
950-900	0.26	225.9	1.83	123.6
900-850	0.26	191.3	1.73	110.8
850-800	0.41	151.8	1.51	100.3
800-750	0.38	136.4	1.01	135.4
750-700	0.43	131.9	0.71	184.7
700-650	0.29	104.6	0.49	212.2
650-600	0.23	128.0	0.31	406.6
600-550	0.23	228.4	0.49	461.0
550-500	0.24	360.4	1.37	262.6
500-450				
Average	0.28	211.7	1.22	173.8

Average cut cross-section: 119.8 ft^2

Table 2-2. Excavation Productivity: Caterpillar D8H Bulldozer (SI Units)

Section	Clearing Rate (ha/h)	Excavation (bank m³)	Excavation Time (hours)	Production Rate (bank m³/h)
1000-950				
950-900	0.11	172.7	1.83	94.5
900-850	0.11	146.3	1.73	84.7
850-800	0.17	116.1	1.51	76.7
800-750	0.15	104.3	1.01	103.5
750-700	0.17	100.8	0.71	141.2
700-650	0.12	80.0	0.50	162.2
650-600	0.09	97.9	0.31	310.9
600-550	0.09	174.6	0.49	352.5
550-500	0.10	275.5	1.37	200.8
500-450				
Average	0.11	161.9	1.22	132.9

Average cut cross-section: 11.13 m²

DISTRIBUTION OF SCHEDULED TIME: CATERPILLAR D8H BULLDOZER

The data for the study were obtained during full-time observation of eight separate shifts in September 1976 (Figure 2-f).

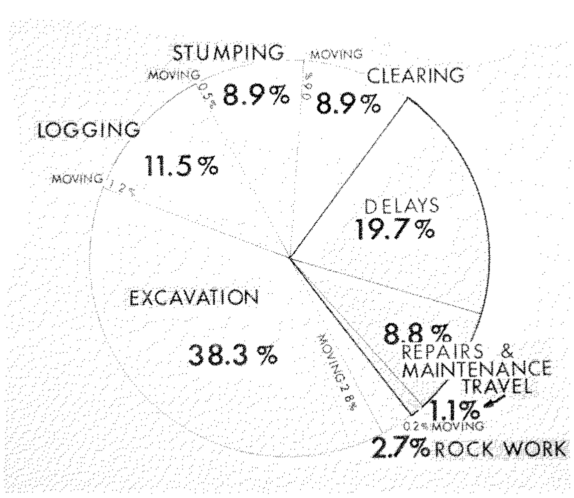


Figure 2-f. Percentage Distribution of Scheduled Time

Even though a Timberjack 404 skidder did most of the logging, the bulldozer still spent 11.5% of its scheduled time helping the skidder and organizing log piles on the log decks. All the other machines, (with the exception of the line shovel), had a delay factor of about 7%, compared with the bulldozer's 19.7%. Fifteen percent of the bulldozer's time was spent idling, keeping out of the skidder's way, or waiting for it.

The 8.9% stumping time (higher than for any of the others) indicates the difficulty this machine has with stumps and shows the longer distances it moves them.

QUALITY OF COMPLETED SUBGRADE

The bulldozer produced the best quality subgrade in our study series, a subgrade good enough to be used as a completed logging road. Only mineral soil was used for the top of the subgrade which supported the running surface (Figure 2-g).

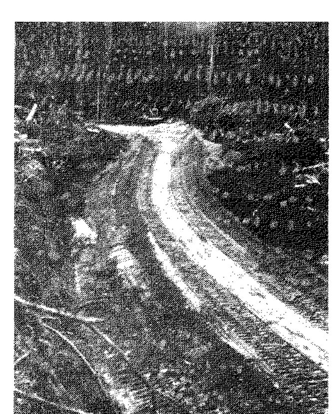


Figure 2-g. Mineral soil was used to finish the subgrade.

The road was well shaped with a good ditch. The Roughness Indicator (Appendix III) was 6.03 ft^2/sta (1.84 $m^2/100m$), indicating a good, even, road surface. The cut slopes were not well finished, however. Frequent vertical slopes with overhang on the top resulted from the extra material excavated at the toe of the cut to cover the road surface. The machine did not have the capability to shape the slope from the finished subgrade level. Ditches could be maintained easily. The gently sloping ditch-side and the absence of ballasting reduced the potential damage from sloughing and would enable the road-grader to clean the ditches easily.

SUBGRADING TECHNIQUE IMPROVEMENT

The technique of right-of-way falling affected the bulldozer more than it did the other types of equipment. This machine works on a longer section of the road (50 to 100 ft) (15 to 30 m) at the same time. While the other machines only have to move the logs within their stationary reach, the bulldozer, not being able to sidecast them, has to move them out of the working section. For this reason the bulldozer spends more time logging. Log yarding and treetop removal slow down construction. Too much timber felled on the centerline lowers bulldozer production--unless logging can be done with another machine without reducing subgrading production.

We might note here that the right-of-way should not be felled wider than necessary for the excavation and the deposition of waste material and fill. It is better to have the toe of the fill in the timber edge on a narrow right-of-way than to cover up logs with the fill on a wide right-of-way where some logs are left behind. If right-of-way widening or subsequent falling on a setting is needed, this should be started only after the subgrade has been built.

Considerable time was spent on preparing log decks and building log piles. A cable grapple-loader was used to load the trucks. the loader had a boom with snorkel extension to give it long reach. Whether or not the logs were laid on the road or a short distance away from it, the loader could reach them easily. When a cable machine is loading the logging trucks, it is not necessary to spend time organizing log piles. Logs scattered on the fill side within easy reach could be loaded out almost as efficiently as logs in the pile. The log-loader operator has time between logging trucks to prepare a log pile so that he can load without delay. In our case, the log-loader idled between truckloads because the log piles were prepared by the bulldozer.

When the side cut reached about ten feet (3 m) in height, the machine was no longer able to widen the subgrade. To overcome this problem we would recommend another method, the following four-pass system. (This should work well on slopes gentle enough for the machine to work downhill.)

1. Build about 200 ft (60 m) of tote road on the upper side of the centerline. Complete all logging before starting other phases.
2. Strip debris and topsoil from the top of the cut to the outside edge of the future crown, working straight downhill (or obliquely, if the slope is too steep). This phase normally proceeds from the far end backward.
3. Going back to the original starting point, build subgrade from the exposed mineral soil. This work starts at the top of the cut and works down progressively to final grade. No overhang remains in the cut.
4. Excavate the ditch, using material to crown the surface of the road. Construct cross-ditches for drainage (or install culverts if feasible).

MACHINE IMPROVEMENT

The bulldozer was well equipped to carry out the work; other available options would be a matter of economics or personal taste.

It might benefit if a small logging arch were mounted over the winch to help lift one end of the logs and reduce hangups and damage. Such an arch would not reduce subgrade productivity to any extent and would improve the machine's ability to reach over the bank to yard the logs without digging into the hillside.

CASE STUDY 3

AMERICAN MODEL 750C LINE (DIPPER) SHOVEL

EQUIPMENT DESCRIPTION

Manufacturer's Specifications

Engine:	GM 6-71, 6-cylinder diesel Flywheel horsepower: 175 at 1,800 rpm
Bucket:	Amsco 1 1/2-yd^3 (1.15 m^3) shovel dipper
Tracks:	Width: 27 in. (0.69 m) Crawler bearing length: 142 in. (3.61 m)
Ground Clearance:	13 in. (0.33 m)
Working Range:	Maximum horizontal reach: 35 ft 6 in. (10.82 m) at 40 degrees boom angle Maximum level digging reach: 20 ft 4 in. (6.20 m) Maximum vertical reach: 26 ft 6 in. (8.08 m) Maximum depth: 10 ft 5 in. (3.17 m) Maximum travel speed: 0.9 mph (1.4 km/h)

Auxiliary Equipment

The machine worked from a set of shovel mats to be more effective under soft ground conditions. The set covered an area 20 X 30 ft (6.10 X 9.14 m), made up by five 3-log pads, 20 X 5 ft 4 in. (6.10 X 1.63 m). The shovel towed a fuel sleigh (Figure 3-a) with enough fuel to last two weeks. Tools, oil, grease, maintenance and repair equipment were also stored on the sleigh with the necessary replacement parts.

Figure 3-a. Completed subgrade with fuel sleigh in foreground

Line Shovel Characteristics for Road Building

Reach: Has a permanently-fixed bucket which makes handling and sorting soil difficult at the perimeter of its reach.

Flotation: Of the four machines studied, the line shovel was the best producer on soft, swampy ground. However it normally has low flotation and uses mats on most ground--restricting its mobility and necessitating the use of a fuel sleigh (Figure 3-a).

Speed: Has a slow travelling speed, especially on mats, and this restricts the machine to a one-pass subgrading system where the material sorting is not as good as in multipass systems. Higher ballasting costs can result.

Working Speed Test: 0.74 minutes (Appendix IV).

Operator comfort: The line shovel cab is an extension of the engine compartment, exposing the operator to fumes and noise. There is no heating or cooling system and the steel-plate cab seat is contoured but not comfortable. (Readers should check manufacturers for later designs which can modify such features.)

Visibility: The operator's field of vision is reasonably good but is somewhat blocked by the bucket.

Ease of operation: Difficult to operate; new operators need a comparatively long break-in period to learn how to use its many controls and levers and to synchronize the actions of brakes and clutches.

Maintenance: Requires a time-consuming, complicated daily maintenance schedule, but the machine is easy to repair if there is a breakdown.

Condition of machine: The machine studied was 20 years old. (Note: the line shovel has a "long expected machine life," a factor in reducing ownership costs.)

The controls for the most frequently-used functions of the machine (moving the crowd, retract, hoist lines and the swing) were air-operated. Controls for operating the boom and for travel were mechanical. The dipper trip was activated by an air cylinder on the boom.

Operator and Crew

The contractor who owned the shovel was paid by stationage produced. The crew was paid by the hour and the operator received a station bonus.

Those involved with the performance of the machine were generally satisfied with it although some concern was voiced about the muddy state of the subgrade it produced. The crew also expressed an interest in operating a modernized version of the machine.

Effect of Right-of-Way Falling on Subgrading

The right-of-way was felled 60 to 80 feet (18 to 24 m) wide, with trees parallel to the centerline. The faller was under pressure to get ahead of the shovel and confined his bucking to the largest timber. This left many large-diameter trees which were only topped.

One Pass-Subgrading System

The machine completed every phase of subgrading in one pass.

LOGGING

Because of poor bucking, the logs were too long and there was breakage loss. Occasionally the machine had to break the logs into easily-handled sizes in order to move them or store them in piles.

Most of the logging was done with the help of an extra man and a set of loading tongs (Figure 3-b). The padman would attach the tongs to the bucket and the operator would set them on the logs without the padman's help.

The tongs used were not suitable for handling small logs, and when the operator used the bucket he had difficulty placing the logs in a pile. Because the tongs were not big enough, very large logs were rolled and pushed around to the right location with the bucket's side and teeth. Chokers were not used and as the loading tongs were too small for large logs, pushing and rolling was the only way to move them and many were damaged. Logging productivity with the line shovel is shown in Table 3-1.

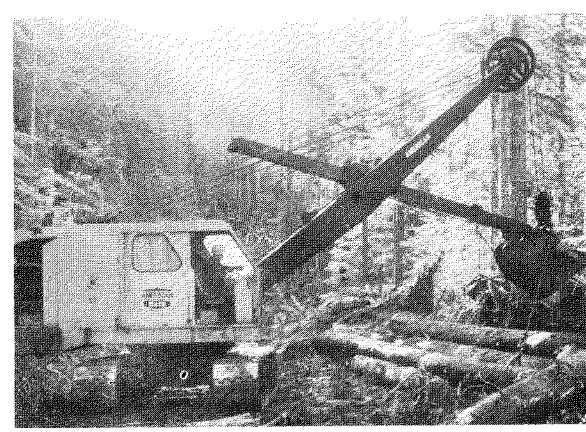


Figure 3-b. Line shovel handling logs with a set of loading tongs

Because many of the trees were left tree-length during the right-of-way falling, the shovel did much of the bucking. (Often the machine spent additional time producing a large log it could handle without further damage.)

The production rate of 39.8 logs-per-hour is equivalent to 0.03 hours, or 1.51 minutes per log.

Table 3-1. Logging Productivity: Line Shovel

Section	No. of Logs	Av. Log Size (ft³)	Av. Log Size (m³)	Logging Time (hours)	Production Rate (logs/hr)
150A-100A					
100A- 50A	11.7	67.0	1.90	0.30	38.6
50A- 0	9.7	60.0	1.70	0.28	35.0
0- 50	11.3	54.8	1.55	0.27	41.6
50-100	11.3	42.3	1.20	0.25	45.4
100-150	11.7	58.6	1.66	0.24	47.9
150-200	15.7	52.7	1.49	0.37	42.4
200-250	15.3	60.6	1.72	0.37	41.7
250-300	13.3	53.4	1.51	0.28	47.5
300-350	10.7	47.4	1.34	0.21	49.8
350-400	11.3	71.5	2.02	0.34	33.5
400-450	9.7	113.3	3.21	0.34	28.5
450-500					
Average	12.1	65.5	1.85	0.30	39.8

STUMPING

The line shovel was able to dig the stumps and cut the roots on three sides but it could not work on the far side of the stump. After cutting the roots, the operator would turn the stump on its side away from the machine, or to the downhill side of the stump, breaking away most of the remaining roots (Figure 3-c). Once the stump was on its side, he would reach under it again to cut the large roots still attached to the ground. Then he would roll the stump further or lift it up by resting most of it on the bucket and then sidecasting it.

When stumps were too big for the shovel to handle in one piece the operator would rip off the major roots before attempting to turn them, or he would split these stumps and move them in pieces. In cases where the stump was too big to be pulled out easily, even though the machine could get a grip on it, the machine's lever action was used. The operator placed the bucket under the stump, raised the machine up and let it fall, catching it with the brakes half way down. The impact of the fall yanked the stump out of the ground. (This method causes wear on lines and brakes but the machine was never raised high enough to be accidentally damaged by falling on the ground.)

The shovel produced the best digging force on stumps close to the machine but the further the stumps were from the machine the more difficulty it had moving them. It could not remove large stumps from the outer 20% of its reach.

Table 3-2. Stumping Productivity: Line Shovel

Section	No. of Stumps	Av. Diameter (in.)	Av. Diameter (cm)	Removal Time (hours)	Production Rate (stumps/hr)
150A-100A					
100A- 50A	8.0	20.0	50.8	0.15	51.6
50A- 0	5.7	24.3	61.7	0.12	48.9
0- 50	6.3	25.4	64.5	0.14	46.4
50-100	5.7	22.3	56.6	0.12	48.0
100-150	10.0	18.1	46.0	0.15	65.6
150-200	11.0	18.7	47.5	0.16	70.1
200-250	11.7	19.6	49.8	0.20	57.6
250-300	8.3	24.2	61.5	0.20	41.9
300-350	9.3	21.3	54.1	0.22	43.0
350-400	8.0	21.6	54.9	0.15	52.3
400-450	9.3	19.3	49.0	0.14	64.2
450-500					
Average	8.4	21.0	53.3	0.16	52.9

The average stumping productivity of 52.9 stumps per hour could also be expressed as 0.02 hours/stump or 1.13 minutes per stump.

Stumps and other waste material were sidecast to the low side of the subgrade and covered up with dirt. They were seldom visible from the road after construction was finished. Some debris was covered up under the edge of the subgrade's crown, but stumps were moved further away. Stumping productivity is shown in Table 3-2.

Figure 3-c. The line shovel uproots a large stump.

Stumps closer to the machine were quickly uprooted while stumps further away were not so easy to dig out. There was also a time element in moving the stumps at a distance because it took less time to roll a large stump over a five-foot distance than to move a small stump in the bucket from the top of the cut to the bottom of the fill.

EXCAVATION

The line shovel's travel speed was slow because the machine was confined to shovel mats and could not walk on the subgrade. A small hook attached to the bucket was used to swing the mats around from behind the machine to the front. The operator could hook most of the shovel mats without a second man helping.

The machine had a reasonably good reach and could perform the work around the mats. After logging and stumping, the operator continued with clearing. He removed most of the waste material and some of the topsoil and sidecast it. Larger pieces of waste material such as treetops, branches, small trees, rotten logs, and some small green stumps were mulched up and pulverized, then moved to the side and covered up with dirt to achieve an orderly-looking subgrade.

Along the road a large dirt pile from the excavation material built up because the machine could not leave the mats to push the material off with the bucket. The machine had a somewhat similar problem when it tried to move the logs further out to the side or behind.

Spreading three or four inches (7 to 10 cm) of mineral soil over the grade and smoothing it with the bucket (Figure 3-d) helped the appearance of the grade and saved some ballasting material. The machine's vibrating action helped compact the ground. (The shovel mats were not placed close to each other and made an indentation on the ground.)

Table 3-3. Excavation Productivity: American 750C Line Shovel (Imperial Units)

Section	Clearing Rate (ac/hr)	Excavation (bank yd³)	Excavation Time (hours)	Production Rate (bank yd³/hr)
150A-100A				
100A- 50A	0.22	228.1	0.92	247.9
50A- 0	0.16	200.3	0.73	273.5
0- 50	0.16	176.2	0.74	237.7
50-100	0.17	162.6	0.71	230.0
100-150	0.21	154.4	0.72	214.4
150-200	0.21	141.6	0.65	219.1
200-250	0.34	133.9	0.71	189.3
250-300	0.45	128.6	0.75	172.5
300-350	0.71	123.2	0.76	162.0
350-400	0.27	117.0	0.73	159.7
400-450	0.19	127.5	0.67	191.0
450-500				
Average	0.23	160.9	0.76	212.5

Average cut cross-section: 89.9 ft²

Table 3-3. Excavation Productivity: American 750C Line Shovel (SI Units)

Section	Clearing Rate (ha/h)	Excavation (bank m^3)	Excavation Time (hours)	Production Rate (bank m^3/h)
150A-100A				
100A- 50A	0.09	174.3	0.92	189.5
50A- 0	0.06	153.1	0.73	209.1
0- 50	0.06	134.7	0.74	181.7
50-100	0.07	124.3	0.71	175.8
100-150	0.08	118.0	0.72	163.9
150-200	0.08	108.3	0.65	167.5
200-250	0.14	102.4	0.71	144.7
250-300	0.18	98.3	0.75	131.9
300-350	0.29	94.2	0.76	123.9
350-400	0.11	89.5	0.73	122.1
400-450	0.08	97.5	0.67	146.0
450-500				
Average	0.09	123.0	0.76	162.5

Average cut cross-section: 8.35 m^2

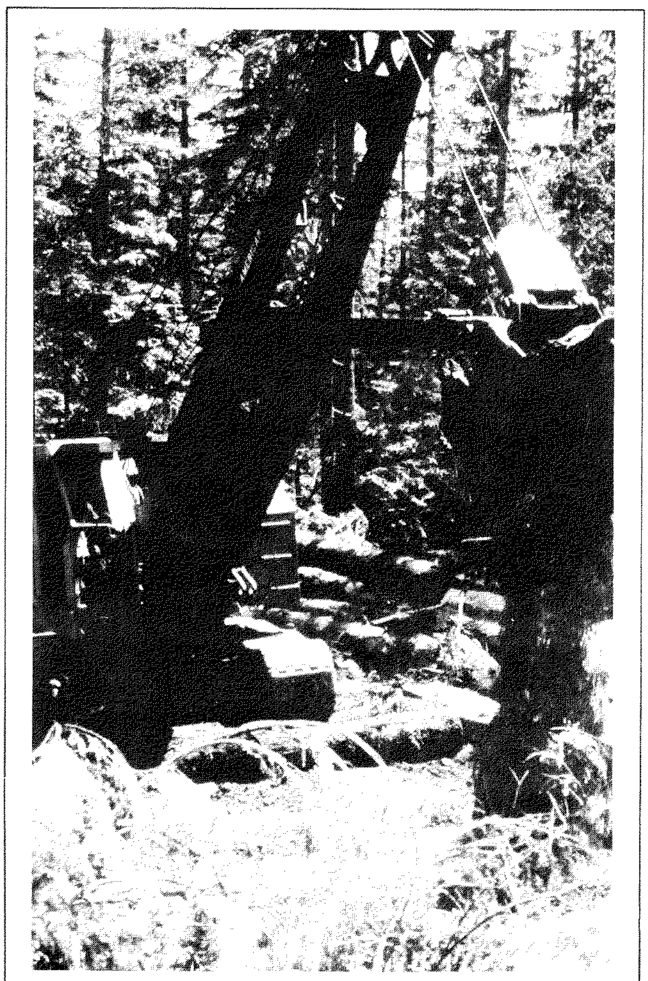


Figure 3-d. The line shovel covers the subgrade with a light layer of clean mineral soil.

The operator was motivated by a station bonus and did not have definite subgrading instruction or a profile, but he did his best to produce as much subgrade as he could with a minimum amount of digging. Table 3-3 shows the excavation productivity rate for the line shovel.

The figures in Table 3-3 represent running averages of the three adjoining sections.

Some of the variation in the section production figures was caused partly by the machine's difficulty in lowering the subgrade in hard ground to achieve good vertical alignment, and in getting rid of the excess excavation material.

DITCHING

After building a flat crown for the subgrade, the operator completed the excavation by digging a ditch in the hard mineral soil on the upper side of the road. This material was spread over the subgrade, giving it a hard, smooth surface and also sealing the organic soil underneath to make it somewhat water-repellent. The shovel had difficulty excavating the hard ditch material.

DISTRIBUTION OF SCHEDULED TIME: AMERICAN 750C LINE SHOVEL

The data for the study of this machine were obtained during full-time observation of six consecutive 10-hour shifts in July 1976.

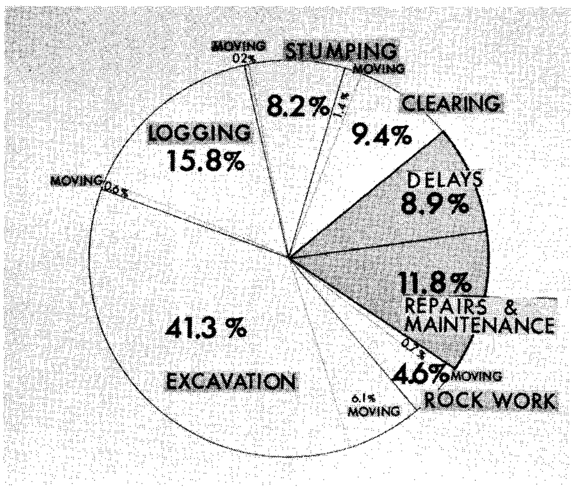


Figure 3-e. Percentage Distribution of Scheduled Time

Figure 3-e indicates how few repairs were needed on a machine as old as this one. A large amount of this time was spent on daily maintenance carried out by a two-man crew.

QUALITY OF COMPLETED SUBGRADE

The quality of this subgrade was reasonably good, although it was constructed of muddy organic soil. Despite the fact that initially it was difficult to walk around the machine without sinking into mud, the subgrade firmed up within several days. (It was firm by the time ballasting took place, because the ballasting crew was usually about 1,500 feet (450 m) behind the shovel and the subgrade had time to dry out.) However, because of the subgrade's high organic content it did not stand up to logging traffic and required extensive maintenance.

The finished subgrade was considered smooth; using mats had a positive effect. Levelling out the ground with a sweeping movement of the bucket did not make it as smooth as it became after the mats were used.

The Roughness Indicator (Appendix III) was 8.32 ft^2/sta (2.54 $m^2/100$ m), confirming an acceptable subgrade quality.

SUBGRADING TECHNIQUE IMPROVEMENT

The machine used a one-pass subgrading system and it would be hard to alter the technique, although cutting down another six inches could have eliminated most of the mud on the subgrade, saving on ballasting and future maintenance.

MACHINE IMPROVEMENTS

The machine required daily maintenance on the boom and on the track rollers. Most of the lubrication was done outside scheduled work time, during lunchtime or after quitting time. Permanently-lubricated track rollers and idlers would help cut down on maintenance time and would eliminate the danger of these service points being neglected. A centralized lubrication system for the boom would make the daily routine of climbing it unnecessary, eliminating a safety hazard.

CASE STUDY 4

POCLAIN HC300 HYDRAULIC SHOVEL (LOADER)

EQUIPMENT DESCRIPTION

Manufacturer's Specifications

Engine:	GM 8V-71 diesel Flywheel horsepower: 233 at 1,800 rpm
Bucket:	Bite width: 71 in. (1.80 m) Capacity: 3¼ yd^3 (2.5 m^3) struck
Tracks:	Width: 34 in. (0.86 m) Crawler bearing length: 147 in. (3.73 m) Clearance: 23 in. (0.58 m)
Working Range:	Maximum level reach: 27 ft 2 in. (8.28 m) Maximum vertical reach: 25 ft 1 in. (7.65 m) Maximum depth: 11 ft 10 in. (3.61 m) Maximum travel speed: 0.72 mph (1.16 km/h)
Hydraulic System:	A high pressure (4,550 psi (320 bar) at 2,100 rpm) hydraulic system operates the working circuits to power the boom, stick, bucket, swing and travel.

Mechanical Description

Each track was powered by a one-speed hydraulic motor with a maximum specified speed of 0.72 mph (1.16 km/h), and the tracks were triple-ribbed and tended to chew into the shovel mats. The mats covered an area of 18 feet (5.5 m) wide and in varying lengths, depending on the spacing of the pads. (A set of mats lasts for 2 to 2½ months, depending on ground conditions.)

Hydraulic swing motors were mounted outside the large ring gear. An air-operated grease gun helped to reduce the time needed to tension the tracks.

The Poclain HC300 has a ground pressure of less than 12 lb/in.^{2} (0.84 kg/cm^2). The machine had been specially adapted to logging road subgrading conditions and was equipped with a loader front. A heavy steel cage was built around the operator's cab to protect him from possible accidents. The engine compartment was also protected on the sides by an angle-iron screening. A large fuel tank was mounted over the counterweight so that the machine could operate for several days without refuelling. Because the ballasting crew worked only a few hundred feet behind it, the machine had no need of a fuel sleigh.

Extra hydraulic oil, grease, and other necessary equipment for maintenance and repairs were also stored on the machine. A holder for loading tongs and a small winch were located on its right side.

Hydraulic Shovel Characteristics for Road Building

Reach: Has a short reach, making it difficult to shape high cutbanks.

Bucket design: Large bucket is not designed to produce smooth cutbanks and subgrade finish, or to dig out stumps; it creates a rough ditch-line which does not channel water properly and which leads to sloughing. The machine had difficulty excavating hard material.

Flotation: Uses shovel mats most of the time because the machine tends to create a muddy subgrade on soft ground. On hard ground, however, its flotation is reasonably good.

Speed: Has a slow travelling speed.

Working Speed Test: 0.98 minutes (Appendix IV)

Operator comfort: Cab most comfortable of the four studied; the operator is well protected in a ventilated cab.

Visibility: Has fair visibility conditions, but the large bucket obscured much of the work activity. Windshield easily cleaned.

Ease of operation: Difficult to operate. (Newer models of the Poclain 300 line have joystick control system which is a considerable improvement over the mechanical levers of the older model used in our study.)

Maintenance: Easy to service. One disadvantage is that neither motor drives nor ring gear are protected and debris and brush can get inside.

Condition of machine: The machine studied was five years old. It was powered by a 2-pump hydraulic system operating at a working pressure of 4,550 psi (320 bar). The operator manipulates a number of mechanical levers to open and close hydraulic valves in order to control the machine. (The mechanical travel lever was later replaced with air control.)

Operator and Crew

The crew was paid an hourly rate and in addition the operator received a station bonus. Daily maintenance and smaller repairs were carried out by the crew. Mechanical help was readily available for more difficult repair jobs.

The crew was generally satisfied with the machine and its performance.

Effect of Right-of-Way Falling on Subgrading

The right-of-way was felled in an orderly manner 80 feet (24 m) wide. Trees were parallel to the centerline and bucking was good. The right-of-way timber did not affect the logging ability of the machine.

One-Pass Subgrading System

The machine completed every phase of subgrading in one pass.

LOGGING

Because of its short reach the machine had difficulty logging without using loading tongs. The operator could only poke at many of the logs and this was an inefficient way of moving them. Once he got hold of the log, he placed it on the fill side of the machine or slightly ahead of the mats on the fill side, but always close to the shovel. During the excavation stages of subgrading many of the logs became partly buried. To prevent this an attempt was made to pile the logs by using the bucket. Logs were damaged during this process and the piles themselves had a messy, disorganized appearance.


Figure 4-a. Hydraulic shovel moving log on the bucket

The most convenient way for the hydraulic shovel to move logs was to use the wide bucket as a platform (Figure 4-a). The logs were moved close enough to the machine so they could be positioned perpendicular to the boom and the operator used the bucket teeth to drag the logs closer to the machine and turn them to the right position. Once the log was in place, he put the bucket teeth underneath it and curled the bucket up to the horizontal position so the log was balanced over the bucket, resting across the side edges, and held in place by the bucket teeth on one side and the lower end of the stick on the other. Logs in this position were swung to the side and rolled downhill. (Although the bucket teeth were used for positioning, they caused only superficial damage to the logs in this phase.) In cases where the logs were difficult to pull closer to the machine or hard to balance, or where they were lying on the centerline or below it in the direction of the machine, the operator usually moved them, one end at a time, by resting them between the vertical bucket teeth. In this position, the machine swung the log end downhill until it fell or dropped off the bucket.

Once the machine was positioned closer to the log, it would finish moving it by using the bucket teeth to push it away or by using the bucket itself as a bulldozer blade to move it to the lower side of the right-of-way. When the bucket teeth handled the log this way damage was done to one end of it and some breakage occurred at the other. Logs with rot in them--especially decadent cedar logs--seldom survived moving. Most of them were pulverized and became part of the fill (Figure 4-b).

Valuable larger logs which were too far away to be moved with the bucket were moved with a set of loading tongs. The tongs were stored in a holder welded to the guard rail on top of the engine compartment and hoisted up there with the help of a small winch. When in use they were attached to the bucket on a short cable strap. It was the padman's job to hang the tongs on the strap when they were needed and most of the time he set the tongs on the logs. The operator then placed the logs on the side of the fill, or in piles for storage. Handling the logs this way eliminated most of the damage.

Table 4-1 shows the logging productivity of the hydraulic shovel.

Many of the larger logs were laboriously shoved out of the machine's way because the machine had difficulty handling them. It was able to move smaller logs further away. The operator also spent time with some of the long, smaller-diameter logs, trying to get them to balance over the bucket.

Figure 4-b. Damaged decadent cedar logs

STUMPING

The Poclain HC300 was able to remove all the stumps without the need for blasting. The short reach of the machine was a hindrance to the crew for this function, however (as it was for the other phases of subgrading), because only those stumps close to the machine could be easily moved.

Table 4-1. Logging Productivity: Hydraulic Shovel

Section	No. of Logs	Av. Log Size (ft^3)	Av. Log Size (m^3)	Logging Time (hours)	Production Rate (logs/hr)
150A-100A					
100A- 50A	8.7	73.2	2.07	0.20	43.2
50A- 0	8.3	83.3	2.36	0.25	33.5
0 - 50	9.0	77.7	2.20	0.29	30.8
50 -100	11.3	48.9	1.38	0.35	32.3
100 -150	14.3	45.9	1.30	0.52	27.6
150 -200	17.0	56.2	1.59	0.57	29.9
200 -250	13.7	65.8	1.86	0.44	30.9
250 -300	12.3	61.7	1.75	0.25	50.0
300 -350	6.7	62.4	1.77	0.11	60.2
350 -400	7.3	49.1	1.39	0.14	51.5
400 -450	5.3	62.8	1.78	0.21	25.2
450 -500	7.0	69.1	1.96	0.26	27.2
500 -550	6.3	127.7	3.62	0.25	25.3
550 -600	6.0	133.1	3.77	0.23	26.3
600 -650	5.0	88.5	2.51	0.19	26.3
650 -700	4.7	67.5	1.91	0.16	29.5
700 -750	5.3	57.9	1.64	0.20	26.0
750 -800	6.0	52.7	1.49	0.23	25.9
800 -850					
Average	8.5	60.2	1.70	0.26	32.6

The 32.6 logs/hour production rate is equivalent to 0.03 hours per log or 1.84 minutes per log.

As a rule, the machine could dig on low sides of the stump and cut the roots in front of it. Then with a twisting motion, the stump was spun around, tearing the rest of the roots out of the ground. Once the roots were loose, the operator could reach under the stump with the bucket and lift it up. He was able to rest any size stump on the large bucket and sidecast it. For the sake of convenience, the stumps were dropped off close to the subgrade fill section or rolled to a place where they would not be in the way of the other phases of subgrade construction. Some of the stumps were only moved as far as the fill side of the subgrade and were buried under the road with fill.

When it was difficult to dig out large stumps, the operator split them in sections. He placed the protruding center bucket teeth on the stump and split it by bearing down.

Some of the small stumps were dug out at the limit of the machine's working range, moved a long distance, and sidecast away from the subgrade. The machine moved as close as possible to the larger stumps and moved them the shortest possible distance, often just rolling them to the fill side of the subgrade and burying them under the road.

Stumping productivity is shown in Table 4-2.

Figure 4-c. Hydraulic shovel moving ahead on shovel mats

EXCAVATION

The machine worked from a set of shovel mats (Figure 4-c), completing every phase of subgrading on a ten-foot (3-m) section of the road before moving two pads ahead to do another ten feet (3 m).

This machine has a practical reach of only 20 feet (6 m). To save moving time the operator tried to do all the ditching at the side of the mats and had

Table 4-2. Stumping Productivity: Hydraulic Shovel

Section	No. of Stumps	Av. Diameter (in.)	Av. Diameter (cm)	Removal Time (hours)	Production Rate (stumps/hr)
150A-100A					
100A- 50A	6.0	23.0	58.4	0.21	29.1
50A- 0	6.0	22.3	56.6	0.33	18.4
0- 50	4.3	20.5	52.1	0.18	23.9
50-100	3.3	19.0	48.3	0.13	26.4
100-150	5.3	17.2	43.7	0.24	21.6
150-200	5.7	19.4	49.3	0.20	27.8
200-250	6.0	18.7	47.5	0.31	19.4
250-300	4.7	19.9	50.5	0.11	41.7
300-350	4.0	20.5	52.1	0.08	53.1
350-400	3.3	22.2	56.4	0.13	26.0
400-450	4.0	21.0	53.3	0.18	22.6
450-500	5.3	18.1	46.0	0.20	26.7
500-550	6.0	16.8	42.7	0.13	45.2
550-600	5.0	20.4	51.8	0.11	45.9
600-650	3.3	22.3	56.6	0.07	43.8
650-700	2.7	24.2	61.5	0.10	25.9
700-750	3.7	15.4	39.1	0.10	35.1
750-800	4.7	15.6	39.6	0.22	21.0
800-850					
Average	4.7	19.5	49.5	0.15	30.9

The average stumping productivity of 30.9 stumps per hour could also be expressed as 0.03 hours or 1.94 minutes per stump.

difficulty penetrating the mineral soil with the bucket teeth. The bucket's spade-type cutting edge was forced into the hard ground to pry it loose. After producing about half a yard (0.4 m^3) of loose material, the operator loaded it in the bucket and used it as a fill in front of the machine.

The subgrade width was determined by the width required to accommodate the shovel mats and the machine excavated only the minimum required. Usually the topsoil and slash were moved from the upper side of the subgrade to be used as a fill on the lower side. In this process the machine utilized its large bucket to excavate the material and move a large volume in a short time despite its slow swing. (The machine seldom touched hard mineral ground except when it smoothed the ditch-line.)

The fill section of the subgrade was not cleared of debris, partly because of the machine's short reach and partly because of the poor quality of organic material used for construction. Only a few stumps and most of the large logs were removed from the fill part of the road. The smaller logs and the rest of the larger ones were covered up with mud used for fill. Stumps were sidecast or rolled to the lower side of the mats from the cut section. Some of them were unintentionally covered with waste, but generally they were not covered with fill. The fill was unsorted and contained debris, slash, stumps and logs which made it soft and wet.

Many times the large bucket was used as a bulldozer blade for grubbing in soft excavation material. The teeth were placed in a straight up and down position and were used to scrape the slash off the soil or to move the dirt. The machine performed this operation awkwardly.

Moving during excavation occupied a large segment of the machine's time. This large percentage is an indicator of the machine's slow walking speed and the time loss from walking on and off the mats. Occasionally the operator tried subgrading without using shovel mats.

DITCHING

The crew did not try to do any ditching because of the difficulties in digging hard mineral soil and the large bucket's inability to shape a small ditch properly. Instead, they finished the subgrade by sloping it to the cut side of the road where the ditch was supposed to be. Eliminating the ditch let water run over the subgrade and soak it (Figure 4-d).

Excavation productivity is shown in Table 4-3.

Table 4-3. Excavation Productivity: Poclain HC300 Hydraulic Shovel (Imperial Units)

Section	Clearing Rate (ac/hr)	Excavation (bank yd³)	Excavation Time (hours)	Production Rate (bank yd³/hr)
150A-100A				
100A- 50A	0.21	94.8	0.89	105.2
50A- 0	0.19	63.9	0.77	82.4
0- 50	0.17	61.3	0.63	97.6
50-100	0.09	91.4	0.79	115.5
100-150	0.15	131.6	0.86	152.1
150-200	0.13	134.2	0.90	149.4
200-250	0.20	96.7	0.96	101.0
250-300	0.14	54.6	0.89	61.1
300-350	0.30	42.5	0.83	51.0
350-400	0.31	65.0	0.66	97.9
400-450	0.21	82.5	0.56	147.1
450-500	0.22	81.1	0.81	99.7
500-550	0.13	71.1	1.07	66.6
550-600	0.14	65.3	1.08	60.4
600-650	0.14	64.6	1.13	57.0
650-700	0.19	66.6	0.80	82.8
700-750	0.18	75.5	0.78	96.6
750-800	0.17	101.2	0.64	157.8
800-850				
Average	0.17	84.1	0.85	98.5

Average cut cross-section: 47.5 ft^2

Figure 4-d. Flooded subgrade illustrates poor ditching.

The low production rate could have been increased slightly if the moving time had been reduced by using the shovel mats continuously or by subgrading without them.

The variation in the production rate between sections was caused mainly by the difference in walking time for each section and in the volume of hard subsoil the machine had to excavate in the sections.

Table 4-3. Excavation Productivity: Poclain HC300 Hydraulic Shovel (SI Units)

Section	Clearing Rate (ha/h)	Excavation (bank m³)	Excavation Time (hours)	Production Rate (bank m³/h)
150A-100A				
100A- 50A	0.08	72.5	0.89	80.4
50A- 0	0.08	48.9	0.77	63.0
0- 50	0.07	46.9	0.63	74.6
50-100	0.04	69.9	0.79	88.3
100-150	0.06	100.6	0.86	116.3
150-200	0.05	102.6	0.90	114.2
200-250	0.08	73.9	0.96	77.2
250-300	0.06	41.7	0.89	46.7
300-350	0.12	32.5	0.83	39.0
350-400	0.13	49.7	0.66	74.8
400-450	0.08	63.1	0.56	112.5
450-500	0.08	62.0	0.81	76.2
500-550	0.05	54.4	1.07	50.9
550-600	0.06	49.9	1.08	46.2
600-650	0.06	49.4	1.13	43.6
650-700	0.08	50.9	0.80	63.3
700-750	0.07	57.7	0.78	73.9
750-800	0.07	77.4	0.64	120.6
800-850				
Average	0.07	64.3	0.85	75.3

Average cut cross-section: 4.41 m^2

DISTRIBUTION OF SCHEDULED TIME: POCLAIN HC300 HYDRAULIC SHOVEL

The data for this machine were collected during 8 full shifts in late November and early December 1976. The weather was sunny during the day, clear and freezing overnight.

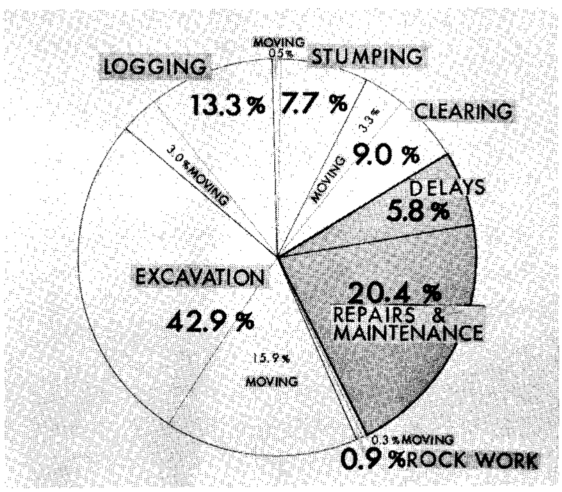


Figure 4-e. Percentage Distribution of Scheduled Time

Two breakdowns accounted for nearly 15.3% of the 20.4% of repair and maintenance time. During the study period, 2.6 hours were spent on repairing one of the swing motors. The machine was idle for another 1.9 hours when the left track jumped the idler and had to be pulled back in place.

QUALITY OF COMPLETED SUBGRADE

The subgrade looked reasonably smooth but because of mud and soft organic material used for building the fill section, the surface smoothness had little effect on the amount of ballasting material required to complete the road. Many of these problems resulted from poor construction technique.

This machine did not build a ditch. Instead the subgrade was sloped to the toe of the cutbank. At the very least, an extra 4.2 inches (10.7 cm) of ballasting material was required to compensate for the 3.7% side slope.

The use of shovel mats did not help to compact the subgrade. In muddy sections the ground was smoothed by sweeping with the bucket after the mats were moved. We estimated that in drier sections, 19.6 inches (49.8 cm) of extra ballasting would be needed to compensate for the indentions in the ground.

Our Roughness Indicator (Appendix III) for the centerline of this road was 13.20 ft^2/sta (4.02 $m^2/100m$), demonstrating a bouncy subgrade surface.

SUBGRADING TECHNIQUE IMPROVEMENT

Because it was more convenient for the crew to move logs the shortest possible distance while logging the right-of-way, the logs usually ended up at the side or in front of the machine, where many of them were partly covered with fill or pushed over in bunches with the bucket. This procedure is time-consuming and damages both the machine and the logs. Logs should be placed behind the machine on the completed fill slope where they are handled only once.

All the larger logs which require positioning should be moved by a set of loading tongs. Extra-large logs which cannot be handled with the tongs should be moved with chokers attached to the bucket.

Stumps and slash should not be discarded in the center of the road unless they are needed in the fill, but should be deposited on the sidehill close enough for the machine to cover them with waste materials and dirt. It is easier to cover stumps when they rest in their original right-side-up position. In this position - even when not covered - they blend in with the right-of-way.

Because of the soft ground the machine used a one-pass system, doing all the phases of subgrading from a set of shovel mats. When it is possible to work without shovel mats, however, a multipass system should be used, keeping the walking to a minimum. During the first pass, a tote road made of waste material and topsoil should be constructed just below the centerline. At the same time stumps, logs, and waste material should be removed and all the topsoil stripped off to expose the subsoil. The final subgrade could then be shaped out of the exposed mineral soil, the ditch could be dug, and the surface smoothed for the ballasting crew.

In spite of the machine's difficulty digging a ditch into hard subsoil, it is less expensive in the long run and creates better drainage to dig a rough ditch by widening the subgrade (but not sloping it). Nevertheless, it is a good idea to lean the subgrade slightly toward the ditch although the side slope on a green subgrade should not exceed 1:24. It will shed the water more easily and the water will not stagnate or soak in for long periods of time. When the fill side of the subgrade settles by aging or compacting during the ballasting process, the subgrade will slope evenly to both sides.

The cutbank of the road should have a proper slope and it should also be scaled of loose material and flattened to prevent future sloughing. It is at times difficult and not productive to scale the organic soil off the cutbanks working shovel style away from the machine. On long cutbanks it is better to use the bucket as a rake to clean off the organic material from the subsoil, piling it up close to the machine and bailing it by full bucket-loads.

Despite the size of its large bucket, the machine was able to smooth the surface of the subgrade. The operator should take care, however, to see that the teeth are in a level position to keep the hydraulic piston rod and rod-ends from dragging in the mud. It is also good policy when parking to prevent mud from caking to the rods by retracting the bucket.

When the operator excavates material that is soft enough for the shovel to cut in one motion, the teeth and cutting edge should do this by facing the direction of cutting. Only a thin slice should be removed, just thick enough to fill the bucket when the cut is completed. Cutting a large slice—or having the cutting edge facing in the wrong direction—produces a very rough cut-slope.

The subgrade should be built from mineral soil to reduce the amount of ballasting necessary. In the section of the road studied, cutting the subgrade down another foot could have eliminated most of the mud problems and could have saved at least the same thickness in ballasting.

MACHINE IMPROVEMENTS

The controls and control system were similar in design to those of the line shovel. Mechanically-operated levers actuated hydraulic valves. The original lever controlling the direction of travel was replaced on site with an air-control valve. (The original lever had to be pushed or pulled continuously by the operator while travelling. The new air valve needed to be turned only once.)

To sum up, the machine's control system was obviously an old design not compatible with the joystick control system we would recommend (and which has been added to later models).

An optionally-available dual displacement drive motor which increases the machine speed to 1.78 mph (2.86 km/h) would be valuable when the machine is not using mats.

The undercarriage was heavy-duty. The tracks, rollers, sprockets and idlers were open, and mud, stones and wood chunks could get in between the components and damage them or reduce their service life. Rock or mudguards which close up the lower part of the tracks could provide some protection. The rim of the idler also proved to be too small. After the edges were rounded, the tracks could not be kept tight enough to prevent them from coming off.

SUMMARY OF CASE STUDIES: PRODUCTIVITY AND COST ESTIMATION

Subgrade costs are difficult to estimate because of the many variables affecting construction time. These variables include machine productivity during each phase of the construction under the ground conditions encountered--as well as moving, waiting and other delays. The estimated construction time is multiplied by the machine-and-labour rates to give a total cost. The cost of operating the machines studied is given in Appendix V. This section of the report will provide productivity information and discuss three methods for calculating costs.

MACHINE PRODUCTIVITY

Table PC-1 shows the influence of machine speeds and productivity on subgrade construction and costs.

Table PC-1. Machine Speeds and Production

	Backhoe	Bulldozer	Line Shovel	Hydraulic Shovel
Working speed test --minutes	0.63	0.83	0.74	0.98
Estimated walking speed				
--mph	2.3	6.5	0.9	0.7
--km/h	3.7	10.5	1.4	1.2
Excavation production				
--yd^3/hr	187.2	173.8	212.5	98.5
--m^3/h	143.1	132.9	162.5	75.3

Figure PC-a shows the logging time of the three machines studied and Figure PC-b shows stumping time. These two graphs can be used for costing most subgrade construction and are used to explain the costing system on pages 32 and 33.

Figure PC-a
The Relationship Between Logging Time and Log Volume

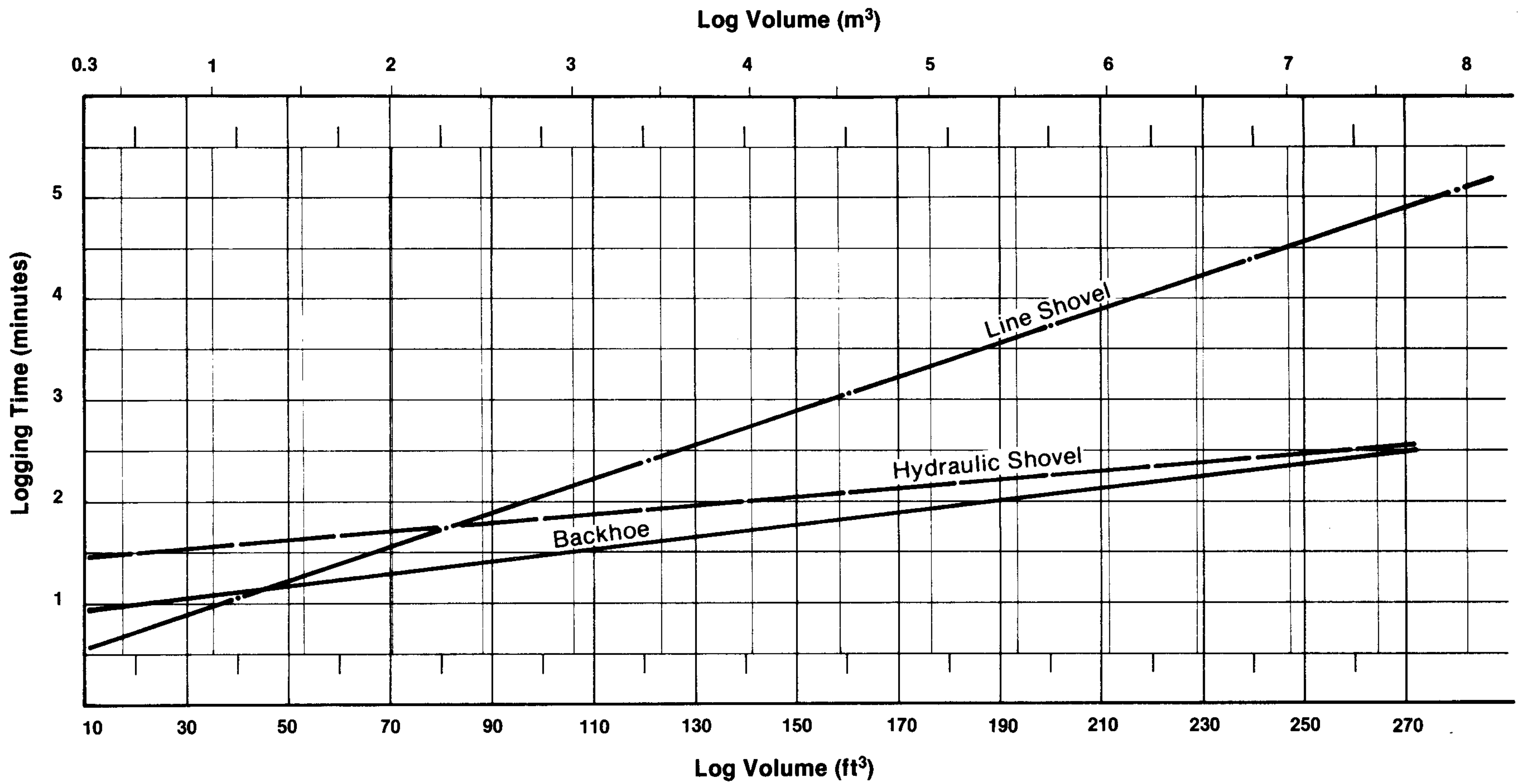
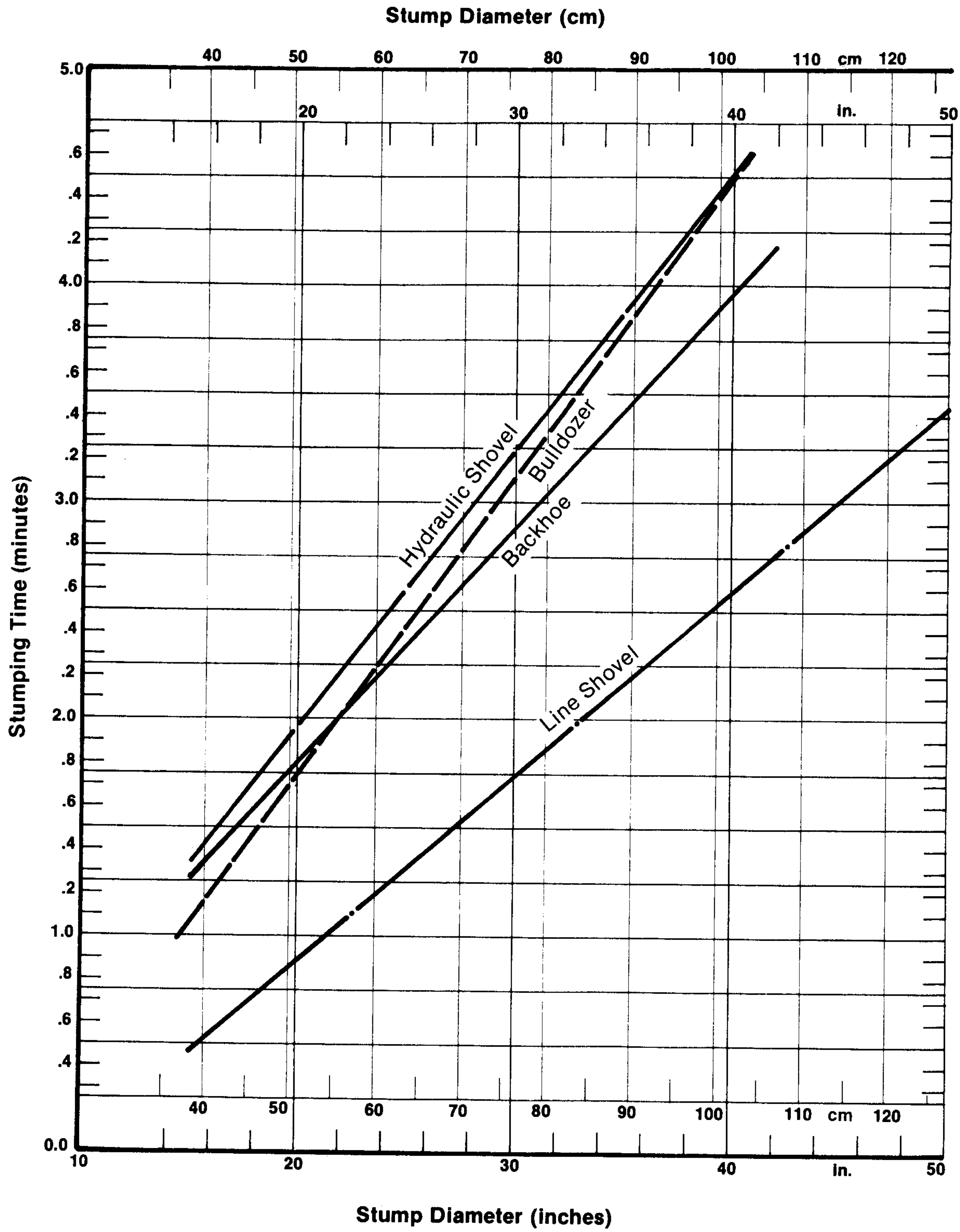


Figure PC-b
The Relationship Between Stumping Time and Stump Diameters



COST PER STATION BASED ON JOB ESTIMATES

The tables and graphs in this report can be used as guides to estimate the machine time to perform jobs and to work out most calculations. It is important to remember, however, that any machine times compared to those in our tables must be adjusted to suit the specific conditions. For instance, a machine's working speed may be tested (Appendix IV). It can then be reduced or increased by comparing the results with those in this report.

Let's say a line shovel completed the Working Speed Test in 0.77 minutes. Using 0.74 minutes (Table PC-1) as 100%, 0.77 minutes represent 104 percent. In our example, the line shovel's Summary of Subgrading Time, 37.17 hours, should be increased by the same percentage to 38.66 hours.

The capacity of the machine should also be taken into account. For example, when the design capacity of a line shovel with a standard bucket of 1 yd^3 (0.76 m^3) is compared to our model with 1.5 yd^3 (1.15 m^3) capacity, the excavation time should be increased 150 percent. (1 yd^3 (0.76 m^3) is taken as 100%, 1.5 yd^3 (1.15 m^3) as 150%.)

For logging, stumping, and clearing, (where a straight ratio is not available), a tentative estimate should be made, and if possible, the estimate should be field-tested. For better results after field testing, the tables and graphs should be adjusted to represent local conditions.

The productivity tables and graphs in this report are based on 100% utilization of the machine's available time. Using local data, a machine-utilization factor should be computed. In the examples given here, the utilization was calculated the following way:

Machine Utilization:

Line and Hydraulic Shovels

Delays:	
Startup time	20 minutes
Coffee breaks	40 "
Shutdown, after-shift maintenance and walkout time.	40 "
	100 minutes
Total available time	480 minutes
Utilized time	380 "
Machine Utilization	79%

We estimate the shutdown time for the bulldozer and backhoe to be 20 minutes. Utilized time is therefore 400 minutes and machine utilization, 83 percent.

Tables To Use For Time Calculations

When log and stump sizes are known, use the stumping and logging productivity result graphs (Figures PC-a and PC-b). A local table could be made for stump sizes, or information could be used from the British Columbia Forest Service timber inventory. When this data is not available, the average production rate in the Stumping and Logging Production tables can be used, but with less accuracy.

For clearing and excavation, the averages in the Excavation Productivity tables should be used (Tables 1-3, 2-2, 3-3, 4-3). Using the following information, we will calculate the cost of a road section 2,000 ft (610 m) long (Table PC-2) where the subsoil is hard-packed glacial till with 1 ft (0.3 m) of overburden.

Table PC-2 is based on these assumptions for the average cross-section: that the original ground slope is 30%; the built subgrade crown width is 26 ft (7.92 m), (including a ditch 2 ft x 1 ft) (0.61 m x 0.30 m) and the finished cut slope is 200%. The cut at the centerline is 1.5 ft (0.46 m).

The total yardage to excavate is 4,667 yd^3 (3 568 m^3), including 1,667 yd^3 (1 275 m^3) of overburden.

The assumptions for timber volume are 115 cunits/ac (804.7 m^3/ha) gross, with 20% of loss attributed to decay, breakage and construction waste, resulting in 92 cunits/ac (643.7 m^3/ha) Net Volume.

Total area to log: 2.0 ac (0.81 ha) (44 ft (13.4 m) R/W width).

Log size: 85 ft^3 (2.41 m^3)

Number of logs: $\frac{2.0 \text{ ac} \times 92 \text{ cunits/ac}}{85 \text{ ft}^3} = 217$

(same result using SI units).

Area for stump removal is 1.3 ac (0.53 ha) (28 ft (8.53 m) R/W width) with 208 stumps to remove.

In this example we assume that the machine is moved from another location by lowbed for a distance of less than five miles (8 km) and that the one-way move is charged to the road section. We also assume that metal culvert pipes are used for drainage structures by the ballasting crew and their costs are not charged to subgrading.

Subgrading Cost Calculations (Line Shovel)

Moving Time & Expenses

(moving distance less than 5 miles)

Moving on lowbed	3 hr@\$64.31 =	\$192.93
Truck lowbed	4 hr@\$55.00 =	220.00
Gravel trucks hauling fuel sleigh and mats	4 hr@\$42.00 =	168.00
Padding out and organizing to move	2 hr@\$64.31 =	128.62
		\$709.55

Subgrading

Logging:

217 logs to move: (log size 85 ft^3) (2.41 m^3)

using Graph PC-a:	1.8 min/log
217 logs x 1.8 min:	6.51 hr
using Productivity Table 3-1:	39.8 logs/hr
217 logs/39.8 logs/hr:	5.45 hr

Stumping:

208 stumps to move: (av. dia. 20 in.) (50.8 cm)

using Graph PC-b:	0.88 min/stump
208 stumps x 0.88 min:	3.05 hr
using Productivity Table 3-2:	52.9 stumps/hr
208 stumps/52.9 stumps/hr:	3.93 hr

Clearing:

1.3 acres (0.53 ha) using Excavation Productivity Table 3-3:	0.23 ac/hr (0.09 ha/h)
1.3 ac (0.53 ha) /0.23 ac/hr (0.09 ha/h):	5.65 hr

Excavation:

4,667 yd^3 (3 568 m^3) using Excavation Productivity Table 3-3: 212.5 yd^3/hr (162.47 m^3/h)	
4,667 yd^3 (3 568 m^3)/ 212.5 yd^3/hr (162.47 m^3/h):	21.96 hr

Summary of Subgrading Time

Logging	6.51 hr
Stumping	3.05
Clearing	5.65
Excavation	21.96
Total	37.17 hr

For the above summary we considered the figures calculated by using the graphs for logging and stumping. Using the respective production tables we find that these figures would be 5.45 hr and 3.93 hr, adding up to a total of 36.99 hr.

The subgrading time should be increased for machine utilization (79% in the case of the line shovel).

79% of machine time:	37.17 hr
100% of machine time:	47.05 hr
Subgrading cost 47.05 hr x \$64.31/hr:	\$3,025.78
Machine shift production (8-hour shifts)	

$$\frac{20 \text{ sta } (610 \text{ m}) \times 8 \text{ hr}}{47.05 \text{ hr} + 5 \text{ hr}} = 3.07 \text{ sta/shift } (93.6 \text{ m/shift})$$

Total machine cost for the road section (2,000 ft) (610 m)

Moving cost	\$ 709.55
Subgrading cost	3,025.78
Total	3,735.33 (\$186.77/sta)(\$6.13/m)

Table PC-2 is a cost summary worked out for the four machines studied in this report, using the method just outlined (see Appendix V for per-hour costing details).

The costing system just illustrated requires detailed information not easily obtained. Two other costing systems in common use which require less detailed information are described briefly.

MATERIAL UNIT-COST METHOD

With this method each phase of the construction, logging, stumping, clearing and excavating is estimated separately from the measured volumes of material to be moved. Costs are also calculated separately as if each portion of the work were done by different machines. Knowledge of ground conditions is important. Timber volume per acre (hectare) and tree size is required for logging-cost estimation. Tree size is used for stump estimates. Where applicable, Cutting Permit timber volume estimates are used for this purpose. The area to be cleared is calculated. The estimated yardage (volume in m^3) of different soil types is used to calculate the time and cost of excavation. This method requires a detailed survey of the road location and records of the machine's ability to perform each phase. Based on the survey, earth volumes are computed using mass graphs, average cross-sections, or by detailed calculation of each section's volume. In this method, care must be taken to include the time and cost of the job for moving, delays and repairs. In some cases the cost of repairs and delays is added to the hourly

Table PC-2. Production Cost Summary for the Four Machines (Imperial Units)

		Case Study I Hydraulic Backhoe		Case Study 2 Bulldozer		Case Study 3 Line Shovel		Case Study 4 Hydraulic Shovel	
Moving (less than 5 miles)		Time/Cost	Total Cost ($)	Time/Cost	Total Cost ($)	Time/Cost	Total Cost ($)	Time/Cost	Total Cost ($)
Subgrade Machine	hr	3	190.47	3	182.22	5	321.55	3½	250.22
	$	63.49		60.74		64.31		71.49	
Lowbed	hr	3	165.00	3	165.00	4	220.00	3	165.00
	$	55.00		55.00		55.00		55.00	
Trucks	hr	-	-	-	-	4	168.00	-	-
	$	-		-		42.00		-	
Total			355.47		347.22		709.55		415.22

	Production Rate	Production Time (hr)	Production Rate	Production Time (hr)	Production Rate	Production Time (hr)	Production Rate	Production Time (hr)
Subgrading								
Logging	1.35 min/log	4.88	3.00 min/log*	10.85	1.80 min/log	6.51	1.75 min/log	6.33
Stumping	1.80 min/s	6.24	1.73 min/s	6.00	0.88 min/s	3.05	1.96 min/s	6.79
Clearing	0.24 ac/hr	5.41	0.28 ac/hr	4.64	0.23 ac/hr	5.65	0.17 ac/hr	7.65
Excavation			173.8 yd^3/hr	26.85	212.5 yd^3/hr	21.96	98.5 yd^3/hr	47.38
Mineral	227.8 yd^3/hr	13.17						
Overburden	166.8 yd^3/hr	10.00						
Utilized Time		39.70		48.34		37.17		68.15
Utilization	83%		83%		79%		79%	
Total Time		47.83		58.24		47.05		86.27
Subgrading Cost		$3036.73		$3537.50		$3025.78		$6167.44

	Case Study 1	Case Study 2	Case Study 3	Case Study 4
Total Subgrading Time (hr)	50.83	61.24	52.05	89.77
Total Subgrading Cost	$3392.20	$3884.72	$3735.33	$6582.66
Station Cost	$ 169.61	$ 194.24	$ 186.77	$ 329.13
Shift Production	3.15 sta	2.61 sta	3.07 sta	1.78 sta

s - stump

*Logging time (3.00 min/log) is an assumed figure without skidder.

Table PC-2. Production Cost Summary for the Four Machines (SI Units)

		Case Study 1 Hydraulic Backhoe		Case Study 2 Bulldozer		Case Study 3 Line Shovel		Case Study 4 Hydraulic Shovel	
Moving (less than 8 km)		Time/Cost	Total Cost ($)	Time/Cost	Total Cost ($)	Time/Cost	Total Cost ($)	Time/Cost	Total Cost ($)
Subgrade Machine	h	3	190.47	3	182.22	5	321.55	3.5	250.22
	$	63.49		60.74		64.31		71.49	
Lowbed	h	3	165.00	3	165.00	4	220.00	3	165.00
	$	55.00		55.00		55.00		55.00	
Trucks	h	-	-	-	-	4	168.00	-	-
	$	-		-		42.00		-	
Total			355.47		347.22		709.55		415.22

	Production Rate	Production Time (h)	Production Rate	Production Time (h)	Production Rate	Production Time (h)	Production Rate	Production Time (h)
Subgrading								
Logging	1.35 min/log	4.88	3.00 min/log*	10.85	1.80 min/log	6.51	1.75 min/log	6.33
Stumping	1.80 min/s	6.24	1.73 min/s	6.00	0.88 min/s	3.05	1.96 min/s	6.79
Clearing	0.10 ha/h	5.41	0.11 ha/h	4.64	0.09 ha/h	5.65	0.07 ha/h	7.65
Excavation			132.9 m³/h	26.85	162.5 m³/h	21.96	75.3 m³/h	47.38
Mineral	174.2 m³/h	13.17						
Overburden	127.5 m³/h	10.00						
Utilized Time		39.70		48.34		37.17		68.15
Utilization	83%		83%		79%		79%	
Total Time		47.83		58.24		47.05		86.27
Subgrading Cost		$3036.73		$3537.50		$3025.78		$6167.44
Total Subgrading Time (h)	50.83		61.24		52.05		89.77	
Total Subgrade Cost	$3392.20		$3884.72		$3735.33		$6582.66	
Unit Cost	$ 5.56/m		$ 6.37/m		$ 6.13/m		$ 10.80/m	
Shift Production	95.9 m		79.6 m		93.7 m		54.3 m	

s - stump

*Logging time (3.00 min/log) is an assumed figure without skidder.

operating cost to arrive at the cost per productive-machine-hour which is combined with the estimated job time. In other cases, it is more convenient to include these factors with the time required to complete the specific job and combine these figures with the total cost per shift.

This section-volume method is popular for costing highway construction but rarely used for logging roads.

Even in this case it is recommended that after calculations are completed an experienced road-builder field-check by walking the road-location line and comparing the calculated times with his estimated times and costs. Table PC-3 shows some unit productivity and costs resulting from this study.

COST BASED ON STATION-PER-SHIFT MACHINE PRODUCTION

The engineer estimates the number of shifts required to complete a certain section of subgrade or the subgrade that will be built by a particular machine. Company records will usually show the number of stations a machine has recently built and the number of shifts worked. Critical evaluation of all the factors affecting road construction on a new location will permit the engineer familiar with local conditions to adjust the yearly average production figure and to make a reasonable production estimate. The average cost per shift is also based on past experience adjusted for the increase in operating, repair, and maintenance cost.

Combining the shift cost and the number of shifts needed to build the road will give the total machine cost for the subgrade (Appendix V). This estimate is fairly accurate when the ground conditions and the road section lengths are uniform. It requires a minimum amount of field work or surveying but relies heavily on the experience and judgment of the estimator. This method is widely used for forecasting budget requirements or for preparing three-year and five-year plans. For this purpose, the average machine-shift production is seldom changed; only the shift cost is adjusted to allow for price and labour cost increases.

The stations built by the machines during the study were not a large enough sample to use for cost calculations by this method. Each machine produced a different size and quality of subgrade. The backhoe worked on a wide main road and produced a very good quality subgrade. The bulldozer's subgrade was also very wide and it was used as a finished road. The line shovel worked under difficult conditions. The hydraulic shovel's subgrade did not have the heavy cut of the others and the grade was not finished as well. In order to compare results on a station-per-shift basis, the work done must be essentially the same.

Table PC-3. Machine Productivity and Cost Comparison

	1 Backhoe		2 Bulldozer		3 Line Shovel		4 Hydraulic Shovel	
	Production	Unit Cost	Production	Unit Cost	Production	Unit Cost	Production	Unit Cost
Logging (Log av. 70 ft^3 or 2.0 m^3) min/log $/log	1.29	1.36	-	-	1.56	1.67	1.70	2.02
Stumping (Stump dia. av. 20 in. or 64 cm) min/stump $/stump	2.34	2.48	2.42	2.45	1.30	1.39	2.60	3.10
Clearing ac/hr $/ac	0.24	264.54	0.28	216.93	0.23	279.61	0.17	420.53
ha/h $/ha	0.097	653.69	0.113	536.05	0.093	690.93	0.069	1039.15
Excavation yd^3/hr $/yd	187.2	0.34	173.8	0.35	212.5	0.30	98.5	0.73
m^3/h $/m^3	143.1	0.44	132.9	0.46	162.5	0.40	75.3	0.95
Machine Cost Per Hour		$63.49		$60.74		$64.31		$ 71.49

Table DC-1. Comparison of Operating Characteristics

Operating Characteristics	Backhoe 1	Bulldozer 2	Line Shovel 3	Hydraulic Shovel 4
Ground pressure (approx.) lb/in.^{2} kg/cm^2	9 0.63	10 0.70	13 0.91	12 0.84
Machine reach in ft m	39 11.9	N/A N/A	30 9.14	27 8.2
Chances of requiring assistance when stuck	could push & pull	used winch	usually	could push & pull
Ability to dig hard ground	very good	good	poor	very poor
Logging ability	good	good	fair	poor
Stumping ability	good	fair	fair	poor
Ability to work on slopes	fair	good	poor	fair

DISCUSSION AND CONCLUSION

FERIC observed the machine performance of the basic types of machinery used to build subgrade in British Columbia — the excavator backhoe, the bulldozer, the line (dipper) shovel and the hydraulic shovel excavator. The machines show variations in productivity, cost, comfort, and safety features. Under the particular site and test conditions which applied during this study, the backhoe was the most productive machine and produced subgrade at the lowest cost per station. The bulldozer cost-per-station was slightly higher, but the bulldozer's mobility and versatility are in its favour. The line shovel's cost per station was slightly higher yet and the machine is less mobile, although its capability for pure excavation was high. The hydraulic shovel was the least productive and cost substantially more per station than the others during our study, but since that time the manufacturer has made significant improvement in the design of this machine. Readers should compare specifications of all new machines as well as proposed designs for the various equipment types used for building subgrade when they work with the performance figures and costing methods explained in this study.

A number of tables compare the four machines. Table DC-1 is a comparison of operating characteristics. Table DC-2 gives the Roughness Indicator of the four machines.

Table DC-2. Roughness Indicator

1. Backhoe	5.85 ft^2/sta (1.78 m^2/100 m)
2. Bulldozer	6.03 ft^2/sta (1.84 m^2/100 m)
3. Line Shovel	8.32 ft^2/sta (2.54 m^2/100 m)
4. Hydraulic Shovel	13.20 ft^2/sta (4.02 m^2/100 m)

The ease of machine maintenance was related to the machine design and age. This factor and other factors which affect the operator are shown below.

Ergonomics	1	2	3	4
Ease of operation	good	good	fair	good
Ease of learning to operate	easy	easy	difficult	fair
Ease of maintenance	easy	easy	poor	fair
Operator's comfort	good	fair	poor	good
Operator's visibility	fair	good	poor	fair
Access to cab	fair	good	fair	fair
Operator's protection	fair	fair	poor	good

1 = Backhoe 3 = Line Shovel
2 = Bulldozer 4 = Hydraulic Shovel

See Appendix VI for an Explanation of Terms.

ROLE OF THE OPERATOR IN MACHINE PERFORMANCE

Only one man was needed to operate the backhoe, bulldozer and hydraulic shovel but the bulldozer needed a swamper for logging. The line shovel requires an operator and a padman.

However, for reasons of safety in the field, a two-man crew was assigned to each machine.

During the course of the study it became apparent that machine productivity depends on the skill of the operator to a significant degree. Most of the operators were self-trained men who had received little help in acquiring knowledge of subgrade construction. As a result, they had developed some poor construction techniques along with more sound procedures.

Operators should have a set of instructions pertaining to the road, including road design and construction requirements. If the subgrade is to be built on a definite line, (like a surveyed centerline), and to a certain standard, it is necessary to have the line marked in front of the machine so that the operator can follow it. The operator should be familiar with the standards. Flagging tape should have a highly-visible color and should be hung on high brush or small trees (less than 15 feet (4.5 m) in height) so it will remain visible even after the right-of-way has been felled.

The operator should have a road profile referenced to the road at many points. The profile should be detailed enough to indicate the required cuts and to show creeks, culvert locations, and special instructions. Indentifiable points on the ground should be marked for the operator and shown on the profile so he can follow an engineered location line.

As a result of this study, FERIC believes there is a need to compile comprehensive guidelines to educate new operators and upgrade established personnel by describing successful techniques and ways of eliminating common errors in building subgrade. Supervisors and operators could judge the technique best suited to the operator, the machine, and the site conditions. These guidelines might take the form of a handbook or booklet, but whatever their final format, there is clearly a need for such reference material to help operators choose the right subgrading techniques to achieve maximum machine efficiency at each site.

APPENDIX I
TIME ELEMENT DEFINITIONS
LINE SHOVEL, HYDRAULIC SHOVEL AND BACKHOE

Element of Description	Beginning Points
Stumping	Empty or semi-filled bucket, or bucket tooth, touches the stump or its root the first time to remove the stump, or the machine starts excavation for the sole purpose of removing the stump.
Logging	Bucket stops to allow the hanging of tongs, or empty or semi-filled bucket touches the log for logging purposes, or (when the bucket is already equipped with tongs) the moment the bucket stops in position for setting the tongs, or when the bucket or tongs touch the log for logging, or when the operator is placing the tongs without a helper.
Ground Excavation	Shovel in position to dig, bucket tooth touches ground for excavation.
Clearing	Clearing, same as excavation, but for the purpose of clearing.
In-Cycle Move	The time of positioning the machine during the excavation, stumping, logging, or clearing cycle, or the bucket stops for moving or the track or tracks start turning.
Travelling	When bucket stops or tracks start turning to move the machine in or out on the subgrade, to or from the worksite.
Delays	When the bucket stops for any other reason.

BULLDOZER

Element of Description	Beginning Points
Stumping	When blade touches the stump or a root of the stump the first time for removal (all excavation for digging the stump out is included); or when starting excavation for the sole purpose of removing the stump; or the machine stops or starts maneuvering to set the line on the stump.
Logging	When empty blade touches log for moving; or when machine stops to have the mainline pulled; or the machine starts maneuvering into a position for logging.
Ground Excavation	When the blade touches ground for excavation.
Clearing	Same as excavation, but for the purpose of clearing.
In-Cycle Move	Time of moving the machine to a different work place within the worksite--track or tracks start moving.
Travelling	Tracks start turning to move the machine to or from the worksite.
Delays	When the machine stops for any other reason.

We kept a running record of all delays and these were later entered as repair and maintenance; other operational delays; and crew-originated delays, such as late starts, coffee breaks, long lunch breaks, early shutdown and rest periods. The machine's travelling time to and from the work area, time spent outside the test section, and culvert-building time were also recorded as delays.

APPENDIX II
SOILS

The mineral soils on the test sites were glacial till with considerable overburden.

Test Sites

	Average Overburden (ft)	Average Overburden (m)
Backhoe	3.5	1.07
Bulldozer	4.7	1.43
Line Shovel	2.8	0.85
Hydraulic Shovel	2.0	0.61

During construction, soil samples were taken of the mineral soil and lower organic layers for laboratory analysis. In the laboratory, tests were made on these samples for moisture content and for plastic and liquid limits. The samples were also analyzed for grain size.

Soil Moisture Content

Test Site	Moisture Content (%) Mineral Soil	Moisture Content (%) Overburden
Backhoe	12.6	110.8
Bulldozer	18.5	45.2
Line Shovel	11.5	49.8
Hydraulic Shovel	14.8	N/A

Plastic Limit & Liquid Limit

Test for cohesiveness of non-plastic granular soils of ASTM.

Test Results

Backhoe:	Non-plastic: NP
Bulldozer:	Non-plastic: NP
Line Shovel:	Slightly plastic, permanent: SL. PL. (P)
Hydraulic Shovel:	Slightly plastic, temporary: SL. PL. (T)

Organic Matter in Mineral Soil

Test site soils are listed in the order of the amount of organic content.

1. Hydraulic Shovel
2. Backhoe
3. Bulldozer
4. Line Shovel

SOIL CLASSIFICATION

Soils are classified in the Unified Soil Classification System. The appropriate sieve and hydrometer analyses were used. The mixed samples were sieved through #4, 10, 20, 40 and 100 sieves. Hydrometer analysis was carried out on mixed samples sieved through a #40 sieve. Results of the tests are presented in Figure A-II-a on a grain size-percent finer curve. All soils were silty sands.

Soil Characteristics

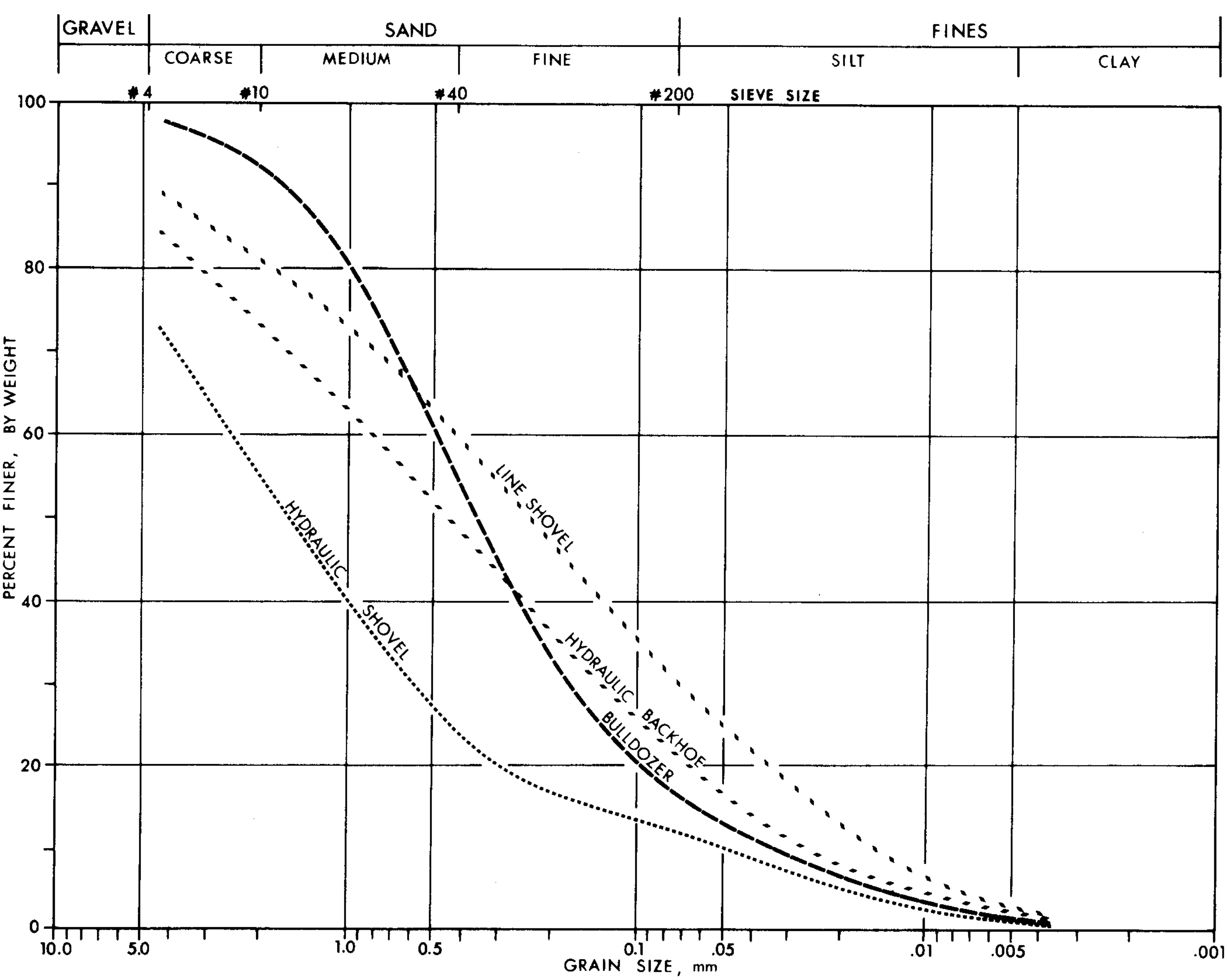
Backhoe Site:
- No dry strength
- Poorly-graded
- 21% non-plastic fines
- Coefficient of uniformity 32.8
- Coefficient of curvature 0.956

Bulldozer Site:
- No dry strength
- Well-graded
- 16% non-plastic fines
- Coefficient of uniformity 14.16
- Coefficient of curvature 1.864

Line Shovel Site:
- Some dry strength
- Poorly-graded
- 30% non-plastic fines
- Coefficient of uniformity 32.14
- Coefficient of curvature 0.845

Hydraulic Shovel Site:
- Slight dry strength
- Well-graded
- 13% non-plastic fines
- Coefficient of uniformity 59.1
- Coefficient of curvature 1.93

Figure A-II-a. Grain Size Chart (Unified Soil Classification System)



APPENDIX III
ROUGHNESS INDICATOR

In the context of this report, the Roughness Indicator is the area (in ft^2 or m^2) which requires cut or fill to form a straight line between successive points 20 ft (6.1 m) apart in the longitudinal cross-section of a station (or 100 m) length of road along the centerline.

During the final survey, the centerline of the subgrade was levelled at 10 ft (3.05 m) intervals. The elevations of these points were plotted. The area to be filled and cut was measured and averaged to arrive at a value for a station of subgrade.

Figure A-III-a shows a cross-section of 100 ft (30.48 m) of subgrade showing the areas to fill and to cut. From levelling points 1 to 11 the distance is 100 feet (30.48 m) or a station. Summarizing the cut areas and the fill areas, the average of the two is the Roughness Indicator for this station.

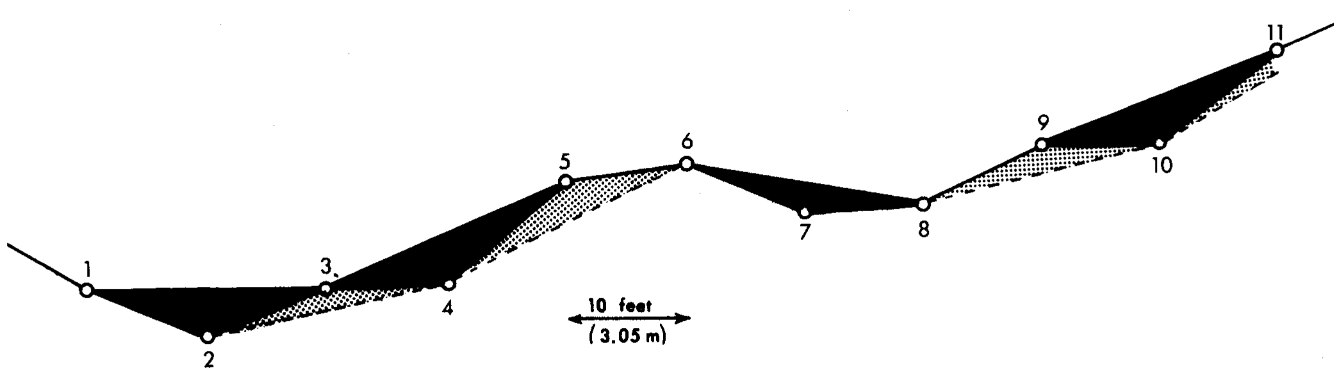
To get an indication of the ballasting material needed to even out the subgrade, the Roughness Indicator is multiplied by the average width of the ballasting (expressed in feet or metres). The result is a volume in cubic feet or cubic metres.

Figure A-III-a. Longitudinal Cross-Section of the Subgrade at Centerline

○ - levelling points at 10-ft (3.05 m) intervals on the centerline

■ - fill area to even out the subgrade on 20-ft (6.10 m) tangents in ft^2 (m^2)

▨ - cut area to even out the subgrade in 20-ft (6.10 m) tangents in ft^2 (m^2)



$$\text{Roughness Indicator} = \frac{50\ (\Sigma\ \text{cut area} + \Sigma\ \text{fill area})}{\text{Road Length}} = \frac{50\ (24.2 + 22.6)}{100} = 23.4\ ft^2/\text{sta}$$

$$= \frac{50\ (2.25 + 2.10)}{30.48} = 7.14\ m^2/100\ m$$

APPENDIX IV
WORKING SPEED TEST

How fast a machine can work depends on the machine design, the engine speed and power, the machine's mechanical condition and the ability of the operator to use the equipment.

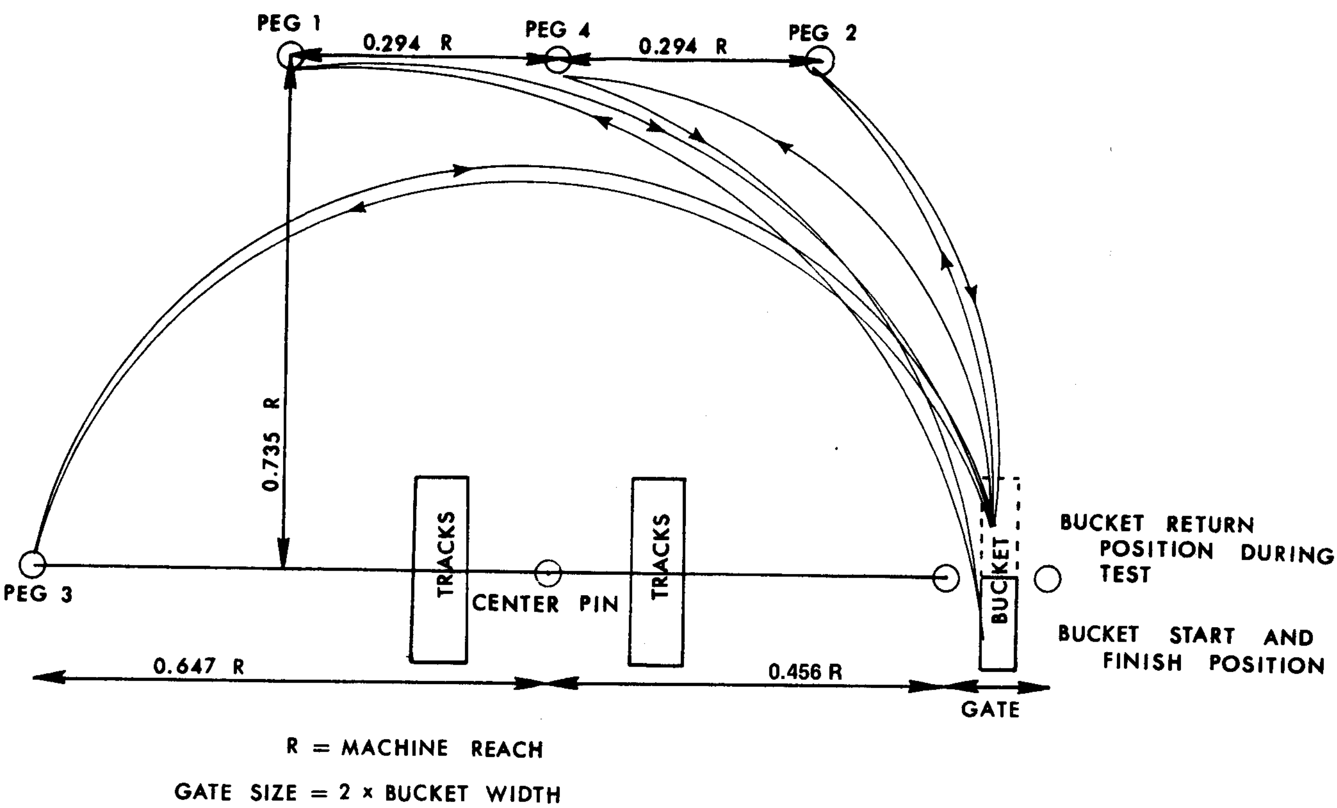
The working speed test is a simulation set up to establish the combined capacity of machine and operator to move through a working cycle. This test does not rate flotation, travelling speed or digging ability. During the test, the operator has to move the bucket of the excavator in a set pattern to imitate the working cycle. For the excavators, four wooden pegs 4 1/2 ft (1.37 m) long were stuck in the ground around the machine according to its extent of reach. The operator had to touch or knock these pickets down one by one using the bucket's cutting edge or teeth in a normal working pattern. The backhoe had to touch them by moving the bucket's cutting edge toward the machine, always coming back to the starting point after touching each picket.

The starting point or gate is always at the operator's side of the machine. The operators were allowed one trial run to become familiar with the test. The test was repeated three times and operators could not have improved their time much in further trial runs. The time shown in this report is the best time the operators achieved during the test.

Figure A-IV-a illustrates the location of the pegs, the machine on the test site and the testing pattern.

To start the test, the bucket is positioned outside the gate, in the air but close to the ground. The timing starts when the signal is given to the operator and the bucket starts moving. During the test, the bucket only has to touch the line of the gate—it does not have to cross it. Timing stops when the last peg is knocked down or

Figure A-IV-a. Test Site and Testing Pattern for Excavators



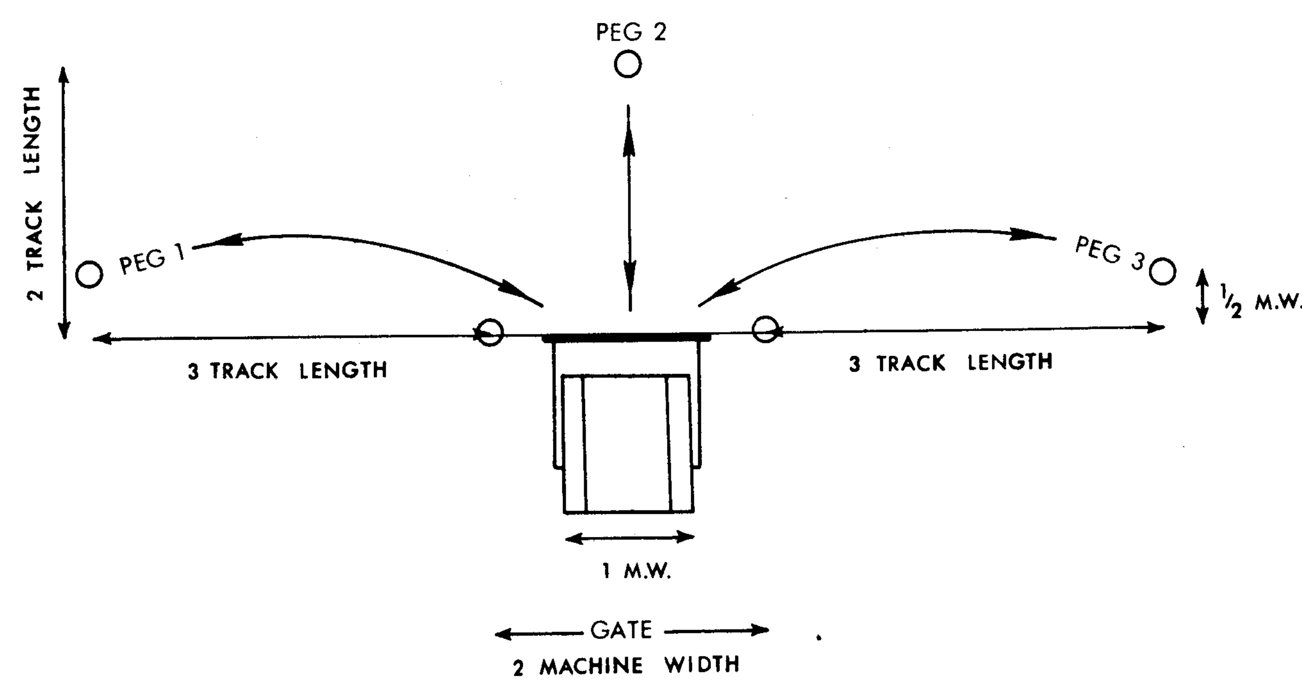
touched and the bucket goes through the gate. The picket numbers in the figure indicate the sequence for knocking down the pegs. The pegs forming the gate are not knocked down during timing.

The test for a bulldozer is different. The maneuverability and the walking speed is combined with the operator's ability to control the machine. The following figure shows the test pattern and the location of the pegs (Figure A-IV-b).

To start the test, the machine is positioned behind the gate as indicated on Figure A-IV-b. Timing starts when the machine moves after the start signal. The pegs are knocked down or touched in the sequence indicated with the midsection of the blade's cutting edge. After touching a peg, the machine must back into the gate until the blade crosses the baseline of the gate. The operator must take care not to touch the gateposts with the machine. Timing is ended after the machine touches peg No. 3 and backs through the gate.

When making working speed tests, it is important that the operator be familiar with the machine and experienced in operating it. There is a clear relationship between the working speed test times and the productivity for the same machine models. There is some relationship between test times and the productivity of different excavators, but the bulldozer tests cannot be compared to the excavator tests. Bulldozers compare only with other bulldozers and there is a strong relationship between the same bulldozer models.

Figure A-IV-b. Test Site and Testing Pattern for Bulldozer



APPENDIX V
EQUIPMENT COSTING

(Calculated for the Vancouver area and based on 1976 Vancouver prices for new equipment)

CASE STUDY 1 — BACKHOE: CATERPILLAR 235

Delivered Price: $185,000
Depreciation Period (n): 6 years
Resale Value: 15% of Delivered Price = $27,750
Annual Usage: 1,600 hours
Value to Depreciate: $185,000 minus $27,750 = $157,250

Depreciation: $\frac{\text{Value to Depreciate}}{n} = \frac{\$157{,}250}{6} = \$26{,}208\text{/year}$

or $16.38/hour

Interest: 10% annual rate on average investment

Annual Interest:

$$\frac{(0.5 \times \text{Value to Depreciate}) + \text{Resale Value}}{100} \times \text{Interest Rate (\%)}$$

$$\frac{(0.5 \times \$157{,}250) + \$27{,}750}{100} \times 10\% = \$10{,}637\text{/year or } \$6.65\text{/hour}$$

Fuel: 46.1 gal/day @ $0.55/gal = $25.36/day or $3.17/hr

Lubricants: $1.20/hour

Repairs, Maintenance & Supplies:

$$\frac{\text{Delivered Price} \times \text{Repair Factor}}{1{,}000} = \frac{\$185{,}000 \times 0.07}{1{,}000} = \$12.95\text{/hour}$$

Labour Costs:
Hourly rate of:

Operator	$ 8.51
Padman	7.34
Operator's pay for maintenance	1.06
25% fringe benefits	4.23
Total	$21.14

Transportation: $2.00/hr.

Summary of Costs:

Depreciation	$16.38
Interest	6.65
Fuel	3.17
Lubricants	1.20
Repairs, Maintenance, Supplies	12.95
Labour	21.14
Transportation	2.00
Total hourly cost	$63.49

CASE STUDY 2 — BULLDOZER: CATERPILLAR D8H

Delivered Price: \$145,000
Depreciation Period (n): 6 years
Resale Value: 15% after 6 years = \$21,750
Annual Usage: 1,600 hours
Value to Depreciate: \$145,000 minus \$21,750 = \$123,250

Depreciation: $\frac{\text{Value to Depreciate}}{n} = \frac{\$123{,}250}{6} = \$20{,}542/\text{year}$
or \$12.84/hour

Interest: 10% annual rate on average investment

Annual Interest:

$$\frac{(0.5 \times \text{Value to Depreciate}) + \text{Resale Value}}{100} \times \text{Interest Rate (\%)}$$

$$\frac{(0.5 \times \$123{,}250) + \$21{,}750}{100} \times 10\% = \$8{,}337.50/\text{year}$$
or \$5.21/hour

Fuel: 87.9 gal/day @ \$0.55/gal = \$48.35/day or \$6.05/hour

Lubricants: \$0.45/hour

Repairs, Maintenance & Supplies:

$$\frac{\text{Delivered Price} \times \text{Repair Factor}}{1{,}000} = \frac{\$145{,}000 \times 0.09}{1{,}000} = \$13.05/\text{hour}$$

Labour: Same as Backhoe = \$21.14/hour

Transportation: \$2.00/hour

Summary of Costs:

Depreciation	\$12.84
Interest	5.21
Fuel	6.05
Lubricants	0.45
Repairs, Maintenance, Supplies	13.05
Labour	21.14
Transportation	2.00
Total hourly cost	\$60.74

CASE STUDY 3 — LINE SHOVEL: AMERICAN 750

Delivered Price: $240,000
Depreciation Period (n): 10 years
Resale Value: 10% after 10 years = $24,000
Annual Usage: 1,600 hours
Value to Depreciate: $240,000 minus $24,000 = $216,000

Depreciation: $\frac{\text{Value to Depreciate}}{n} = \frac{\$216{,}000}{10 \text{ years}} = \$21{,}600/\text{year}$
or $13.50/hour

Interest: 10% annual rate on average investment

Annual Interest:

$$\frac{(0.5 \times \text{Value to Depreciate}) + \text{Resale Value}}{100} \times \text{Interest Rate } (\%)$$

$$\frac{(0.5 \times \$216{,}000) + \$24{,}000}{100} \times 10\% = \$13{,}200/\text{year or } \$8.25/\text{hour}$$

Repairs, Maintenance & Supplies: $9.23/hour

Fuel: 32.3 gal/day @ $0.55/gal = $17.77/day or $2.22/hour

Lubricants: $0.80/hour

Shovel Mats: $2,000 set of mats would last 3 months = $4.17/hour

Fuel Sleigh: $0.50/hour

Labour Costs: Same as for backhoe, plus production bonus

Labour	$21.14
Production bonus of $400/month, av.	2.50
Total hourly labour costs	$23.64

Transportation: Crew transportation and standby vehicle: $2.00/hour

Summary of Costs:

Depreciation	$13.50
Interest	8.25
Repairs, Maintenance, Supplies	9.23
Fuel	2.22
Lubricants	0.80
Shovel mats	4.17
Fuel Sleigh	0.50
Labour	23.64
Transportation	2.00
Total hourly cost	$64.31

CASE STUDY 4 — HYDRAULIC SHOVEL: POCLAIN HC300

Delivered Price: \$220,000
Depreciation Period (n): 6 years
Resale Value: 15% after 6 years = \$33,000
Annual Usage: 1,600 hours
Value to Depreciation: \$220,000 minus \$33,000 = \$187,000

Depreciation: $\frac{\text{Value to Depreciate}}{n} = \frac{\$187{,}000}{6} = \$31{,}166/\text{year}$
or \$19.48/hour

Interest: 10% annual rate on average investment

Annual Interest:

$$\frac{(0.5 \times \text{Value to Depreciate}) + \text{Resale Value}}{100} \times \text{Interest Rate (\%)}$$

$$\frac{(0.5 \times \$187{,}000) + \$33{,}000}{100} \times 10\% = \$12{,}650/\text{year}$$

or \$7.91/hour

Fuel: 59.07 gal/day @ \$0.55/gal = \$32.49/day or \$4.06/hour

Lubricants: \$1.50/hour

Repairs, Maintenance & Supplies:

$$\frac{\text{Delivered Price} \times \text{Repair Factor}}{1{,}000} = \frac{\$220{,}000 \times 0.07}{1{,}000} = \$15.40/\text{hour}$$

Labour: Same as for Backhoe = \$21.14/hour

Transportation: \$2.00/hour

Summary of Costs:

Depreciation	\$19.48
Interest	7.91
Fuel	4.06
Lubricants	1.50
Repairs, Maintenance, Supplies	15.40
Labour	21.14
Transportation	2.00
Total hourly cost	\$71.49

APPENDIX VI
DESCRIPTION OF TERMS USED IN CASE STUDIES 1, 2, 3 AND 4

Ease of Operation: judged by the number, position, shape and simplicity of controls, their logical function and precise movement and the location of important instruments.

Ease of Maintenance: judged by the number and accessibility of service points, regular servicing requirements and duration of service time.

Operator Comfort: judged by seating comfort, working position, cab ventilation, temperature control and protection from outside elements.

Operator's Field of Vision: judged by visibility of blade or bucket action, design of side windshield (if any), and windshield-cleaning convenience.

Access to Cab: judged by ease of mounting and dismounting.

Operator Protection: judged by ROP devices and protection against objects hitting the cab as well as escape exit in case of accident.

Working Speed Test: Appendix IV

Ground Pressure: flotation; defines relative ability to work on soft ground without shovel mats.

Walking Speed: combined with ground pressure to define the machine's ability to use multipass subgrading systems.

Machine Reach: judged by its ability to work high cutbanks, place material on fill slopes and excavate more with less movement than other machines.

Need for Emergency Assistance: judged by machine's ability to free itself in an emergency, saving delay time and the cost of extra crew.

Ability to Dig Hard Ground: judged by machine's ability to excavate mineral soil to produce a better quality subgrade in less time at less cost.

Logging Ability: judged by the machine's ability to spend less time on logging (and more on excavation); its ability to move logs without damaging them; and its log-placement technique.

Stumping Ability: judged by the machine's ability to dig out stumps, lift them and place them.

Subgrade Surface Finish: the indicator of the smoothness or roughness of the surface.

Roughness Indicator: (Appendix III); the indicator of the amount of ballasting material needed to take the bounciness out of the road.

APPENDIX VII
CONVERSION FACTORS

Imperial Units		SI (Metric) Units*
1 acre (ac)	=	0.404 685 6 hectare (ha)
1 square foot (ft^2)	=	0.092 903 04 square metre (m^2)
1 square foot/station (ft^2/sta)	=	0.304 799 99 square metre/100 metre length (m^2/100 m)
1 square inch ($in.^2$)	=	6.451 6 square centimetres (cm^2)
1 foot (ft)	=	0.304 8 metre (m)
1 inch (in.)	=	2.54 centimetres (cm)
1 mile (mi)	=	1.609 344 kilometre (km)
1 cunit (C)	=	2.831 685 cubic metre (m^3)
1 cunit/acre (C/ac)	=	6.997 246 5 cubic metre/hectare (m^3/ha)
1 cubic foot (ft^3)	=	0.028 316 85 cubic metre (m^3)
1 yard (yd^3)	=	0.764 55 cubic metre (m^3)
1 pound (lb)	=	0.453 592 37 kilogram (kg)
1 pound/square inch (lb/in^2)	=	0.070 306 95 kilogram/square centimetre (kg/cm^2)

*SI is the abbreviated name for International System of Units (Système International d'Unitès) in all languages.