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Logging Trucks: Comparison of Productivity and Costs

D.G. Smith and P.P. Tse

300 - 2045 WEST BROADWAY, VANCOUVER, B.C., CANADA V6J 1Z5
245 HYMUS BLVD., POINTE CLAIRE, P.Q., CANADA H9R 1O6

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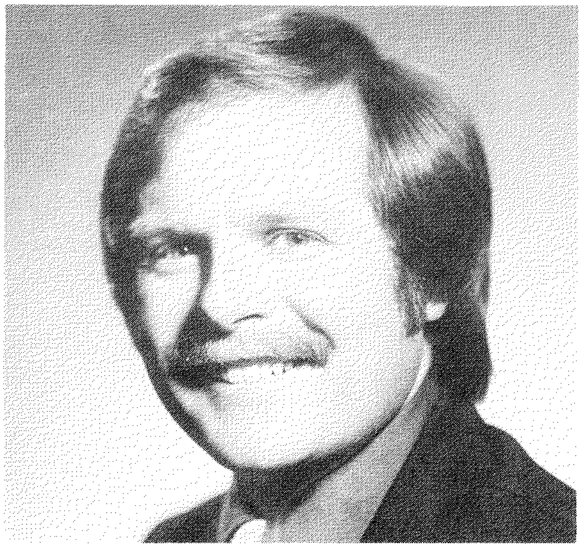
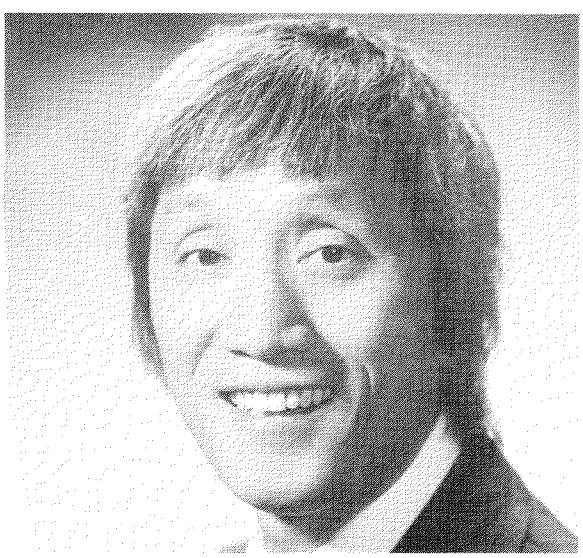


D.G. Smith received his M.Eng. (Transportation) from Carleton University in 1971. From 1971 to 1975 he was employed as a transportation consultant in private industry. In 1975, he joined FERIC in Vancouver, British Columbia, to work on transportation and materials handling projects.

He is a Registered Professional Engineer in both Ontario and British Columbia.



P.P. Tse taught at Alert Bay Elementary School in B.C. when he first arrived in Canada from Hong Kong. He then spent three years at the University of British Columbia majoring in Computer Science. Prior to joining FERIC in May 1975, he had worked for three years in the Sawmilling Section of the Western Forest Products Laboratory. His position now in FERIC is Computer Programmer.

FOREWORD

The Forest Engineering Research Institute of Canada wishes to thank the personnel of the cooperating company and the participating truck drivers for their generous assistance during the course of the study.

The discussion of the field study and methodology was too lengthy to combine in a single report. There is a Supplement to this Technical Report describing the survey and analysis procedure as well as the computer program developed to manipulate the raw survey data. The Supplement is available upon request from FERIC West.

The number and complexity of the tables contained in this report necessitated the use of Imperial units only. The appropriate conversion factors to S.I. units appear in Appendix A.

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SUMMARY

The operators of log truck fleets have been subjected to conflicting opinions about the merits of various sizes of vehicle for off-highway hauling. To investigate the productivity and cost trade-offs between various gross combination weights[1] of logging trucks, the Forest Engineering Research Institute of Canada conducted a detailed truck rider survey at a Central Interior British Columbia operation. Three size classes of truck--standard highway trucks with 8-foot bunks, off-highway trucks with 10-foot bunks and off-highway trucks with 12-foot bunks--were observed as they operated over a common 43 mile off-highway haul route.

The timing of hauling cycles, including delays, permitted productivity and cost comparisons of the classes on a hypothetical off-highway haul. Further, a sensitivity analysis indicated the impact on haul cost of variations in the major input parameters, particularly operational delay.

Results

(a) Loading time was greatly influenced by piece size. The loading time per cunit for large wood was little more than half that for small wood. The most realistic method of estimating loading capacity should be pieces per hour, followed if necessary by a local conversion to cunits per hour.

(b) The travel time of the various truck classes over the same segment of road was not largely influenced by the size of payload.

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[1]GCW - gross weight of a combination of vehicles (tractors, trailers, semi-trailers) in one hauling unit including load.

(c) Road standard had a considerable impact on the travel time of all the vehicles. Speed dropped sharply as the road standard decreased.

(d) The timing of the trips indicated wide variations in travel time for each truck class over a given piece of road. Since these travel times excluded the measured delays, the difference in average speed is probably caused by adverse driving conditions, or the driver's deliberate slow down because he is aware of a delay at the landing.

(e) The most significant delays occurred at the landing, either waiting in a queue or waiting for the loader to sort logs and clean the landing.

(f) Under the assumed conditions the 10- and 12-foot classes were virtually equal in productivity at about 9,000 to 10,000 units per truck per year. The productivity of the 8-foot class was perceptibly lower at about 6,500 cunits per truck per year.

(g) The cost analysis indicated that for each class of truck the variable costs of operating the vehicle (fuel, oil, tires) were secondary relative to the fixed costs such as: capital cost of the vehicle, driver wages, repair labour and cost of spare parts.

(h) Total haul cost per hour and per trip increased with payload size. On a cunit-mile basis, the 8-foot truck had the highest cost. The increased load size of the 12-foot truck could not offset the increased costs, so that the 10-foot showed the least cost per cunit-mile.

(i) Under the assumed conditions the sensitivity analysis indicated that:

- removal of all observed delays would increase the annual production of each vehicle by 11% to 22% (depending on class and usage) while the total annual haul costs of the mixed fleet could be reduced by approximately 11%.

- increasing the vehicle ownership period to 10 years from 3 or 4 years would reduce the cost per cunit-mile up to 23%, assuming no decrease in productivity or increase in repair costs.

- increasing the annual in-use hours from an average of 1900 to 2100 hours per year would reduce haul cost up to 4%.

- increasing the haul distance would greatly increase the fleet required and the total cost of hauling the same annual production. However, the cost per cunit-mile of the individual truck would decrease with increasing distance.

Conclusions

The following suggestions could be implemented to improve productivity and reduce costs:

(a) Load the vehicle to capacity every trip.

(b) Balance the trade-off between road standard, truck speed and maintenance of the road and truck to achieve lowest cost.

(c) Reduce delays through improved dispatching and careful selection of the number of trucks.

(d) Extend the life of the vehicle.

(e) Consider preloading or other different techniques.

Future Studies

(a) Investigate, in depth the causes, impact and means of reducing system operational delay.

(b) Investigate the relationship between road standard and truck performance, particularly the effect of road maintenance (grading).

(c) Investigate the traffic capacity of various segments of the haul route, utilizing delay monitoring techniques.

(d) Investigate the total cost and cost trade-offs of log hauling, that is, all factors related to trucks, roads and their interaction.

(e) Investigate the productivity and operational delay involved in very short distance off-highway hauls, as well as the combination of off-highway and highway hauls at an intermediate reload yard.

The results of this study should be generally applicable elsewhere in Central British Columbia. The methodology developed should also be applicable, with some changes, for detailed trucking studies in the future.

SOMMAIRE

Les propriétaires de flottes de camions ont émis des opinions divergentes quant aux avantages et aux inconvénients de diverses capacités de charge de véhicules destinés au transport de bois en billes hors des voies publiques. Afin d'établir la productivité et le coût par unité de production relatifs à diverses combinaisons de poids brut[1] de ces camions, l'Institut canadien de recherches en génie forestier a exécuté une étude détaillée de camionnage dans une exploitation du centre de la Colombie-Britannique. On a observé trois catégories de camions effectuant le même trajet hors des voies publiques sur une distance de 43 milles: camions conventionnels répondant aux normes de transport sur voie publique avec traverse porte-billes de 8 pieds de largeur, camions de route privée avec traverse de 10 pieds et enfin camions de route privée avec traverse de 12 pieds.

A partir du chronométrage des cycles de camionnage, incluant les temps morts, on a établi une comparaison de la productivité et des coûts des diverses catégories lors d'un camionnage simulé hors des voies publiques. De plus, grâce à une analyse de sensibilité, on a pu connaître l'impact sur le coût du camionnage de variations dans les principaux paramètres, particulièrement les temps morts inhérents à l'opération.

Résultats

(a) Le temps de chargement varie beaucoup selon les dimensions des billes et peut même s'abaisser par cunit dans

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[1] CPB - poids brut d'une combinaison de véhicules (tracteurs, remorques, semi-remorques) en une seule unité de camionnage incluant la charge.

le cas de bois de fort diamètre à un peu plus de la moitié de celui du bois de faible diamètre. Ainsi la méthode la plus réaliste d'évaluer la productivité du chargement devrait tenir compte du nombre de billes par heure, auquel on ajoutera si désiré une conversion locale en cunits par heure.

(b) Pour un même tronçon de route, le temps de déplacement des diverses catégories de camions ne semble guère influencé par les dimensions de la charge.

(c) La qualité de la route a un impact considérable sur le temps de déplacement de tous les véhicules. La vitesse s'abaisse rapidement à mesure que la qualité de la route diminue.

(d) Sur un même tronçon de route, le chronométrage des cycles de transport indique pour chaque catégorie de camions de grandes variations dans le temps de déplacement. Comme ces temps de déplacement excluent les temps morts observés, la différence dans la vitesse moyenne provient sans doute soit de conditions défavorables de conduite (e.g. le temps), soit du fait que le chauffeur étant au courant de l'existence d'un temps mort à la jetée, circule alors plus lentement qu'à l'accoutumée.

(e) Les temps morts les plus significatifs se produisent à la jetée, soit l'attente en file, soit l'attente de la chargeuse pour trier les billes et nettoyer la jetée.

(f) Selon les hypothèses posées, les catégories de camions de 10 et 12 pieds atteignent pratiquement la même productivité d'environ 9,000 à 10,000 cunits par camion annuellement. La productivité de la catégorie de

8 pieds est sensiblement inférieure et n'atteint qu' environ 6,500 cunits par camion annuellement.

(g) L'analyse de coûts indique que pour chaque catégorie de camions les coûts variables d'opération du véhicule (essence, huile, pneus) sont secondaires par rapport aux coûts fixes tels que: le coût de capital du véhicule, le salaire du chauffeur, le temps de réparation et le coût des pièces de rechange.

(h) Le coût total de camionnage par heure et par cycle de transport augmente avec les dimensions de la charge. En prenant comme unité le cunit-mille, on voit que le camion de 8 pieds atteint le coût le plus élevé. Dans le cas du camion de 12 pieds, l'augmentation de la charge ne peut pas compenser l'augmentation des coûts, de sorte que le camion de 10 pieds s'avère le moins coûteux par cunit-mille.

(i) Selon les hypothèses posées, l'analyse de sensibilité démontre que:

- l'élimination de tous les temps morts observés augmenterait la production annuelle de chaque véhicule de 11% à 22% (suivant la catégorie et l'utilisation) alors que le coût total annuel de camionnage pour l'ensemble des camions pourrait être réduit d'environ 11%.
- si l'on utilisait le même véhicule pendant 10 ans au lieu de 3 ou 4 ans, on réduirait le coût par cunit-mille jusqu'à 23%, en supposant qu'il n'y ait pas de diminution de productivité ni d'augmentation des coûts de réparation.
- l'augmentation du nombre d'heures de service au cours de l'année d'une moyenne de 1,900 jusqu'à

2,100 heures réduirait le coût de camionnage d'environ 4%.

- l'augmentation de la distance de camionnage augmenterait considérablement le nombre de camions requis ainsi que le coût total de transport dans le cas d'une même production annuelle. Cependant, le coût par cunit-mille de chaque camion diminuerait avec l'accroissement de la distance.

Conclusions

Suggestions pour améliorer la productivité et réduire les coûts:

(a) Charger le véhicule à pleine capacité.

(b) Rechercher le coût le plus bas possible en équilibrant de façon optimale la qualité de la route, la vitesse du camion et l'entretien de la route et du camion.

(c) Réduire les temps morts grâce à un meilleur dispatching et grâce aussi à un choix judicieux du nombre de camions requis.

(d) Prolonger la vie du véhicule.

(e) Songer à la possibilité d'utiliser le pré-chargement ou diverses autres techniques.

Etudes futures

(a) Etudier en profondeur les causes, l'impact et les moyens de réduire les temps morts inhérents à l'opération.

(b) Etudier les relations entre la qualité de la route et la performance du camion, spécialement l'effet de l'entretien de la route (nivelage).

(c) Etudier la capacité de circulation sur divers tronçons de la route de camionnage, en se servant des techniques de contrôle des temps morts.

(d) Etudier le coût total du camionnage des billes, c'est-à-dire tous les facteurs reliés aux camions, aux réseaux routiers et à leur interaction.

(e) Etudier la productivité et les temps morts inhérents à l'opération dans le cas de très courtes distances de camionnage hors des voies publiques, ainsi que la combinaison de transport sur routes privées et routes publiques impliquant l'existence d'un parc intermédiaire de rechargement.

De façon générale, les résultats de cette étude devraient s'appliquer ailleurs en Colombie-Britannique intérieure. La méthodologie développée devrait également servir dans l'avenir, avec quelques modifications, aux études détaillées de camionnage.

1. INTRODUCTION

During the past three decades, the productivity and cost of hauling logs by truck has been investigated several times.[1,2,3] Substantial research is still being conducted by the Transportation Analysis Group of the U.S. Forest Service, and the Swedish Logging Research Foundation (Skogsarbeten).

The early research concentrating mainly on the road travel portion of the truck's duty cycle indicated that productivity increased and costs decreased with increased payload size. This accounts for the trend, in Canada at least, to larger and heavier trucks.

More recent investigations have considered trucking in a systems context; that is, all portions of the cycle -- travel, queues, loading, unloading and the multitude of operational delays -- must be studied before the overall productivity and costs can be estimated. For alternative trucking systems, increased productivity alone does not necessarily mean reduced total haul costs. Rather, there are trade-offs between truck productivity and costs that must be evaluated in order to choose the optimum size of truck to match the conditions of the particular haul application.

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[1] Byrne, J.J., Nelson, R.J., Googins, P.H. Logging road handbook: The effect of road design on hauling costs. Agriculture Handbook No.183, U.S. Department of Agriculture, Washington D.C., 1960, 65 pp.

[2] Larsson, M. Computerized trucking systems analyses. Meddelande nr 10, Skogsarbeten, Stockholm, 1974, 136 pp.

[3] Belcher, R.G. Minimization of trucking costs. WS Index 2484 (B-8-e), Can. Pulp Pap. Assoc., Montreal, 1968, 4 pp.

The effect of the operating environment upon truck performance is critical. Much existing information is empirically derived and analyzed on an aggregate basis. This implies that the cost and productivity data are relevant only to the studied operation. The analysis and evaluation contain built-in cost factors and operating parameters which are not likely to apply precisely to other haul systems. Published data and conclusions available to individual company analysts are often too general to be applied to a particular haul, and the techniques that could be used to evaluate each haul in depth are not readily available.

As an alternative to specific empirical studies, there exist sophisticated simulation techniques.[1,2] These are general in application and require detailed input data, and computer facilities. They cannot be utilized easily as a regular planning tool by company logging personnel.

The objective of the FERIC study was to compare the productivity and costs of three weight classes of logging trucks under similar operating conditions, such as haul route and weather. An operation in the Central Interior of British Columbia cooperated for a three-week survey in February 1976. While the data are specific for this time and location they typify many similar operations in this region.

During the course of the study a comprehensive methodology for collecting and evaluating productivity and cost

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[1] Vehicle Mission Simulation. Cummins Engine Company Inc., Columbus Indianna.

[2] Routhier, J.G. A simulation model for the analysis of pulpwood and sawlog trucking. LRR/57, Pulp and Pap. Res. Inst. of Canada, Pointe Claire, 1974, 51 pp.

data associated with log trucking operations was developed. This methodology is available, upon request, in a supplement report, to persons interested in analysing their own log trucking alternatives.

2. DESCRIPTION OF COMPANY OPERATION

In order to understand the significance of this study, it is necessary to describe the operating conditions that prevailed during the field study at the operations of the cooperating company. This includes cutting areas, road network, truck fleet, drivers and overall operating conditions.

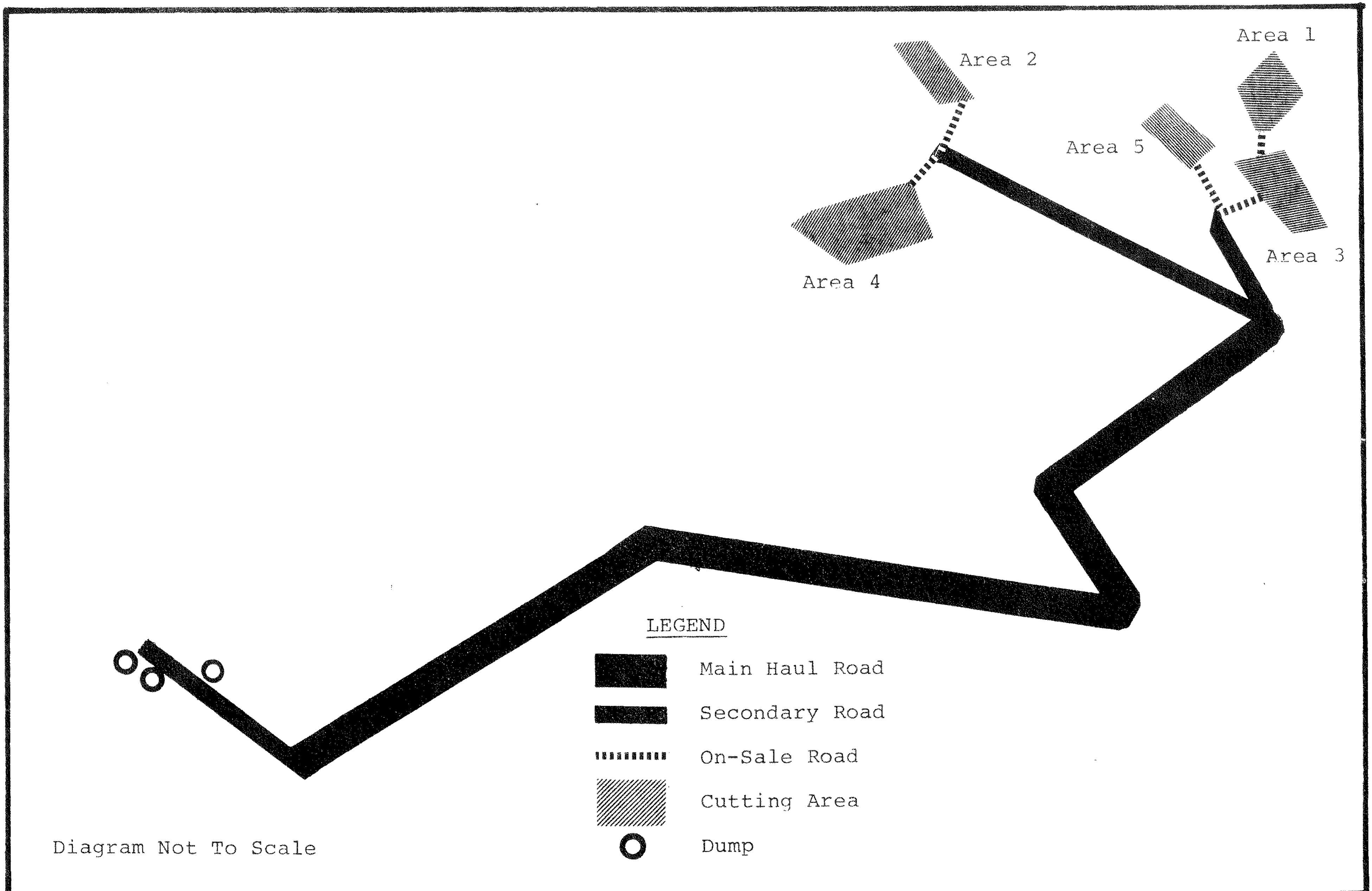
2.1 Cutting Areas

The operation under study included five cutting areas located at the extreme end of the main haul road (Figure 1). All vehicles hauling from these areas travelled over much the same route. Three areas were supervised by company personnel and the remaining two by different contractors. The origin of each trip was identified by an area number (Figure 1).

2.2 Road Network

The haul route was divided into three basic classes of design standard (Figure 1).

FIGURE 1. STUDY AREA: ROAD NETWORK.



Class	Characteristics
Main Haul	2-lane speed to 40-50 miles per hour graded regularly large-radius turns moderate grades
Secondary	1½-lane speed to 40 miles per hour undulating graded periodically turnouts & radio contact important
"On-Sale"	1-lane crawl speed rough, pot holes steep grades sharp turns

A truck could load at one or more of several landings in each cutting area. Hence, an average distance for several adjacent landings in each sale area was used.

The survey was conducted during the winter (February) haul season. Frequent grading and sanding kept the snow-packed mainhaul and secondary roads in good condition. However, chains were required occasionally. The turnouts were plowed but a truck could easily become stuck on the road shoulder. Due to the shortness of the daylight and long working hours, many trips were surveyed at night.

2.3 Truck Fleet

The three classes observed were:

(a) '8-Foot' : On-Highway

Bunk width	: 8-Foot
Average GCW	: 84,000 pounds
Tare weight	: 28,000 pounds
Average payload	: 68,000 pounds

(b) '10-Foot' : Off-Highway

Bunk width	: 10-Foot
Average GCW	: 84,000 pounds
Tare weight	: 30,000 pounds
Average payload	: 102,000 pounds

(c) '12-Foot' : Off-Highway

Bunk width	: 12-Foot
Average GCW	: 175,000 pounds
Tare weight	: 50,000 pounds
Average payload	: 120,000 pounds

For the remainder of the report, the truck classes are identified by the nominal bunk width (8-, 10-, 12-foot).

2.4 DRIVERS

While the effects of different haul routes and weather were equalized for the different truck types during the study, it was not feasible to equalize the effect of differing driver ability. Each driver remained with a single truck throughout the study period. All of the drivers participating were basically competent and experienced with local conditions. It was observed, however, that some drivers exhibited slightly more skill at maintaining travel speed and avoiding delays than others. On the average, it was not observed that any one truck type had a preponderance of these superior drivers. While the possibility of some variation attributable directly to driver ability cannot be entirely ruled out, differences in productivity between the truck classes appeared to result mainly from other factors.

2.5 OPERATIONS

Full trees were skidded to central landings where they were limbed and bucked to log lengths. Caterpillar 988 front-end loaders were used for sorting and loading. Large sawlogs with butt diameter down to 14 inches were carried off-highway by 10- and 12-foot trucks to the large-log sawmill. Small sawlogs were carried by 8-foot trucks, partially on-highway, to the small-log sawmill.

As a rule, each truck hauled from only one area. However, three distinct dumping places were used for the off-highway trucks, requiring the destination of each survey trip be specified.

3. STUDY METHODOLOGY

The methods developed in this study are described in detail to assist industry personnel evaluate their specific haul operation. This chapter presents an overview of the methodology while the Supplement provides the working details of the survey procedure, formulae and analysis.

No survey vehicles were equipped with a tachograph. To obtain detailed data as to the causes and durations of operational delays a FERIC employee rode with selected logging trucks. In the case of the off-highway trucks, the rider observed the entire day's operation of one truck. With the 8-foot class, driving both off-highway and on-highway, the rider observed both the empty and loaded off-highway portion of one trip, then waited for the next in-bound (empty) highway truck.

In addition to the timing data, other information collected included truck specifications (make, age, condition), the measured length of each uniform class segment of the haul route (mainhaul, secondary, on-sale), fuel purchase records, and B.C. Forest Service scale records.

The analysis utilized these base data to generate and compare for each truck class:

(a) fundamental performance indicators such as travel speed;
(b) productivity indicators such as trips per year and cunits delivered per year;
(c) cost and revenue indicators.

The cost analysis was conducted in two phases. A base case was evaluated which represented observed conditions such as hours of work per year, vehicle ownership period and incidence of delay. Further, a sensitivity analysis was conducted to determine the impact on haul cost of varying these key parameters.

4. RESULTS

The base data consisted of 71 truck trips observed from a population of 500 during February 1976. This resulted in a sample of approximately 14%.

4.1 Analysis of Observed Trips

(a) Load and Loading Time: Table 1 summarizes the load and loading time by truck class and cutting area. Within each class the differences in load weight and loading rate indicate the variation in loader operators and wood characteristics between cutting areas. The differences can be substantial; for the 8-foot class the average load weight from area 1 was 15% greater than that from area 4.

The variation in log size substantially affected the loading time per cunit. Thus the average time for loading large sawlogs on a 12-foot truck was comparable to that for loading small logs on an 8-foot truck, even though the payload was 77% greater.

(b) Travel Time: Travel times were recorded and summarized with the calculated average speed (Table 2) for each truck class travelling both loaded and empty over each road segment. Within each truck class there was a trend toward increased travel time (reduced speed) as the road standard decreased. This comparison of speed and travel time per mile allows company personnel to determine the potential time saving by upgrading specific road segments. For example, for a 12-

TABLE 1. LOAD AND LOADING TIME.

TRUCK CLASS (BUNK WIDTH)	LOAD AND LOADING TIME	SALE AREA					AVERAGE
		1	2	3	4	5	
8-FT	OBSERVATIONS	2	6	6	6	2	N.A.
	LOAD (LBS)	74,420	69,097	66,373	64,920	71,060	67,877
	LOAD (CUNITS)	14.6	13.5	13.0	12.6	13.5	13.2
	LOADING TIME (MIN)	27.5	40.7	24.2	30.8	34.0	31.7
	LOADING RATE (MIN/1000 LBS)	0.37	0.59	0.36	0.48	0.48	0.47
	LOADING RATE (MIN/CUNIT)	1.90	3.02	1.86	2.45	2.51	2.40
10-FT	OBSERVATIONS	8	4	14	0	1	N.A.
	LOAD (LBS)	107,331	102,113	99,743	-	99,100	102,319
	LOAD (CUNITS)	21.5	20.4	20.0	-	19.8	20.5
	LOADING TIME (MIN)	26.5	28.8	27.1	-	14.0	26.7
	LOADING RATE (MIN/1000 LBS)	0.25	0.28	0.27	-	1.14	0.26
	LOADING RATE (MIN/CUNIT)	1.24	1.41	1.36	-	0.71	1.30
12-FT	OBSERVATIONS	0	13	0	9	0	N.A.
	LOAD (LBS)	-	114,196	-	128,600	-	120,089
	LOAD (CUNITS)	-	22.8	-	25.7	-	24.0
	LOADING TIME (MIN)	-	33.2	-	27.8	-	31.0
	LOADING RATE (MIN/1000 LBS)	-	0.29	-	0.22	-	0.26
	LOADING RATE (MIN/CUNIT)	-	1.46	-	1.08	-	1.29

N.A. - not applicable

TABLE 2. TRAVEL TIME AND SPEED: AVERAGED OVER ALL ROAD SEGMENTS OF SIMILAR STANDARD.

ROAD SEGMENT	TRUCK CLASS (BUNK WIDTH)					
	8-FOOT		10-FOOT		12-FOOT	
	Speed mph	Time min/mi	Speed mph	Time min/mi	Speed mph	Time min/mi
Empty						
. mainhaul	43.9	1.37	48.9	1.23	40.0	1.50
. secondary	26.4	2.27	27.2	2.20	29.1	2.06
. on-sale	22.7	2.67	17.6	3.41	14.9	4.04
Loaded						
. mainhaul	37.4	1.60	39.2	1.53	34.4	1.74
. secondary	24.2	2.48	24.1	2.49	22.7	2.64
. on-sale	15.9	3.77	16.4	3.66	11.4	5.27

foot truck, upgrading 10 miles of secondary road could increase travel speed from 23 to 34 miles per hour (loaded), potentially saving 15 minutes of travel time per round trip. Utilizing the productivity and cost evaluations shown later in this report, this time saving could be translated into increased productivity and reduced haul costs for the fleet, if reduced trip times permitted an additional trip per day for each truck. These savings could then be compared to the costs of improving the road.

The deviations from the average travel time were substantial within each truck class. This variation indicates a significant difference between slow and fast trips. Since these times exclude delays, a likely explanation for slow trips was that the driver had to slow down either for deteriorating road conditions, or because he knew he would be delayed at the landing.

(c) Delay: Total delay was the sum of time spent in loading and unloading queues plus the time consumed in other operational delays (Table 4). Loading was observed for all classes, while the unloading was not. Therefore, only the loading queue was considered in detail.

Table 3 compares the loading queues by truck class with the overall average. The 8-foot class not only had a higher probability (.55 vs .33) of encountering a queue, but the average queue duration was longer (35 minutes vs 24 and 28 minutes), than those encountered by the 10-foot and 12-foot classes. For those trips with a queue, the delay represented from 17% to 24% of

TABLE 3. LOADING QUEUES.

	TRUCK CLASS			ALL TRUCKS
	8-FOOT	10-FOOT	12-FOOT	
Number of Observations	22	27	22	71
Number of Queues	12	9	7	28
Probability of Queue	.55	.33	.32	.39
Average Queue Duration (min)	35	24	28	30
% Travel Time	24	18	17	20
% Cycle Time	13	11	11	12
Queue Duration[1] per Trip (min)	19.3	8.0	9.0	11.7

[1] The queue duration per trip is calculated either by dividing the total queue time for each class by the total observations of that class or the product of the probability of queue and the average queue duration. (Slight discrepancies between the two methods result from rounding off.)

TABLE 4. DISTRIBUTION OF OPERATIONAL DELAY BY CAUSE.

DELAY CAUSE	ALL TRUCKS			
	EMPTY		LOADED	
	Number of Delays	Delay Duration (min)	Number of Delays	Delay Duration (min)
Truck Driver - Rest & Food	1	2	10	262
Truck Driver - Aid Other Driver	7	23	3	37
Truck Driver - Wait For Instructions	6	67	1	9
Truck - Mechanical Breakdown	3	25	6	66
Truck - Fuel	8	47	0	0
Truck - Stuck	5	26	1	106
Truck - Add/Remove Chains	2	7	5	40
Loader - Operator Not Ready	7	119	3	20
Loader - Busy Elsewhere	10	220	1	5
Loader - Cleaning Landing/Sorting	8	236	1	2
Road - Blocked	6	69	5	15
Road - Wait For Loaded Truck	11	47	0	0
Scale - Scale Queue	0	0	2	4
TOTAL	74	888	38	566

total travel time, and 11 to 13% of total cycle time. While the operational causes of the difference in loading delay for the 8-foot class were not obvious, potential factors could be the greater number of highway trucks and the fact that they hauled to a more distant destination.

To predict truck productivity and cost, an estimate of cycle time must be made. This required that the queue length be expressed as minutes per typical trip rather than a probability of occurrence. The expected delay per trip is the product of the probability of occurrence and average queue duration. For a typical trip, the driver could expect a loading queue of 19.3, 8.0 and 9.0 minutes for the 8-, 10-, and 12-foot classes respectively.

Table 4 presents the other operational delays recorded. In the majority of cases, the most significant delay occurred at the landing waiting for the loader when empty and at camp for driver rest when loaded.

The 8- and 12-foot classes were similar in terms of frequency and duration of delays, whereas the 10-foot class was seen to have fewer delays, and a shorter average duration.

Table 5 sums the queues and operational delays to estimate the total delay time. Total delay was similar for the 8-foot and 12-foot classes at 44 and 39 minutes per trip respectively, while that for the 10-foot vehicles was approximately half, at 24 minutes per trip. The frequency of delays per trip follows the

TABLE 5. SUMMARY: TOTAL SYSTEM DELAYS.

	TRUCK CLASS			ALL TRUCKS
	8-FOOT	10-FOOT	12-FOOT	
Number of Trips Observed	22	27	22	71
Number of Trips with Delay	17	17	19	53
Number of Delays Observed	71	53	54	178
Total Delay Duration (min)	959	661	859	2479
Average Delay Duration (min)	14	12	16	14
Delay as % of Travel Time	28.5	20.7	23.5	24.3
Delay as % of Cycle Time	17.4	13.2	15.3	15.4
Distributed Number of Delays/Trip	3.2	2.0	2.5	2.5
Distributed Delay Time/Trip (min)	44	24	39	35

same pattern: 3.2, 2.0, and 2.5 for the 8-, 10-, and 12-foot classes respectively. These total delay estimates represent, for the entire fleet, 24% of total travel time and 15% of total cycle time.

(d) Preparation Time: The preparation times indicated in Table 6 for loading, unloading and leaving the landing and dump are minor elements, included for the sake of completeness of analysis. The preparation times did not vary significantly between the truck classes.

4.2 Productivity, Cost, Revenue

The survey provided basic performance data[1] for each of the three truck classes considered. Because of the different cutting areas and dump areas involved these observations could not be used directly to compare productivity, costs and revenues. The analysis of productivity and cost was structured around a standardized but hypothetical operation, with performance estimated from the actual survey data.

Six hypothetical haul examples were considered:

- 8-, 10-, and 12-foot truck classes carrying small sawlogs (butt diameter less than 14 inches)
- 8-, 10-, and 12-foot truck classes carrying large sawlogs (butt diameter 14 inches and greater).

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[1] The haul season was assumed to be 150 days per year. The poor haul conditions prevailing during spring break-up would certainly reduce annual vehicle productivity. Because of changes in operations, plans to include spring and summer surveys in this report were abandoned. Thus seasonal variations in cycle time and daily production were not included.

TABLE 6. PREPARATION TIME (MINUTES).

	TRUCK CLASS		
	8-FOOT	10-FOOT	12-FOOT
Preparation to load	6.1	7.4	6.9
Preparation to leave landing	6.5	4.3	4.7
Preparation to Unload	N/A[1]	1.4	1.3
Preparation to leave Dump	N/A	5.0	4.1

[1] N/A indicates no data available.

These six cases were then evaluated in terms of the following four operating systems:

1. Mixed Fleet
   8-foot trucks carrying 100% of annual small sawlog production, 10-foot trucks carrying 50% of annual large sawlog production and 12-foot trucks carrying 50% of annual large sawlog production.

2. All 8-Foot
   8-foot trucks carrying 100% of annual small sawlog production and 100% of annual large sawlog production.

3. All 10-Foot
   10-foot trucks carrying 100% of annual small sawlog production and 100% of annual large sawlog production.

4. All 12-Foot
   12-foot trucks carrying 100% of annual small sawlog production and 100% of annual large sawlog production.

The analysis compared the total number of trucks required to haul the full year's production and the total annual haul costs for these four operating systems.

(a) Estimated Loading Time: Table 7 summarizes the estimated loading time for each of the six cases.

(b) Estimated Travel Time: The survey results provided travel times in minutes/mile for each truck and road class combination.

TABLE 7. ESTIMATED TRUCK LOADING TIMES.

WOOD TYPE	TRUCK CLASS	AVERAGE[1] LOAD (lb)	LOADING RATE (min/1000 lb)	LOADING TIME (min)
LARGE SAWLOGS	8-foot[2]	67,900	0.26	17.7
	10-foot[3]	102,300	0.26	26.6
	12-foot[3]	120,100	0.26	31.2
SMALL SAWLOGS	8-foot[3]	67,900	0.47	31.9
	10-foot[2]	102,300	0.47	48.1
	12-foot[2]	120,100	0.47	56.4

[1]Rounded to nearest 100 pounds.
[2]Observed values.
[3]Estimated values from average load and loading rate data.

TABLE 8. ESTIMATED TRUCK TRAVEL TIMES.[4]

TRUCK CLASS	TRAVEL TIME (MINUTES)		
	EMPTY	LOADED	TOTAL
8-foot	69.1	82.2	155.3
10-foot	67.9	81.8	149.7
12-foot	79.4	96.4	175.8

[4]Specfic travel times (minutes/mile) were utilized, rather than the averages shown in Table 2.

A common haul route was set up, comprising the following:

Road Segment (Class)	Mileage
mainhaul	30
secondary	6
on-sale	3
dump (secondary)	4

The total travel time for each case was calculated as the sum of the times required for each road segment (Table 8).

(c) Estimated Truck Cycle Time: Table 9 summarizes the total cycle time for each case. All of the element times, except loading and travel, were determined directly from the survey data. None of the cases duplicated a real trip, but overall cycle times were close to those actually surveyed (durations of observed queues and delays were included).

(d) Trips per Day: The Central Interior Loggers' Association (C.I.L.A.) provided the following estimates of average number of truck working hours per year:

Year	Working Hours/Year
1972	1750
1973	2000
1974	1800
1975	1600
Average:	1790

During the study the trucks worked an average of 12.6 hours per day.[1] Assuming 150 haul days per year

[1]The trucks surveyed were mainly owner-operated, hence "overtime" and driver travel time were not differentiated.

TABLE 9. ESTIMATED TRUCK CYCLE TIMES AND TRIPS PER DAY.

FACTOR	SMALL SAWLOGS			LARGE SAWLOGS		
	TRUCK CLASS					
	8 foot	10 foot	12 foot	8 foot	10 foot	12 foot
Total Operation Time (min)	231.6	229.7	263.6	217.4	208.2	238.4
Total Operation Delay (min)	22.0	14.0	28.0	22.0	14.0	28.0
Total Cycle Time (min)	253.6	243.7	291.6	239.4	222.2	266.4
Total Cycle Time (hr)	4.2	4.1	4.9	4.0	3.7	4.4
Average Trips per Day	3.0	3.1	2.6	3.2	3.4	2.9

this works out to 1900 hours per year. Considering the annual range of 1600 to 2000 hours, the selected number of annual working hours was set at 1900. Table 9 summarizes the number of trips per day (assuming 150 haul days per year) calculated from the previously estimated cycle time.

(e) Truck Cost Estimates: The accounting method used in the following cost estimation is the one used by large companies or any investor who has potential for investing in other opportunities as well as in a logging truck. While it would give the independent truck owner-operator a valid picture of his total owning and operating costs, it may not reflect the cash-flow accounting utilized by the small businessman. For example, the owner-operator may not experience the full cost of repair and maintenance of his vehicle if he does a significant amount of repair work on his own time.

The parameters listed in Table 10 were used to estimate costs per in-use hour and per travelling hour for each truck class (Table 11).

A typical trip cost breakdown is indicated below for an 8-foot bunk vehicle.

TABLE 10. TRUCK COST PARAMETERS.[1]

PARAMETER	TRUCK CLASS		
	8-FOOT	10-FOOT	12-FOOT
Capital Cost ($)	60,000	60,000	100,000
Ownership Period (years)	4	3	4
Resale Value Factor (% purchase price)	36	45	36
Finance Rate (%)	15.0	15.0	15.0
Finance Period (years)	3	3	3
Opportunity Interest Rate (%)	8.5	8.5	8.5
Insurance Premium ($/year)	1,705	1,705	2,685
Driver Wage ($/hour)	7.20	7.20	7.31
Fuel Cost ($/gallon)	0.51	0.51	0.51
Fuel Consumption (miles/gallon)	5.4	4.8	3.9
Oil Cost (% of fuel cost)	33	33	33
Tire Cost ($ per tire)	253	253	320
Expected Tire Life (hours)			
- rolling tires	3,630	1,950	1,980
- driving tires	2,420	1,300	1,320
Repair and Maintenance ($/mile)	0.17	0.17	0.17

[1]The cost parameters, based upon the best available information at the time of the analysis, can be expected to vary with time and location.

TABLE 11. SUMMARY OF TRUCK COSTS.

A. Fixed Cost per In-Use Hour ($).

COST FACTOR	TRUCK CLASS		
	8-FOOT	10-FOOT	12-FOOT
Depreciation	5.27	6.15	8.69
Finance Charge	1.78	2.37	2.96
Opportunity Charge	0.75	0.67	1.29
Insurance	0.90	0.90	1.41
Driver Wage	8.64	8.64	8.77
SUBTOTAL	17.34	18.73	23.12

B. Variable Cost per Travelling Hour ($).

COST FACTOR	TRUCK CLASS		
	8-FOOT	10-FOOT	12-FOOT
Fuel	3.12	3.66	3.88
Oil & Lubrication	1.04	1.22	1.29
Tires	1.02	2.32	4.37
Repair & Maintenance	5.62	5.85	5.04
SUBTOTAL	10.80	13.05	14.58

Factor	Cost ($)	Hours	Total ($)
In-Use Costs:			
Depreciation	5.27	4.2	22.13
Finance Charge	1.78	4.2	7.48
Opportunity Cost	0.75	4.2	3.15
Insurance	0.90	4.2	3.78
Wages & Fringe	8.64	4.2	36.29
Travelling Costs:			
Fuel	3.12	2.6	8.11
Oil	1.04	2.6	2.70
Tires	1.02	2.6	2.65
Repair & Maintenance	5.62	2.6	14.61
Total cost per trip:			$100.90

This trip cost breakdown for the 8-foot bunk vehicle indicates the dominance of three costs: driver wages, vehicle depreciation and vehicle repair and maintenance.

The analysis highlighted the difficulty in reducing the cost of a particular vehicle because the main items (driver wages, vehicle capital cost and repair labour and parts) cannot be expected to decrease significantly. The factors which the operator and owner can control to some extent (fuel, oil, tires, and financing) have a lesser influence on the total cost of a trip.

(f) Productivity, Cost, Revenue: Table 12 summarizes the productivity, cost and revenue for the six cases under study. These factors vary slightly for the

TABLE 12. SUMMARY: PRODUCTIVITY, COST AND REVENUE (HYPOTHETICAL HAUL).

FACTOR	SMALL SAWLOGS			LARGE SAWLOGS		
	TRUCK CLASS					
	8 foot	10 foot	12 foot	8 foot	10 foot	12 foot
Productivity:						
trips per year	452	463	388	475	514	432
cunits per year	5,831	8,982	8,924	6,460	10,486	10,454
Cost:						
total cost per year ($)	45,611	50,661	60,361	46,248	52,392	62,212
cost per cunit-mile ($)	0.182	0.131	0.157	0.167	0.116	0.138
average hourly cost ($)	24.03	26.69	31.75	24.36	27.55	32.73
Revenue:						
total revenue per year ($)	38,893	59,910	59,523	43,088	69,942	69,728
revenue per cunit-mile ($)	0.155	0.155	0.155	0.155	0.155	0.155
average hourly revenue ($)	31.53	31.53	31.53	22.68	36.81	36.70

same vehicle depending upon the load volume between large and small sawlogs. The cycles per day also were slightly different for a truck hauling large sawlogs versus small.

The production of the 10- and 12-foot classes was similar at about 9,000-10,000 cunits per year per truck. The larger loads of the 12-foot truck were offset by the longer trip times in comparison to the 10-foot truck.

Total trip cost and average hourly cost increased with the larger payload size. The cost per cunit-mile was predictably highest with the smallest (8-foot) trucks when they were restricted to highway sized loads. However, the cost per cunit-mile of the largest (12-foot) truck was greater than that of the medium (10-foot) class, indicating that the increased cost of operation of the large vehicle was not entirely offset by the increased payload.

When compared to the one-way revenue of $0.155 per cunit-mile, the cost of the 8-foot truck placed it at a distinct disadvantage on the off-highway haul. This conclusion substantiated the judgement of the truck drivers interviewed, that the 8-foot vehicle could not operate profitably off-highway.[1]

Both the 10- and 12-foot classes operated profitably on the 43-mile off-highway haul. Despite the increased tire cost and reduced operating period of the 10-foot class, the profit margin was substantially above that

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[1] During the survey, the 8-foot trucks hauled small sawlogs directly to the sawmill on public roads. Their low profitability during the off-highway segment of each trip was offset by their ability to continue on public highways, increasing their overall revenue.

for the 12-foot vehicle. This indicated that for the moderate haul conditions surveyed, the lowest haul cost may be obtained by overloading a lighter duty vehicle rather than employing a more costly vehicle designed for the heavy load.

(g) Fleet Size: Truck fleet requirements and total haul costs were estimated for the annual transport of 100,000 cunits of large sawlogs and 100,000 cunits of small sawlogs by each of the four trucking systems, again based on the hypothetical 43-mile haul (Table 13).

A fleet of 10-foot trucks was the most favourable system, as it required the fewest trucks and lowest estimated haul cost. A fleet of the 12-foot trucks was similar in number but incurred a higher haul cost, while a fleet composed of 8-foot vehicles required more trucks at substantially higher cost. In comparison to the mixed fleet, using entirely 10-foot vehicles could reduce the truck requirements by 23% and cost by 20%, while the fleet of large vehicles could reduce the fleet by 22% but the cost could be reduced only 4%.

A parallel analysis of the costs of building and maintaining roads appropriate for the three types of truck would be necessary in order to optimize all cost factors attributable to hauling. The road cost variable was not considered in this study.

4.3 Sensitivity Analysis

For planning purposes, it is useful to know the impact on estimated productivity and haul cost of

TABLE 13. FLEET REQUIREMENTS AND TOTAL ANNUAL HAUL COST.[2]

SYSTEM	SMALL SAWLOGS			LARGE SAWLOGS			TOTAL PRODUCTION		IMPACT[1]	
	Truck Class	Fleet Size	Haul Cost ($)	Truck Class	Fleet Size	Haul Cost ($)	Fleet Size	Haul Cost	Fleet Size	Haul Cost
mixed fleet	8	17.1	782,000	10 & 12	9.6	548,000	26.7	1,330,000	100	100
all 8-foot	8	17.1	782,000	8	15.5	716,000	32.6	1,498,000	122	113
all 10-foot	10	11.1	564,000	10	9.5	500,000	20.6	1,064,000	77	80
all 12-foot	12	11.2	676,000	12	9.6	595,000	20.8	1,271,000	78	96

[1] Impact indicated relative to mixed fleet performance = 100.

[2] 'Spare' trucks and their cost were not included.

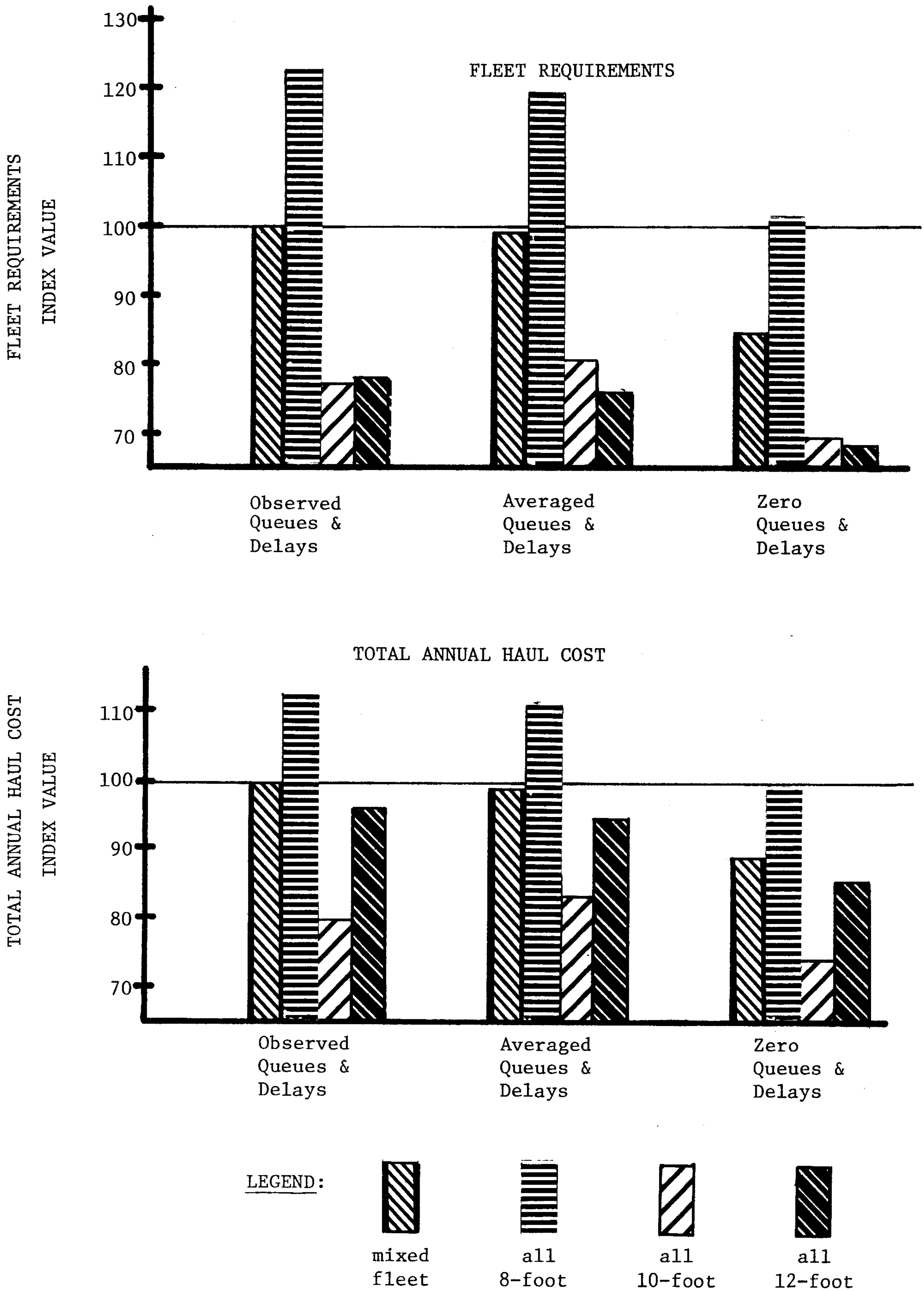
variations in the major operating parameters. A sensitivity analysis was conducted to estimate the effects of the following:

Factor	Alternatives Examined
a) System Delay	. observed delay for each class . equal delay for all classes . zero delay for all classes
b) Vehicle Ownership Period	. 3 years . 4 years . 6 years . 8 years . 10 years
c) Annual "In-Use" Time	. 1700 hours per year . 1900 hours per year . 2100 hours per year
d) Main Haul Distance	. 30 miles . 60 miles . 90 miles

(a) System Operational Delay: Elimination of operational delays could increase annual production of the individual truck 11% to 22% while reducing the cost per cunit-mile 7% to 13%.

Figure 2 indicates the impact of delay reduction on overall fleet requirements and total annual haul cost. To indicate the relationships between the types of trucks in the fleet and level of delay, the mixed fleet option with observed queues and delays is assigned a value of 100. Other options are shown relative to this base.

FIGURE 2. IMPACT OF REDUCING OPERATIONAL DELAYS ON FLEET REQUIREMENTS AND TOTAL ANNUAL HAUL COST.



With a perfectly synchronized operation (all operational delays removed), both the fleet required and annual haul cost could be substantially reduced for all fleet options. For example, with a mixed fleet a 15% reduction in fleet size and a 11% reduction in total haul cost could be realized.

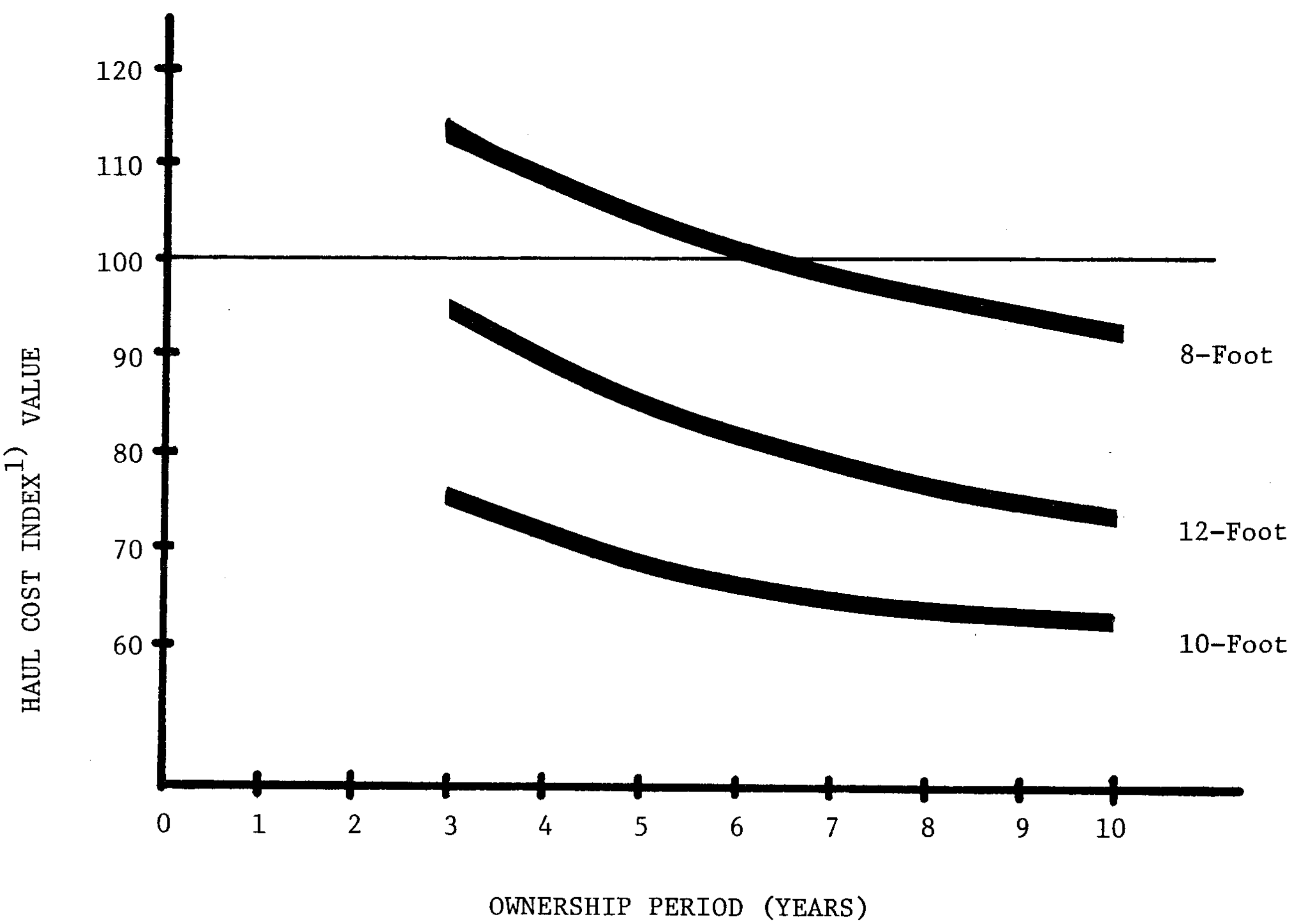
<u>(b) Ownership Period</u>: The typical ownership period was approximately 3 to 4 years. However, the impact of retaining the original vehicle 3, 4, 6, 8, and 10 years was calculated.

Retaining the same vehicle for a greater number of years increased the absolute amount of depreciation. However, as indicated by Figure 3 the haul cost per cunit-mile decreased as the ownership period increased. Depending upon the vehicle class and usage, the cost saving ranged between 16% and 23%. The largest saving was on the largest and most costly vehicle, while the minimum saving was for the 10-foot class which had low capital cost yet high productivity. For this class, only modest savings are indicated between a truck life of 5 and 10 years.

As a vehicle ages its reliability could be expected to fall, reducing its annual productivity, while the maintenance cost per mile could be expected to rise. Figure 3 assumes constant reliability and maintenance cost per mile for the life of the vehicle. While this may be contrary to general experience, more suitable estimates were not available.

<u>(c) Annual Vehicle Operating Hours</u>: As well as the average 1900 "in-use" hours per year, 1700 and 2100 hours (plus and minus 10.5%) were considered. Increasing annual operating hours amortized the fixed costs

FIGURE 3. IMPACT OF OWNERSHIP PERIOD ON INDIVIDUAL TRUCK HAUL COST.



1) $0.155 per cunit-mile was assigned the base value of 100.

over a greater annual production volume. As indicated in Figure 4, the fleet requirements and total annual haul costs (relative to that of the mixed fleet operating 1900 hours per year) decreased for all truck classes as annual operating hours increased. However, the effect was not as great as eliminating operational delays. The relative ordering of the truck classes remained unchanged.

(d) Haul Distance: The effect of increasing haul distance was considered by substituting 60 and 90 miles main haul distances for the original 30-mile main haul.[1] On the average, doubling the main haul distance reduced individual truck productivity by 26% while tripling reduced it by 41%. Even though the annual volume transported per truck decreased, the truck cost on a cunit-mile basis decreased. However, the cost reduction per mile became smaller as the length of haul increased; that is, the cost per cunit-mile would not continuously decrease, but would reach some minimum value.

Based on a fixed revenue[2] per cunit-mile ($0.155), calculations show that trucks became more profitable to the owner/operator as the haul distance increased. For example, for all truck and load combinations, average revenue increases were approximately 25% and 40% for the 60 and 90 mile main haul respectively. Even the 8-foot class which was not profitable on the short off-highway haul became profitable as the distance increased. Again, these results substantiated the judgement of the drivers.

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[1] The calculation of the haul cost did not account for the relation of cycle time to shift length because of the basic owner-operator nature of the truck fleet.

[2] For these long main-haul distances, the revenue per cunit-mile may decrease as distance increased. It was held constant in this calculation for illustration purposes.

FIGURE 4. IMPACT OF ANNUAL OPERATING HOURS ON FLEET REQUIREMENTS AND TOTAL ANNUAL HAUL COST.

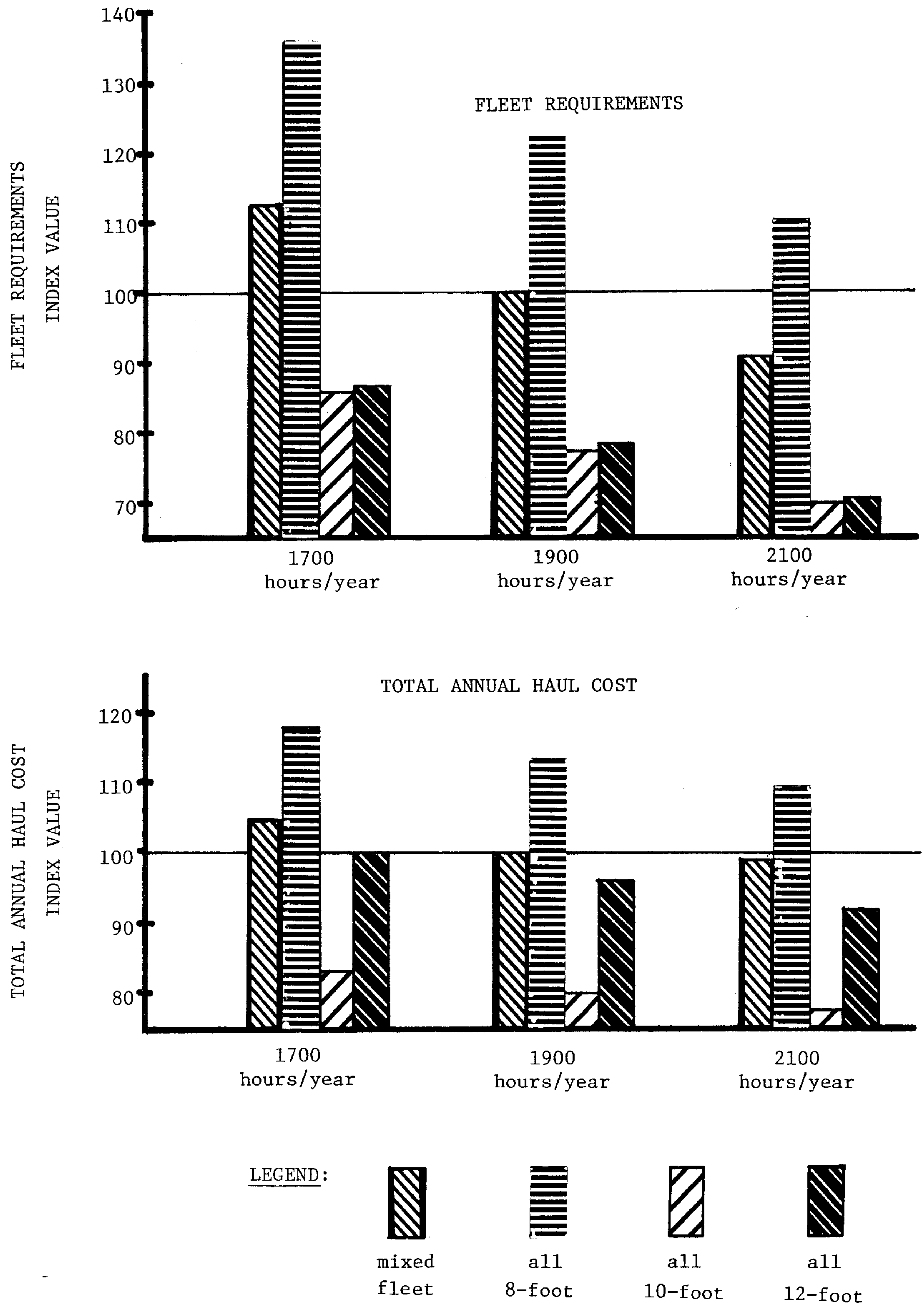

FIGURE 5. IMPACT OF MAIN-HAUL DISTANCE ON FLEET REQUIREMENTS AND TOTAL ANNUAL HAUL COST.

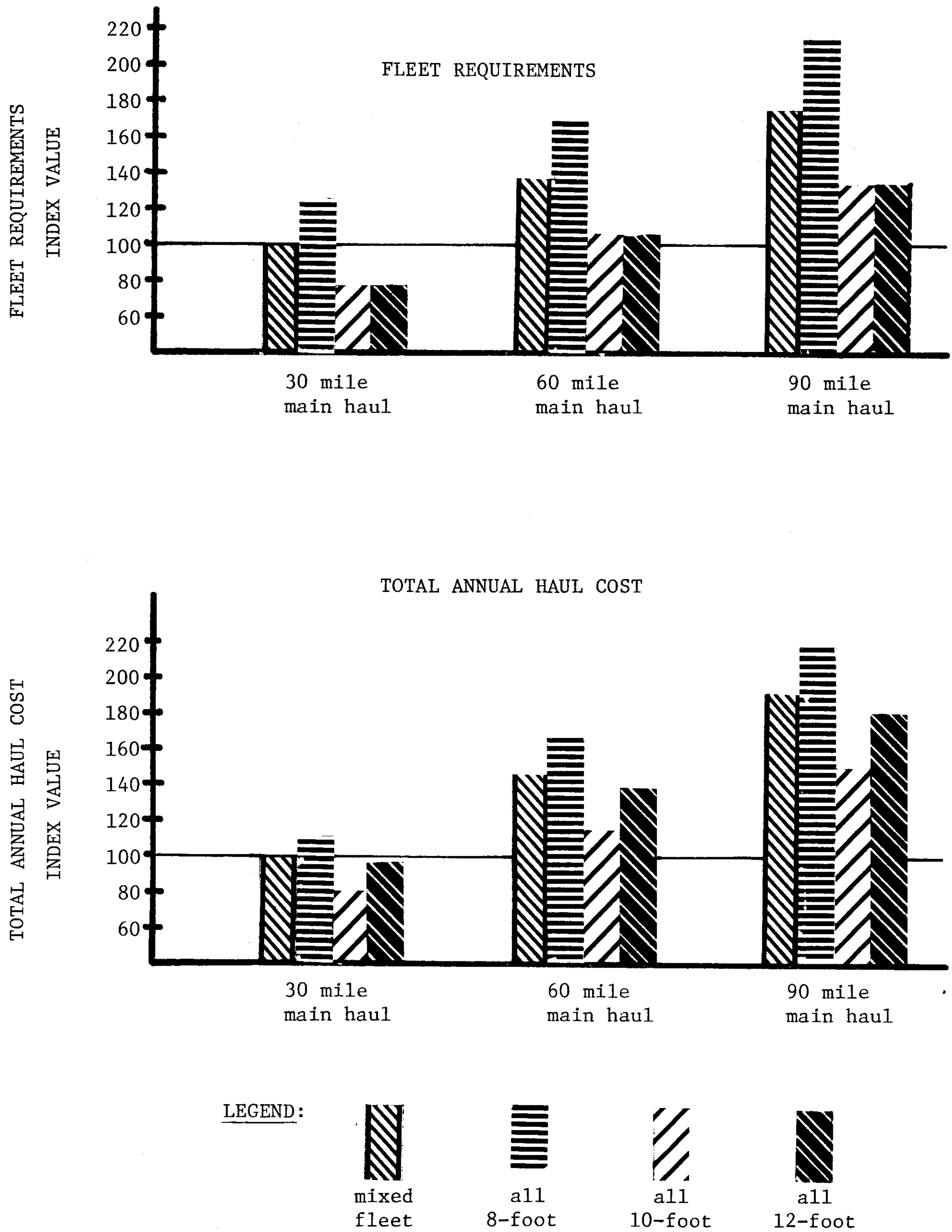

Figure 5 indicates that the truck fleet required to transport 200,000 cunits annually increased substantially as the haul distance increased. For the mixed fleet, the number of trucks required increased by 37% and 73% when the main haul distance was lengthened to 60 and 90 miles respectively, and the total haul cost increased by 46% and 90%.

5. CONCLUSIONS

The objective of this study was to compare the productivity and costs of three weight classes of logging truck operating under similar road and weather conditions. This objective has been accomplished. Although some factors such as driver ability and on-sale road quality could not be controlled it is felt that the results truly show the differences between truck types.

5.1 Truck Types

The 10-foot truck class showed the best performance followed by the 12-foot class. The 8-foot highway trucks performed less favourably and confirmed the local operator's opinion that these trucks should be used only where necessary to satisfy highway regulations.

5.2 Cost and Productivity

Little can be done to reduce the hourly cost of operating a truck. Labour rates, repair costs and the purchase price have all risen rapidly in the past and are beyond the control of the operator. There are, however, opportunities to increase productivity, including:

(a) Load the vehicle to its capacity every trip. It is significant that the 10-foot bunk trucks which showed the best performance were heavily loaded compared to rated capacity. Highway drivers should be encouraged to use bunk scales to measure the payload weight during loading.

Highway trucks are capable of carrying payloads substantially heavier than legal highway limits. Trucking contractors, logging companies and the Provincial Forest Service should cooperate with the Highway Department in the setting of individual highway load limits for each haul route. The criterion for setting these limits should be the ability of the specific haul route to support the loads.

(b) Increase truck speeds by improving roads. Continuously balance the trade-off between improved roads, which permit higher truck speeds and reduce truck repair costs, and the cost of building and maintaining these roads.

(c) Reduce delays. The most serious delays occurred in the landing, either waiting in a truck queue or waiting for logs. These delays indicate the necessity for improved dispatching or better selection of the number of trucks required.

(d) Extend the life of the vehicle. This requires a careful analysis of the trade-off between depreciation costs, repair costs and truck downtime.

(e) Operate truck two shifts per day. The extra annual production will reduce the unit cost of finance, insurance and licence charges. Although the truck will wear out faster, the depreciation cost will be reduced because the resale value of the truck depends in part on its age.

(f) Preloading. Various preloading systems and techniques have been developed and tried with only limited success. Reasons for failure include additional vehicle weight causing a reduction in highway payloads, time losses from trailer hookup not offset by other time savings, and the difficulty of scheduling and matching trailers and trucks in an operation where more than one truck owner is hauling.

A successful preload system would offer the following advantages:

- allow the trucks to operate relatively independent of the woods loaders and so reduce loading and queueing delays;
- permit the use of truck trains;
- permit the use of off-highway trucks or tractors to shuttle trailer loads to a central yard, and thus eliminate the necessity of highway trucks traversing the poorest section of the road.

5.3 Future Studies

This study has highlighted the need for further research in four areas:

(a) Delay studies. The potential for reducing delays through such changes as the introduction of pre-loading or more efficient dispatching systems could be assessed, using adaptations of the methods developed in this study.

(b) Road standards. Study of variations in performance and productivity of log trucks operating over different standards of haul road to clarify the relationships between the truck and the road. Improved knowledge of these relationships could enable forest planners to optimize hauling costs on individual operations.

(c) Road capacity. Development of a technique to determine the ability of a road to carry a load without damage. This would enable industry and government engineers to establish road limits for specific routes and to vary them for weather conditions.

(d) Combination hauls. Study the total costs of operations where trees are hauled on private roads to a central landing and logs are hauled from it on highway trucks.

This study has provided basic information on trucking and developed a method for making further studies. The results should be generally applicable in other areas. The methods and techniques used in log hauling are fully developed and few major changes can be expected. However, continued studies are necessary to point out areas of possible improvement so that the industry can stay current and take advantage of technological change.

APPENDIX A

CONVERSION FACTORS OF BASIC MEASURES

English				Metric
inch	x	25.4	=	millimetre
foot	x	0.30480	=	metre
mile	x	1.6093	=	kilometre
pound	x	453.59	=	gram
cunit	x	2.8317	=	cubic metre
gallon	x	4.5461	=	litre
cunit-mile	x	4.5571	=	cubic metre kilometre
mile per hour	x	1.6093	=	kilometre per hour
minute per mile	x	0.6214	=	minute per kilometre
mile per gallon	x	0.3541	=	kilometre per litre