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

Computer-Aided Comparison of 5, 6 and 7 Axle Log Trucks for Long Distance Highway Hauling

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ABSTRACT

Grade and alignment characteristics were digitized for an unpaved 261-km public haul road in Interior British Columbia, using a Forest Service road recorder. Five-axle, 6-axle and 7-axle truck/trailer combinations like those in local service were then tested mathematically against the digitized road data, using the Cummins Vehicle Mission Simulation program. In this simulation, the truck/trailer combinations differed considerably in load size and annual trips per unit, but were similar in trucking cost per unit of volume.

FOREWORD

The Forest Engineering Research Institute of Canada wishes to thank

- Fred Hutchinson of Pinette and Therrien Mills Ltd.
- the participating truck drivers
- the B.C. Forest Service--Engineering Branch
- the Cummins Engine Company--Vehicle Mission Simulation (VMS) Department

for their generous assistance during the course of this study.

This report contains a mixture of U.S. units of measure and S.I. units. The reports from the Western Highway Institute and the Vehicle Mission Simulation output originated in the U.S.A., while the truck weight and load data are Canadian. S.I. equivalents to values in the report, if not already supplied, can be calculated from the conversion factors in Appendix III.

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SUMMARY

Log hauling by truck can represent from a quarter to a half of the log cost to a mill. The components of trucking cost have increased rapidly in the past and are expected to continue to increase in the future. Provincial highway weight regulations specify the maximum gross combination weights (GCW) permissible for each configuration of truck operating on the public highway system. It is left to the user of the trucking service to transport the greatest wood volume for the least cost.

The objectives of this report are:

1) to illustrate the use and benefits of two advanced techniques for planning log hauls. That is, road digitization (B.C. Forest Service--road recorder) and truck performance simulation (Cummins Engine Company--Vehicle Mission Simulation).

2) to compare (in a case study) the suitability, productivity and cost of three highway configurations (GCW classes) of logging trucks used for long distance highway log hauling.

An entire case study haul route (261 km) in the Central Interior of British Columbia was digitized, courtesy of the B.C. Forest Service Engineering Branch. The Cummins Engine Company wrote an interface program to input these data directly into their Vehicle Mission Simulation (VMS) system.

The study has indicated that the quality of planning for highway log hauling can be significantly improved using route digitization and truck simulation. The ability to input the B.C. Forest Service road recorder data directly into the Cummins VMS allows the simulation of specified vehicles on an accurate representation of the existing haul route. This is a strong foundation for predicting the impact of vehicle changes or road improvements on fleet productivity.

Field data (truck specifications, tare and loaded weight) were collected to support the highway performance simulation of four truck configurations:

Configuration	No. of Axles	Engine
Standard pole trailer	5 axle	350 hp (261 kW)
Tri-axle trailer	6 axle	450 hp (336 kW)
'B' train	7 axle	400 hp (298 kW)
'B' train	7 axle	450 hp (336 kW)

The case study 'B' train averaged 88% of maximum payload. While a fully loaded 'B' train was not simulated, it was included in the productivity and cost estimate for comparison purposes.

Table S-1 summarizes the results of the performance, productivity and haul cost estimate (relative to the standard 5 axle pole trailer as 100).

TABLE S-1. Summary of Performance, Productivity and Haul Cost Estimates.

Configuration	Performance (Travel Time Loaded)	Annual Trips	Trucking Cost
Pole trailer	100	100	100
Tri-axle trailer	97	87	100
'B' train (400 hp)	103	83	105
'B' train (450 hp)	100	83	106
'B' train (100% payload)	-	73	97

Overall, while the higher GCW configurations can deliver the required annual wood volume with significantly less vehicles and trips, there appears to be little difference in the estimated haul cost for each configuration.

The estimated costs used in this study indicate little potential for the user to reduce the costs associated with any vehicle. The greatest opportunity appears to lie in extending the operating life of the truck as much as possible to reduce capital depreciation and finance charges. Repair and maintenance is a significant item. Careful regular service could keep this factor to a minimum.

This study illustrated a technique for choosing a tractor and trailer for use on an existing haul route. The road recorder and truck simulation could also be used to determine the benefit of improvements to road location, grades, curves and surface. It would then be possible to study a haul route and to recommend the best road standard and vehicle type.

SOMMAIRE

Le transport des grumes par camion peut représenter entre le quart et la moitié du coût des grumes rendues à l'usine. Les éléments qui entrent dans le coût du camionnage ont augmenté rapidement par le passé et sont susceptibles de continuer à l'avenir. Les règlements provinciaux relatifs au poids permis spécifient le poids brut combiné (PBC) maximum permis pour chaque type de camion circulant sur les réseaux de voies publiques. Il revient à l'utilisateur du service de camionnage de trouver moyen de transporter le plus grand volume de bois au coût le moins élevé.

Le présent rapport a pour objectifs:

1) d'illustrer l'emploi et les avantages de deux méthodes modernes de planification du camionnage des grumes. Ces méthodes sont la représentation numériques des caractéristiques des routes (Service forestier de la Colombie-Britannique - enregistreur de routes) et la simulation de la performance des camions (Cummins Engine Company - Simulation du trajet des véhicules (VMS).

2) de comparer (à l'aide d'une étude de cas) la pertinence, la productivité et le coût de trois modèles routiers (classes de PBC) de camions grumiers utilisés pour le transport longue-distance de grumes sur la grand'route.

La Division de Génie du Service forestier de Colombie-Britannique a gracieusement accepté de représenter numériquement l'ensemble de la route de camionnage (261 km) servant à l'étude de cas, dans le centre intérieur de la province. La Cummins Engine Company a préparé un programme d'interface permettant d'entrer ces données directement dans leur système de simulation du trajet des véhicules (VMS).

L'étude a démontré qu'il est possible d'améliorer sensiblement la qualité de la planification du camionnage des grumes sur la grand'route à l'aide des techniques de représentation numérique de la route et de simulation des camions. Le fait de pouvoir entrer directement les données de l'enregistreur de routes du Service forestier (B.C.) dans le programme VMS de la compagnie Cummins permet la simulation de véhicules spécifiques sur une représentation exacte de la vraie route

de camionnage. On a ainsi un outil solide permettant de prévois l'impact, sur la productivité de la flotte de camions, d'un changement de véhicules ou d'améliorations de la route.

Des données ont été recueillies sur le terrain (caractéristiques techniques du véhicule, poids à vide et poids en charge) pour étayer la simulation de la performance routière de quatre modèles de camions:

Modèle	Nombre d'essieux	Moteur
Remorque télescopique standard	5 essieux	350 hp (261 kW)
Remorque à trois essieux	6 essieux	450 hp (336 kW)
Train routier à double remorque	7 essieux	400 hp (298 kW)
Train routier à double remorque	7 essieux	450 hp (336 kW)

Le train routier étudié transportait en moyenne 88% de sa charge maximum. Même si on n'a pas simulé un train routier chargé à plein, on l'a quand même inclus dans l'estimation du coût et de la productivité, aux fins de comparaison.

Le tableau S-1 résume les résultats de l'estimation de performance, de productivité et de coût (comparativement à la remorque télescopique à 5 essieux considérée comme 100).

TABLEAU S-1. Sommaire des estimations de performance, de productivité et du coût du camionnage.

Modèle	Performance (Temps de déplacement en charge)	Nombre annuel de voyages	Coût du camionnage
Remorque télescopique standard	100	100	100
Remorque à 3 essieux	97	87	100
Train à double remorque (400 hp)	103	83	105
Train à double remorque (450 hp)	100	83	106
Train à double remorque (charge pleine 100%)	-	73	97

En général, il est a remarquer qu'avec la configuration de PBC la plus élevée il est possible d'effectuer la livraison du volume de bois requis annuellement avec un nombre significativement moindre de voyages et de véhicule. Il semble cependant que la différence des estimations de coût de transport entre chacune des configurations soit minime.

Les estimations de coût utilisés dans cette étude indique qu'il n'existe, pour l'utilisateur, qu'une faible possibilité de réduire les coûts associés à quelconque véhicule. Les meilleurs perspectives semblent résider dans l'accroissement au maximum de la période d'utilisation des camions afin de réduire la dépréciation du capital et les frais de financement. L'entretien et réparation s'avère un facteur très important. Un entretien régulier et méticuleux pourait contribuer à minimiser ce facteur.

Cette étude a décrit une technique de selection de camion et de remorques utilisés sur routes déja existantes. L'enregistrement digital des systèmes routiers et la simulation de camion pourrait aussi être utilisé pour déterminer les avantages des améliorations de la qualité des courbes, de la chaussée et du tracé des chemins. Il serait ainsi possible d'étudier une route de haulage et de recommender le meilleur type de route et le type de véhicule le plus approprié.

1. INTRODUCTION

Log hauling by truck can represent a quarter to a half of the log cost to a mill. The various components of operating cost, such as fuel, tires and vehicle capital cost have increased dramatically in the past and are expected to continue to increase in the foreseeable future. Provincial highway weight regulations specify the maximum gross combination weights (GCW) permissible for each type of truck operated on the public highway system. It is up to the user to optimize his own operation and transport the greatest wood volume for the least cost.

Thoughtful planning is required to achieve efficient operation of the log haul system. The present costs and productivity must be evaluated for the existing haul to provide a firm foundation for the accurate prediction of future costs, performance and productivity of different vehicles on new haul routes. The vehicle type (configuration, gross combination weight) and mechanical specification (horsepower, gearing) must be matched to the intended use.

The objective of this report is to assist planning by:

1) illustrating the use and benefit of two advanced techniques for planning future log hauls--road digitization and truck performance simulation. (In this study, the B.C. Forest Service road recorder[1] and the Cummins Engine Company's Vehicle Mission Simulation (1) were used.)

2) comparing the suitability, productivity and costs of three configurations of logging truck (GCW classes) for long distance highway log hauling.

The road recorder is an instrumented truck which digitizes the entire haul route while driving over it. From this record, accurate plan and profile maps of the route can be made.

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[1]See Appendix I for description.

The Vehicle Mission Simulation (VMS) is a sophisticated computer model used to predict the over-the-road performance of specified vehicles on a specified route. The Cummins Engine Company wrote an interface program to input the digitized case study haul route into the VMS. Thus the operation of the representative vehicles was simulated over the same actual haul road--a 261 km (162 mi) route from Tatlayoko Lake to Williams Lake, B.C.

The project utilized these two techniques to evaluate the performance of three representative classes of highway truck:

- 5 axle (3-S2)[1]--standard pole trailer
- 6 axle (3-S3 or F3)--tri-axle semi or full trailer
- 7 axle (3-S2-S2)--'B' train, two semi-trailers

The case study provided comparative loading times. Average payloads were calculated by analyzing B.C. Forest Service weight scale records for an entire haul season. Data were gathered on several 5 and 6 axle trucks (for better averaging) but only one 'B' train was operated on log hauling.

The combination of actual productivity data and computer estimated performance data permitted the overall comparison of the suitability of each configuration for long-haul log transport by estimating the fleet size required, trip cost and total haul cost.

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[1]The symbol system of designating truck combinations specifies the number of tractor axles followed by S, F or P to indicate semi-, full or pup trailer, and then the number of trailer axles. Thus, a three axle tractor and a two axle semi-trailer combination is designated as 3-S2.

2. CHARACTERISTICS OF REPRESENTATIVE HIGH GROSS COMBINATION WEIGHT VEHICLES

There is scant data presently available about power requirements, traction and tire wear as a function of vehicle gross combination weight for vehicles operated in the logging environment. However, testing has been done by the Western Highway Institute[1] on highway freight trucks. These tests could be relevant to logging trucks operated on the highway as they indicate trends and are representative of the factors to be considered when utilizing the higher GCW combinations.

This chapter is a precis of several WHI publications relating to:

- Power Requirements
- Fuel Consumption and Utilization
- Drive Traction
- Tire Wear
- Offtracking

2.1 Power Requirements

The total installed power required is the sum of that needed to overcome:

- rolling resistance
- grade resistance
- air resistance
- chassis friction resistance
- inertial resistance
- parasitic losses
- imposed performance standards

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[1]The Western Highway Institute (WHI) is a non-profit California corporation. It functions as a research engineering and coordination agency in support of the organized motor carrier industry in the 13 Western states, the 4 Western provinces of Canada and the Yukon Territory. The headquarters of WHI are at 1200 Bayhill Drive, San Bruno, California.

Rolling resistance is the retarding effect of the road on the vehicle. It is a function of GCW, vehicle speed, road roughness and adhesion and tire hysteresis.

Grade resistance is the component of the vehicle weight acting downhill and is determined by GCW and steepness of grade.

Air resistance is the drag caused by the movement of the vehicle through the air. While its effect is negligible below 50 km/h, it is significant at highway speeds[1]. The main determinants are vehicle speed, frontal area and vehicle configuration (2).

Chassis friction resistance is the loss due to the inefficiencies of each component of the vehicle power-train, and is affected by GCW, engine rpm, gear reduction and tire slip.

Inertial resistance is the stored energy in the vehicle's rotating parts and is determined by GCW, engine and driveline design.

Parasitic losses are the power requirements of the accessories such as fan, alternator, air pump and air conditioner. These losses are directly determined by the number and type of driven accessories.

The imposed standards are levels of speed-gradeability and acceleration specified by legislation or economics. The minimum speed permissible on a specified grade and minimum speed change ability when traction is not a factor are complex characteristics to specify for a vehicle, but must be considered for safe passing, merging and clearing intersections.

The interaction of these factors was investigated in a test conducted by the Oregon State Highway Department, McCracken Brothers Motor Freight and Freightliner Corporation in 1968 (3).

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[1]Effective speed is the combination of vehicle speed and wind speed and direction.

Eighty-six test runs were made on paved highway between Portland and Eugene, Oregon using a Freightliner 4x2[1] powered by a Cummins NTC engine operated at 380, 335 and 280 gross horsepower (283, 250, 209 kW).

The tractor was operated with double trailers up to 76,000 pounds (34 550 kg) and triple trailers up to 114,000 pounds (51 824 kg) in order to relate GCW and weight/power ratio to vehicle performance and engine life, as well as to determine any quantifiable advantage of longer combinations and higher GCW's.

Effect of Power and GCW on Driving Time and Average Speed

The overall trends, as expected, indicated that increased power reduced driving time (increased speed) while increased GCW increased driving time (reduced speed). In all cases, the higher GCW combinations were the most affected by power changes.

The absolute magnitude of the changes, while significant, was not overwhelming. At 110,000 pounds GCW the average speed decreased from 46 mph to 42 mph with a decrease in horsepower from 380 to 280. The average speed at 110,000 pounds GCW with 380 hp equalled that of 76,000 pounds GCW with 335 hp. Thus the overall trip time displayed only a modest sensitivity to weight and power.

Average Power Extracted and Engine Load Factor

The average power extracted is a measure of the amount of power actually utilized when driving the vehicle as opposed to the maximum amount available or installed in the truck. The ratio of the average power used divided by the maximum power available is termed engine load factor.

As the GCW and design speed of the vehicle increases so does the power extracted and load factor. However, as long as

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[1]The tractor designation specifies the total number of wheels (single or dual tires) on the tractor followed by the number of powered wheels. Thus, the standard logging tractor with a steering axle and tandem driving axles is designated 6x4.

the engine has surplus power (that is, operated at less than 100% load) the extracted power does not increase with increased rated (installed) power. This implies a critical power level for a particular combination and GCW where the engine is operated at capacity. Beyond this point, vehicle performance is impaired by lack of available power.

For best engine life a moderate load factor--between 50 and 85 percent--is desirable. This must be balanced by the economics of engine installation. Gross over-specification of engine installed power results in high capital cost, while under-specification results in reduced performance levels and possibly reduced engine life.

2.2 Fuel Consumption and Utilization

Fuel Consumption

Similar to extracted power, fuel consumption varies directly with GCW and top speed due to the increased resistance and kinetic energy. Because the power expended does not increase with increased engine size--provided the installed power is greater than the demand--fuel consumption is not greatly affected by engine size within the range studied.

Fuel Utilization

Fuel utilization is indicated by a function of volume of fuel consumed while transporting a unit payload a unit distance. Figure 1 is an interpretation of data presented by WHI (2), which shows fuel utilization increasing with increasing GCW levels. For later comparison a 95,000 pound GCW vehicle yields about 100 payload ton-miles per U.S. gallon of fuel.

2.3 Drive Traction

Drive traction ability is the maximum driving force the truck's wheels can exert against the road surface. It is equal to the total weight on the drive wheels multiplied by the prevailing coefficient of friction. For reliable vehicle operation, sufficient drive traction is required to

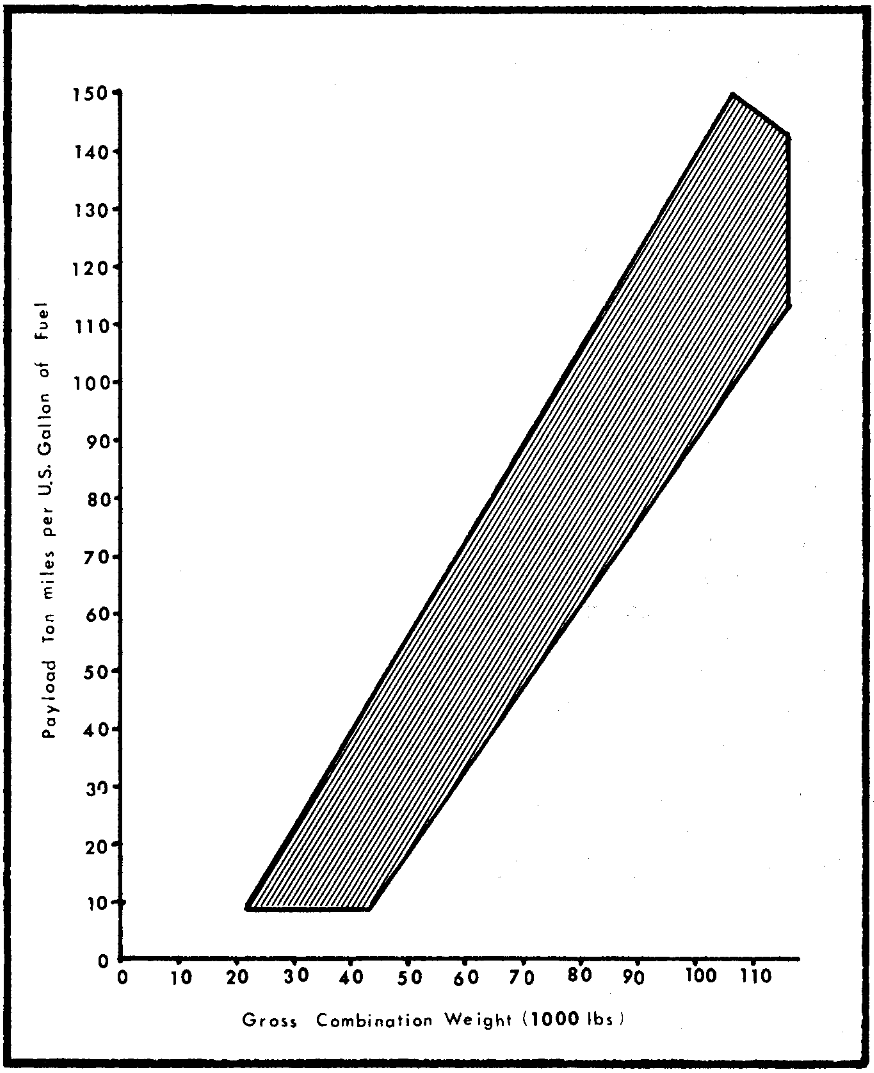

FIGURE 1. Fuel Utilization as a Function of Vehicle GCW.

overcome the external forces resisting its forward motion, such as air, rolling and grade resistance while accelerating.

A tractor-trailer combination cruising at steady speed on a level road will be using only a portion of its drive traction ability in order to meet its drawbar pull requirements. The difference between this utilized traction ability and its total traction ability is termed 'surplus' drive traction. This surplus is available for climbing grades. Thus the drive traction ability of various truck combinations can be compared by the maximum grade they can negotiate under steady speed conditions without loss of traction.

As discussed under "Power Requirements" the higher GCW combinations extract more power when driving (require higher drawbar pull) but do not impose an increase in payload weight on the drive axles. Thus the drive traction ability remains relatively constant for the various truck types utilizing a similar tractor. As the 'surplus' is reduced, the critical traction limited grade (surplus equals zero) also decreases.

For a standard three axle tractor and two axle semi-trailer, the ratio of the static weight on the drive wheels to the total combination weight is about 0.48 while for a 'B' train it drops to about 0.26. WHI tests (4) indicated that the traction-limited grades between a loaded pole trailer and 'B' train were reduced from 13.7% to 9.2% on packed snow and from 19.0% to 13.0% on wet asphalt.

While the relative traction-limited grades can be estimated mathematically or found by field testing, the real-world impact of this reduction for the higher GCW combinations is more difficult to estimate.

Reliable highway operation is not expected on glare ice or in deep snow. Packed snow on a long mountain grade is likely the worst adverse road condition encountered. For a paved public highway the maximum sustained grade is about 8%. Thus on a highway the 'B' train would not likely be traction-limited.

A difficult problem for trucks used in logging is the low-quality spur road--with a soft surface and severe adverse grades. While all trucks can encounter problems, the pole trailer will require less "chaining-up" to negotiate these sections than the tri-axle or 'B' train.

2.4 Tire Wear

For a highway log haul, increasing the payload requires more axles and tires on the vehicle. This causes the proportion of the gross combination weight on the drive axles to decrease.

In normal highway operation more traction is available than needed to drive the vehicle. The closer the balance between power required and traction available, the greater the tendency for drive tire slippage and wear.

WHI studies (5) indicate that a 6x4 tractor pulling a 40-foot semi-trailer with an actual GCW of 59,800 pounds has an average drive axle weight of 28,900 pounds and produces an average tractive effort of 1,270 pounds. The same tractor pulling two trailers with a gross weight of 111,000 pounds averaged 1,780 pounds tractive effort with the same axle weight. The increased tractive effort with the same wheel loading reduced the drive tire mileage from 146,000 to 72,800 miles.

Even though the wear rate increases dramatically on the driven tires as the GCW and number of axles increase, the larger combinations haul greater payloads with the same number of driven tires. Thus the total tire operating cost per ton-mile is the important figure.

The WHI study summarized the total tire costs for several GCW combinations each with a 6x4 tractor.

Tire Cost Comparison

Trailer Combination	Average Actual GCW (pounds)	Relative Total Tire Cost
40-foot semi-trailer	59,800	1.000
27-foot doubles	69,600	1.278
27-foot triples	99,700	1.200
40-foot doubles	111,100	1.040

The study concluded that with a 6x4 tractor, overall tire cost will increase in the same ratio as payload ton-miles above the standard 5 axle (3-S2) for the larger GCW combinations.

2.5 Offtracking

In practical terms, the major concern with offtracking is the distance that the rearmost tire deviates from the path of the corresponding tire on the front axle.

According to the WHI (6) the magnitude of the offtracking depends upon:

- wheelbase length of the unit
- radius of turn
- number and location of articulation points
- truck speed when entering the curve
- turning ability of the truck

The normal tendency is for the trailing axles to deviate inward (towards the centre of the curve) from the path of the leading axle when steering is done solely by the leading axle. Negative offtracking--counter to this tendency--is incurred by stinger-steering. The stinger shifts the point of articulation between towing and towed units rearward from the more common fifth wheel or pintle hook position. Thus the normal tracking performance of the tractor-trailer is considerably improved.

Logging trucks and automobile transporters incorporate the stinger-steering principle. A typical 65-foot overall length tractor and semi-trailer has a mathematically computed maximum offtracking of 5.6 feet (7). A stinger-steered 65-foot auto-transporter has a maximum offtracking of 3.4 feet. A stinger-steered 'B' train with an overall length of 105 feet has a computed offtracking of 4.4 feet.

3. CASE STUDY

FERIC, in cooperation with industry personnel, studied a long haul route and representative truck configurations on an operation in the Central Interior of British Columbia.

B.C. Forest Service weight scale data were analyzed to determine the average tare and gross truck weights over an entire winter haul season for several 5 and 6 axle trucks and the one 'B' train available for monitoring.

The haul route was digitized by the road recorder and a plan and profile prepared, courtesy of the B.C. Forest Service, Engineering Division. The highway performance of each truck type was simulated over this route using the Vehicle Mission Simulation, courtesy of the Cummins Engine Company.

Observed field data, simulation output and standard cost parameters were combined to estimate:

- vehicle cycle time[1]
- vehicle cost per trip
- vehicle productivity
- fleet size requirements
- total haul cost

3.1 Case Study Haul Route

The case study haul route (Figure 2) totalled 261 km (162 mi) from the mill at Williams Lake to the logging site at Tatlayoko Lake with an elevation gain of 1 830 m (6,000 ft). Of this route, 229 km is dual-lane all-weather road (Highway 20) and 32 km is 1½-lane low standard rural access road.

The following table indicates the grade distribution along the route.

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[1]Measurement of actual truck cycle times was not possible for this study.

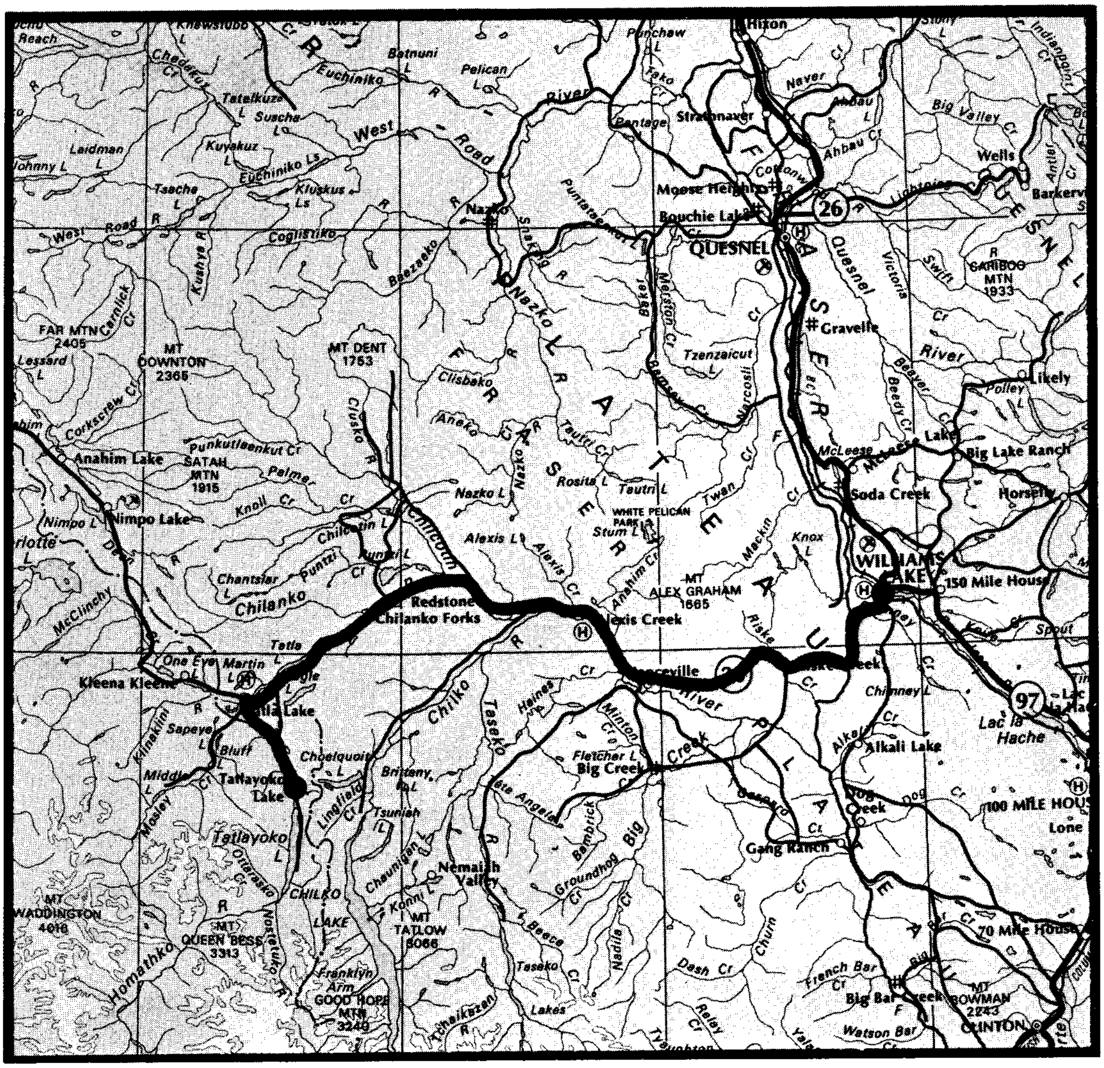

FIGURE 2. Case Study Haul Route.

Grade Distribution

Grade %	Adverse km	Favourable km
0 - 1	46.9	17.4
1 - 2	24.0	46.4
2 - 3	12.9	27.5
3 - 5	19.3	28.2
5 - 7	10.1	12.2
over 7	4.2	11.4

3.2 Representative Highway Logging Trucks

After interviews with logging company personnel, trucking contractors and drivers, three truck-trailer combinations were selected to represent the available highway log haulers.

The types simulated were:

5 axle--standard pole trailer (Figure 3)
6 axle--tri-axle semi or full trailer (Figure 4)
7 axle--'B' train--2 semi-trailers (Figure 5)

Table 1 summarizes the specifications of each vehicle used in the performance simulation.

Because of their similar overall configuration and intended service it is reasonable to compare the 5 axle pole trailer and the 6 axle tri-axle trailer in all applications. The 'B' train with two semi-trailers is designed for a different service. It is expected to load at a central processing yard rather than a woods landing. Thus it is expected to be less suitable for rough off-highway service. However, all three configurations are comparable for highway hauling.

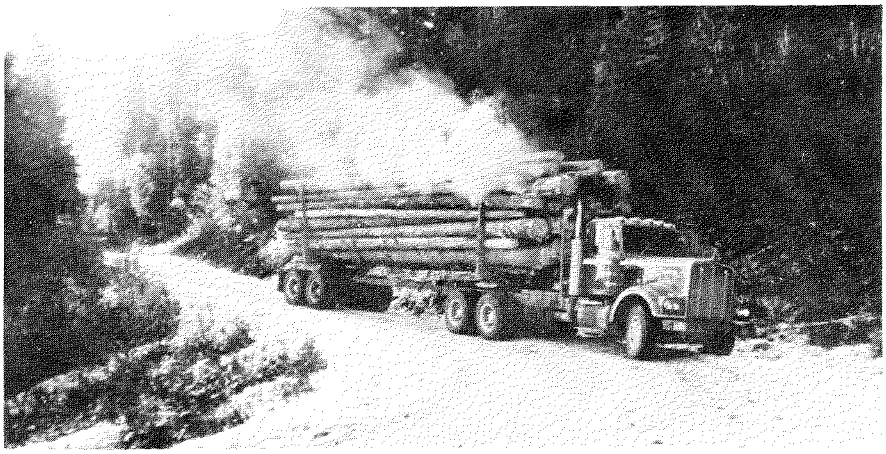

FIGURE 3. 5 Axle - Standard Pole Trailer

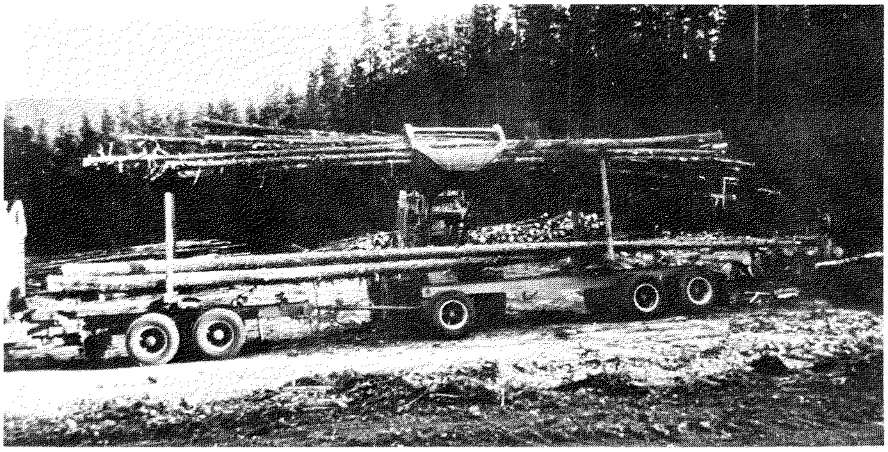

FIGURE 4. 6 Axle - Tri-Axle Semi or Full Trailer

FIGURE 5. 7 Axle - 'B' Train, 2 Semi-Trailers

TABLE 1. Case Study Truck Specifications.

	CONFIGURATION		
	Standard Pole Trailer	Tri-Axle Trailer	'B' Train
Vehicle Configuration Code	3-S2	3-S3 or F3	3-S2-S2
Tractor Model	Kenworth 900 Series	White Western Star, 4900	Freightliner, FLT Series
Tractor Cab Type	Conventional	Conventional	Cab over Engine
Tires	11.00 R 24.5 std. tread tubeless radial	11.00 R 24.5 std. tread tubeless radial	11.00 R 24.5 std. tread tubeless radial
Engine	Cummins NTC 350	Cummins KT 450	Cummins NTC 400 & KT 450
Main Transmission	Fuller RTO - 9513	Fuller RTO - 12513	Fuller RT - 12515
Drive Axle	Rockwell SQHD	Eaton DT 400 P (2 speed)	Eaton DS 480 P
Axle Ratio	5.290:1	5.370:1	4.330:1
Average Tare Weight (kg)	12 146	15 415	19 671
Average Loaded Weight (kg)	43 265	51 146	57 167
Average Payload (kg)	31 119	35 731	37 496

Cummins NTC 350 rated at 350 hp (261 kW)
Cummins NTC 400 rated at 400 hp (298 kW)
Cummins KT 450 rated at 450 hp (336 kW)

Driver Comments Regarding 5, 6 and 7 Axle Logging Trucks

During the course of the case study several drivers of 5, 6 and 7 axle logging trucks were interviewed. Their opinions as to the advantages and disadvantages of the various designs are significant but may be specific to the vehicle, driver or haul route.

5 Axle Pole Trailer (3 axle tractor, 2 axle semi-trailer)

- highly manoeuverable
- best drive traction ability
- tracks and handles well--both on pavement and gravel
- least capital cost
- most flexible in operation
- considered to be the industry standard vehicle

6 Axle Tri-Axle (3 axle tractor, 3 axle semi- or full trailer)

No significant differences were noted between the pole trailer and tri-axle concerning:

- fuel consumption
- tire wear
- average speed
- load distribution
- highway handling
- tracking on switchbacks
- handling on landing
- brake performance
- unloading at the mill

Several tractor specifications were considered important:

- higher horsepower engine makes the heavier vehicle easier to drive
- stronger frame or frame reinforcing required due to the possibility of cracking
- engine brake is very important to reduce wear on the service brakes

The disadvantages relative to the pole trailer noted were:

- difficult to top load to reach maximum legal weight
- empty trailer reload difficult due to extra trailer weight
- extra axle requires maintenance
- tends to be harsh riding on rough roads
- less drive traction when loaded but only a problem in severe mud and snow

<u>7 Axle 'B' Train (3 axle tractor, 2-2 axle semi-trailers)</u>

The large size means:

- larger payload
- higher capital cost
- higher maintenance cost
- decreased manoeuverability
- very limited ability to back up
- requires high power engine
- significantly reduced drive traction
- more frequent chaining required
- fuel consumption increased significantly
- slightly lower average haul speed

Loading:

- accurate log bucking required
- careful log placement required (logs must be butted evenly)

Road handling:

- handles well both empty and loaded
- offtracking acceptable

3.3 Comparison of Truck Operating Performance--Vehicle Mission Simulation Output

The output of the Cummins' simulation was used to compare the various truck configurations as to:

- average extracted power
- average speed and driving time
- startability and speed-gradeability
- fuel consumption and utilization
- gearshifts and time on brakes

Table 2 is the vehicle trip summary for the pole trailer, the tri-axle and two versions of the 'B' train--one powered by a Cummins NTC 400 and the other a Cummins KT 450. The 'B' train with a smaller engine than actually installed was simulated to test the impact of engine power on the performance of the highest GCW vehicle.

Average Extracted Power

Table 3 summarizes the engine load information for the four combinations.

In all cases, the engine load factor is 50% or less. This means the driver over the entire route used a maximum of half of the power available to him. This is much lower than the 50 to 85% load factor of a freight truck.

Further, the load factors are similar for the empty and loaded combinations. The speed of the empty truck, operated mainly in top gear, is limited by the engine governor and legal highway speed limits. While this requires substantial average engine power, it is generally less than maximum (100% throttle). When loaded, the vehicle spends a greater proportion of its time in lower gears and utilizes full available power, 40 to 49% of the time, to pull the load.

These estimates will vary for each vehicle configuration and haul route. Where loads are hauled downhill, the load factor empty could be greater than when loaded.

TABLE 2. Vehicle Trip Summary (VMS Output)[1]

	VEHICLE TYPE											
	5 Axle - NTC 350			6 Axle - KT 450			7 Axle - NTC 400			7 Axle - KT 450		
	Empty	Loaded	Comb.	Empty	Loaded	Comb.	Empty	Loaded	Comb.	Empty	Loaded	Comb.
Weight (lb)	26800	95390	-	34000	112800	-	43400	126040	-	43400	126040	-
Driving Time (hr)	2.98	3.59	6.58	2.98	3.49	6.46	3.06	3.70	6.75	3.02	3.56	6.58
Average Speed (mph)[2]	54.4	45.2	49.4	54.6	46.5	50.2	53.1	43.9	48.1	53.8	45.6	49.4
Fuel Used (U.S. gal)	26.2	31.6	57.8	32.1	38.9	70.9	32.3	38.2	70.4	34.3	40.4	74.7
Fuel Mileage (miles/U.S. gal)	6.20	5.13	5.61	5.06	4.18	4.58	5.03	4.25	4.61	4.74	4.02	4.35
Time at Full Throttle (%)	10.9	44.3	29.1	9.6	39.5	25.7	22.6	48.9	37.0	16.7	43.5	31.2
Average Engine Speed (rev/mile)	2187	2415	2301	2229	2436	2333	2131	2450	2291	2106	2347	2227
Engine Load Factor (%)	47	48	48	45	46	46	50	49	50	47	47	47
Total Gear Shifts	16	153	169	20	156	176	43	195	238	36	149	185
Time on Brakes (min)	2.9	38.6	41.5	3.6	38.4	42.0	5.4	39.1	44.5	4.7	38.6	43.3

[1]The Vehicle Mission Simulation output reports in U.S. units.

[2]The average speed predicted by VMS is expected to be higher than would be measured on this particular route. Delays due to traffic congestion were not considered in the road digitizing or truck performance simulation.

TABLE 3. Average Extracted Power.

Parameter	5 Axle NTC 350 Empty	5 Axle NTC 350 Loaded	6 Axle KT 450 Empty	6 Axle KT 450 Loaded	7 Axle NTC 450 Empty	7 Axle NTC 450 Loaded	7 Axle KT 450 Empty	7 Axle KT 450 Loaded
Engine Load Factor	47	48	45	46	50	49	47	47
Average Power Output (hp)	163	166	201	205	198	194	210	210
Average Engine RPM	1985	1819	2023	1888	1884	1758	1886	1783
Average Power Available (hp)	345	335	447	433	385	380	433	422
Time at Full Throttle (%)	10.9	44.3	9.6	39.5	22.6	48.9	16.7	43.5

ENGINE LOAD FACTOR = average power output/max. power output (Cummins definition)

$$\text{AVERAGE ENGINE RPM} = \frac{\text{average engine speed (rev/mile) x distance (mile)}}{\text{travel time (min)}}$$

AVERAGE AVAILABLE POWER = rated power at Average Engine RPM

The specified engines appear to have considerable reserve power for starting and hill climbing. While this large reserve increases the capital cost of the vehicle it is more likely needed for logging use. The high reserve also should increase engine operating life and permit a more constant cruising speed.

Effects of Power and GCW on Average Speed and Driving Time

Unloaded, all configurations have surplus power and similar cruising speed and driving time.

Loading the vehicle increases the travel time to a similar degree for all vehicles; however, the impact is 3 to 4% less for the high power (450 hp) trucks.

Configuration	Increased Driving Time Loaded vs. Empty
5 axle (350 hp)	+20%
6 axle (450 hp)	+17%
7 axle (400 hp)	+21%
7 axle (450 hp)	+18%

The difference in average speed between the tri-axle (112,800 pounds GCW, 450 hp) and the 'B' train (126,040 pounds GCW, 450 hp) was negligible.

Decreasing the installed horsepower of the 'B' train from 450 to 400 decreased the loaded average speed by 4% from 45.6 mph to 43.9 mph.

The loaded average speed of the 'B' train (126,040 pounds GCW) with 450 hp was similar to that of the pole trailer (95,390 pounds GCW) with 350 hp.

Table 4 presents a comparison of the loaded speed of the vehicles at 10 mile intervals over the entire haul route. The speed differences between vehicles at any point are shown to be minor.

The response to increased GCW and engine power is similar to that reported by the WHI (see Chapter 2). The changes in average speed are small compared to the change in weight and installed power.

TABLE 4. Comparison of Loaded Vehicle Speeds at 10 Mile Intervals Over Haul Route (MPH).

Mileage	Grade %	5 Axle NTC 350	6 Axle KT 450	7 Axle NTC 400	7 Axle KT 450
10	5.1	18.9	21.4	18.0	19.6
20	-4.9	57.2	55.8	57.3	57.3
30	1.2	54.3	54.2	54.2	54.2
40	-3.0	44.4	44.2	44.6	44.3
50	-3.7	56.1	56.0	56.1	56.1
60	0	55.1	55.1	54.6	55.1
70	0	54.4	54.5	54.6	54.5
80	-1.0	55.9	55.3	57.2	56.2
90	4.1	49.8	49.4	48.0	48.9
100	-1.0	54.6	56.1	52.3	55.2
110	-2.1	53.4	54.8	50.9	53.6
120	-1.0	54.1	54.1	54.0	54.1
130	3.0	28.7	32.4	26.6	31.2
140	-8.8	45.6	45.5	45.0	45.6
150	2.9	37.7	39.2	36.1	38.8
160	1.8	47.8	49.5	44.2	47.8

(-) indicates favourable grade.

Effect of Power and GCW on Startability and Speed-Gradeability

Startability is a measure of the ability of the vehicle to begin moving the load from the landing, or to move against an adverse grade after stopping to 'chain-up'. For logging usage, high startability is desirable for reliable operation, reduced driveline wear and reduced driver fatigue.

Table 5 summarizes the maximum and recommended starting grades of the case study combinations. No vehicle meets the Cummins Engine Company recommendation of 28 to 30% startability for off-highway applications. However, only the 400 hp 'B' train does not meet the 13 to 15% startability recommended for highway use.

The increase in GCW and different overall gearing between the tri-axle and 'B' train (both with a KT 450 engine) greatly reduces the recommended startability from 17.3% (tri-axle) to 6.5% ('B' train).

The 'B' train with the KT 450 has significantly higher startability than the NTC 400 due to the extra 125 foot-pounds of torque at clutch engagement.

Speed-gradeability indicates the ability of the vehicle to maintain desired trip average speed. While superior speed-gradeability is important in hilly country it is expensive in terms of installed engine torque, required only for the short duration of the grade.

The haul route grade distribution (page 13) indicated that 24% of the adverse was between 1 and 2 percent. Interpolating the VMS output, which summarizes the speed-gradeability of each study vehicle by gear and engine speed, to compare the combinations' maximum speed on a 1.5% adverse:

- 5 axle (350 hp) (261 kW) 48.5 mph (78.0 km/h)
- 6 axle (450 hp) (336 kW) 52.2 mph (84.0 km/h)
- 7 axle (400 hp) (298 kW) 43.9 mph (70.6 km/h)
- 7 axle (450 hp) (336 kW) 48.1 mph (77.4 km/h)

TABLE 5. Maximum and Recommended Starting Grades for Loaded Vehicle.

GEAR	STARTING GRADE (%)							
	5 AXLE NTC 350		6 AXLE KT 450		7 AXLE NTC 400		7 AXLE KT 450	
	Max	Rec	Max	Rec	Max	Rec	Max	Rec
1	19.2	11.2	25.3	17.3	11.9	3.9	14.5	6.5
2	12.5	4.5	18.4	10.4	9.0	1.0	11.0	3.0
3	9.0	1.0	16.6	8.6	8.1	0.1	9.9	1.9
4			12.0	4.0				
5			8.6	0.6				

MAXIMUM STARTING GRADE - maximum grade possible

RECOMMENDED STARTING GRADE - Consistent startability without excessive clutch wear or excessive transient drive-line loads

CLUTCH ENGAGEMENT TORQUE - NTC 350 - 625 foot-pounds
NTC 400 - 600 foot-pounds
KT 450 - 725 foot pounds

Table 6 summarizes the estimated instantaneous speeds of each loaded truck climbing uphill from the Fraser River as well as the time on grade and average speed on the grade.

The tri-axle with a KT 450 requires 20 minutes versus 22 to 24 for the others and attains an average speed of 32 mph versus 26 to 29 for the other vehicles.

The overall impact of this superior speed-gradeability is not large--Table 2 (Vehicle Trip Summary) indicates a loaded trip duration of 3.49 hours for the tri-axle compared to 3.56, 3.59 and 3.70 hours for the others.

Fuel Consumption and Utilization

Table 7 summarizes the fuel consumption and utilization estimates for each simulated configuration. Table 8 compares the changes in consumption and utilization to increases in GCW and payload between the various configurations.

Fuel consumption generally increases with increasing gross weight except for the tri-axle versus the 400 hp 'B' train. The small increase in weight and the reduced engine size and horsepower demand (205 vs. 194) maintains the same consumption.

The consumption of the 450 hp 'B' train is only 4% above the similar engined tri-axle. While the demand horsepower is up (210 vs. 205) the lower average engine rpm (1783 vs. 1888) allows the engine to operate at a lower Brake Specific Fuel Consumption (BSFC).

The consumption of the 450 hp 'B' train is also 4% above the 400 hp version, which is consistent with the improved highway performance.

The fuel utilization calculations do not coincide with the WHI (2) conclusions. The absolute values of 163 to 176 payload ton-miles per U.S. gallon are substantially greater than the 100 payload ton-miles per U.S. gallon reported by WHI for highway freight trucks. Section 2.2 indicated that a significant improvement in fuel utilization should result from the increase in GCW between the 5, 6 and 7 axle combinations. The simulation results indicate only modest increases at best. The highest utilization was estimated for the smallest vehicle.

TABLE 6. Comparison of Loaded Vehicle Speeds on Fraser River Grade.

Mileage	Grade	VEHICLE SPEED (MPH) 5 Axle NTC 350	6 Axle KT 450	7 Axle NTC 400	7 Axle NTC 450
end of bridge	- 1.2	44.1	44.1	44.2	44.1
0.2	5.2	30.5	31.0	29.2	30.5
0.7	1.9	29.7	34.6	28.8	32.1
1.4	3.1	25.1	30.2	22.3	27.2
1.9	4.0	21.6	27.6	19.4	26.2
2.6	4.1	23.8	26.7	20.8	24.2
2.7	0	30.0	32.3	26.9	29.3
3.0	-1.0	49.2	50.8	47.0	48.9
3.1	2.8	45.8	47.5	43.1	45.1
3.4	0	44.2	46.0	40.3	42.4
	GRADE BREAK				
6.3	0	44.2	44.2	44.1	44.2
6.7	2.9	37.7	39.2	36.1	38.8
7.0	4.9	27.7	33.3	26.4	30.8
8.0	6.0	15.5	18.9	16.0	17.9
8.2	6.0	18.5	21.4	17.1	19.2
8.4	6.1	17.3	20.4	16.4	18.1
9.0	5.0	19.9	22.6	18.1	20.6
9.5	6.0	18.2	18.9	16.1	17.9
9.7	2.0	26.8	27.5	24.0	26.6
10.1	1.0	38.7	41.1	37.2	38.9
10.5	1.1	38.1	41.3	36.0	37.2
Elapsed Time (min)		23	20	24	22
Average Speed (mph)		27	32	26	29

(-) indicates favourable grade.

TABLE 7. Fuel Consumption and Utilization.

FACTOR	5 AXLE NTC 350		6 AXLE KT 450		7 AXLE NTC 400		7 AXLE KT 450	
	Empty	Loaded	Empty	Loaded	Empty	Loaded	Empty	Loaded
Fuel Consumption (U.S. gal)	26.2	31.6	32.1	38.9	32.3	38.2	34.4	40.4
Fuel Economy (mi/U.S. gal)	6.20	5.13	5.06	4.18	5.03	4.25	4.74	4.02
Payload (lb)	-	68,590	-	78,800	-	82,640	-	82,640
Fuel Utilization (payload ton-mile) / U.S. gal	-	176	-	163	-	176	-	166

TABLE 8. Increase in Fuel Consumption and Fuel Utilization vs. Increase in Vehicle Gross Combination Weight.

Vehicle Comparison		% Increase in		% Increase in Fuel Consumption	% Increase in Fuel Utilization
From	To	G C W	Payload		
5 Axle (NTC 350)	6 Axle (KT 450)	18	15	23	-7
6 Axle (KT 450)	7 Axle (NTC 400)	12	5	0	8
6 Axle (KT 450)	7 Axle (KT 450)	12	5	4	2
5 Axle (NTC 350)	7 Axle (NTC 400)	32	20	21	0
5 Axle (NTC 350)	7 Axle (KT 450)	32	20	26	-6

Cummins' personnel have noted some possible reasons for these differences:

- the WHI study was based on full legal height volume van semi-trailers where the payload, as a percent of GCW, is probably smaller than for the logging pole trailer.

- the WHI data were based upon higher cruising speeds. The lower average speed for the logging trucks would reduce aerodynamic drag.

- compared to vehicles built in the late 1960's and early 1970's, the trucks simulated by VMS incorporate engines with 10% to 15% better fuel economy, radial tires which increase mileage 10% to 15% and temperature controlled fans which yield 3% to 5% better fuel economy.

Gear Shifts and Time on Brakes

Table 9 summarizes the number of gear shifts required and the time on brakes for each combination on the empty (E) and loaded (L) portions of the trip.

TABLE 9. Gear Shifts and Time on Brakes.[1]

Parameter	5 Axle NTC 350		6 Axle KT 450		7 Axle NTC 400		7 Axle KT 450	
	E	L	E	L	E	L	E	L
Gear Shifts	16	153	20	156	43	195	36	149
Time on Brakes (min)	2.9	38.6	3.6	38.4	5.4	39.1	4.7	38.6

[1]The truck performance simulations used in this study did not consider the effects of other road traffic or driver behavior on road sections that were rough or had reduced sight distance.

The demand on the brakes (time on brakes) is similar for all configurations. Thus the brakes for the higher GCW combinations appear to be adequate. For the case study vehicles, the brake wear rate (operating lifetime) should be similar throughout the weight range.

The tri-axle, with an extra 100 horsepower, requires approximately the same number of gear shifts as the 5 axle and should not increase driver effort.

The increased weight from 6 to 7 axle at the same power level (450 hp) does not increase the number of shifts required. This comparison is difficult because of the different transmissions involved. With the 12 speed on the 'B' train the driver would stay in each gear longer.

Reducing the power of the 'B' train (450 to 400 hp) significantly increases the number of gear shifts required (149 to 195). Thus the higher power combinations appear to require less driver effort.

3.4 Estimate of Vehicle Productivity, Fleet Size and Trucking Cost

An overall system cost analysis is required to make a final decision regarding the utility of the truck types. This must include the elements required to support the truck haul such as:

- landing size
- central processing yard location and construction
- bucking procedure
- sorting and loading
- road construction and maintenance

A complete analysis of this type would require data far beyond the scope of this project. To meet the more limited objective of evaluating the highway performance, productivity and costs of the various configurations, the components of this analysis are limited to:

- cycle time estimate
- payload analysis
- fleet requirements by vehicle type
- vehicle in-use cost (daily basis)
- vehicle travelling cost (hourly/trip basis)
- vehicle trip cost
- annual haul cost by vehicle type

Truck Cycle Time

The data to estimate the total cycle time is drawn from several sources. The travel times (empty and loaded) are from the VMS modelling; the loading and preparation times are from field observations for this particular study. The estimates for unloading and overall delay times are based on previous field observations. The total cycle time includes allowances for driver food and rest as well as service checks and fueling. The food and rest break is not considered paid time.

Table 10 summarizes the estimated cycle time for each configuration by component. The long working time allows only one trip per day. In this case, it is not possible to increase productivity by travel time reduction. However, the differences in cycle times do have an impact on trip cost. The driver wage per hour increases with hours worked, and the vehicle fuel and oil consumption increase with in-use hours due to engine idling as well as travelling.

Payload Load Factor Analysis

B.C. Forest Service weight scale data for an entire winter[1] haul season were analyzed to estimate the average payload of the case study vehicles. Table 11 summarizes the GCW and payload analysis.

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[1] Summer haul data were not available for this study; the truck productivity comparison is based on winter load weights.

TABLE 10. Estimated Cycle Time.[1]

Component	5 Axle NTC 350	6 Axle KT 450	7 Axle NTC 400	7 Axle KT 450
Travel time - empty (min)	179	179	184	181
Landing time - preparation (min)	15	15	15	15
- load (min)	15	25	40	40
Travel time - loaded (min)	215	209	222	214
Dump (min)	30	30	45	45
Estimated delay - 15% (min)	68	69	76	74
Driver food and rest (min)	90	90	90	90
Service/fueling allowance (min)	60	60	60	60
Estimated cycle time (min)	672	677	732	719
(hr)	11.2	11.3	12.2	12.0
Paid hours per day	9.7	9.8	10.7	10.5

[1]Estimate of cycle time for the 522 km round trip includes a flat 90 minutes for driver food and rest and 60 minutes allowance for service checks and fueling. The rest period is not paid time.

TABLE 11. Payload Load Factor Analysis.[1]

Factor	5 Axle NTC 350	6 Axle KT 450	7 Axle NTC 400 & KT 450
Representative legal maximum GCW (kg)	43 623	51 152	62 143
Average actual GCW (kg)	43 265	51 146	57 167
Average actual tare weight (kg)	12 146	15 415	19 671
Maximum permissible payload (kg)	31 477	35 737	42 472
Average actual payload (kg)	31 119	35 731	37 496
Difference (kg)	358	6	4 976
Payload load factor (%)	99	100	88

[1]B.C. Forest Service weight scale sheets (winter only) were the source of the data; hence they are reported in S.I. units.

The full legal payload capability of the 5 and 6 axle configurations was consistently utilized, even while loading in the woods landing. In contrast, the 88% utilization of the 'B' train even when loaded in a central processing yard seriously reduced its productivity (increased haul cost). To assess this effect, the haul cost of the 'B' train will be later estimated using 100% load factor also.

Fleet Requirements

In the Interior of British Columbia, 1800 hours is the average annual working time of a driver. This would correspond to 150 to 180 working days. The long distance hauling means only one trip per day is possible. It is assumed that the case study operation must move its entire volume of 75 000 m^3 in 180 haul days.

Table 12 summarizes the fleet required using each vehicle type.

Utilizing a fleet of tri-axle trailers would reduce the average number of trucks required, from 10.7 to 9.3 per day. The 'B' train with its lower utilization would only reduce this to 8.9 per day. For the entire haul season, the number of loads decreases from 1928 to 1682 (a reduction of 13%) using the tri-axle. With the 'B' train the total loads would drop to 1603 (a reduction of 17%).

TABLE 12. Fleet Requirements.

Parameter	5 Axle NTC 350	6 Axle KT 450	7 Axle NTC 400	7 Axle KT 450
Average payload (kg)	31 119	35 731	37 496	37 496
Average payload (m^3)	38.9	44.6	46.8	46.8
Trucks required per day	10.7	9.3	8.9	8.9
Annual truck trips	1 928	1 682	1 603	1 603

ASSUMPTIONS:

1. 180 haul days per year
2. Annual volume is 75 000 m^3
3. Conversion factor: ft^3/lb = .02 (averaged company data)
   m^3/kg = .0012485 (converted)

Truck Cost Estimate

The estimate of trucking costs is based on the technique proposed by McNally(8). The procedure recognizes that some costs build up whether the unit is standing or travelling (such as capital depreciation and driver wages) while other costs build up only when the vehicle is moving (fuel, tires).

For the cost estimate, the truck is considered in-use for the entire day. However, as noted earlier, the driver food and rest periods are not scheduled and are not paid. The scheduled in-use time is subdivided into travelling hours and standing hours.

The in-use costs[1], accruing for the entire scheduled operating time (haul day), include:

- capital depreciation (loss in resale value)
- finance charges or interest on average annual investment
- insurance
- annual registration
- driver direct wages
- driver fringe benefits

The travelling costs which build up only as the vehicle is moved (trip or travel hour) include:

- fuel
- oil and lubricants
- tires
- vehicle repair and maintenance

Tables 13 and 14 summarize the generalized in-use and travelling cost parameters and estimates. While these are based upon the best available information at the time of the analysis, they will vary with time and location. Each factor is identified separately so that the cost estimate can easily be revised as the base costs change or be applied to a specific operation.

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[1]Profit was not included in the cost estimate--it can be added separately for an owner-operator vehicle.

TABLE 13. Estimate of Truck In-Use Cost Per Haul Day.

Parameter	5 Axle NTC 350		6 Axle KT 450		7 Axle NTC 400			7 Axle KT 450		
	Tractor	Trailer	Tractor	Trailer	Tractor	Trailer	Trailer	Tractor	Trailer	Trailer
Initial cost ($ x 1,000)	75	17	85	28	80	21	21	85	21	21
Residual value ($ x 1,000)	7.5	1.7	8.5	2.8	8.0	2.1	2.1	8.5	2.1	2.1
Operating life (years)	5	7.5	5	7.5	5	7.5	7.5	5	7.5	7.5
Annual depreciation ($ x 1,000)	13.5	2.0	15.3	3.4	14.4	2.5	2.5	15.3	2.5	2.5
Average annual investment ($)	48,000	10,370	54,400	17,080	51,200	12,810	12,810	54,400	12,810	12,810
Haul days/year	180	180	180	180	180	180	180	180	180	180
Depreciation/haul day ($)	75	11	85	19	80	14	14	85	14	14
Annual interest (18% AAI)	8,640	1,867	9,792	3,074	9,216	2,306	2,306	9,792	2,306	2,306
Interest/haul day ($)	48	10	54	17	51	13	13	54	13	13
Annual insurance cost ($)	5,000	incl.	5,000	incl.	5,000	incl.	incl.	5,000	incl.	incl.
Insurance cost/haul day ($)	28	incl.	28	incl.	28	incl.	incl.	28	incl.	incl.
Annual registration cost ($)	1,250	incl.	1,250	incl.	1,250	incl.	incl.	1,250	incl.	incl.
Registration cost/haul day ($)	7	incl.	7	incl.	7	incl.	incl.	7	incl.	incl.
Driver wage[1]/haul day ($)	145	incl.	147	incl.	165	incl.	incl.	161	incl.	incl.
In-use cost/haul day ($)	303	21	321	36	331	27	27	335	27	27

[1]Driver wage is based on $11.42 per hour for the first 8 hours, time and a half for the next 4 hours and double time for any time beyond 12 hours per day, plus 20% fringe benefit.

TABLE 14. Estimate of Truck Operating Cost Per Trip.

Cost Parameter	5 Axle NTC 350		6 Axle KT 450		7 Axle NTC 400			7 Axle NTC 450		
	Tractor	Trailer	Tractor	Trailer	Tractor	Trailer	Trailer	Tractor	Trailer	Trailer
Travelling hours/trip	6.6	3.6	6.5	3.5	6.8	6.8	3.7	6.6	6.6	3.6
Travelling hours/year	985	537.5	970	522.5	1,015	1,015	555	987.5	987.5	535
Fuel consumption/trip (ℓ)	218.9	-	268.5	-	266.6	-	-	283.0	-	-
Fuel cost[1]/trip ($)	70	-	86	-	85	-	-	90	-	-
Oil cost/travel hour ($)	0.50	-	0.50	-	0.50	-	-	0.50	-	-
Oil cost/trip ($)	3	-	3	-	3	-	-	3	-	-
R & M cost[2]/trip ($)	58	6	69	7	83	8	8	87	8	8
Tire cost[3]/trip ($)	45	incl.	55	incl.	66	incl.	incl.	66	incl.	incl.
Total travel cost/trip ($)	176	6	213	7	237	8	8	240	8	8

[1]Fuel cost = $0.319/litre.

[2]Lifetime R & M for 5 axle combination estimated at $5.14 (plus 10% per trailer) per in-use hour, based upon data from eastern Vancouver Island on/off highway operation. Estimates for 6 and 7 axle combinations increased in ratio of GCW.

[3]Tire cost based on 145 000 km operating life from combination of new ($450) and recapped ($250) tire.

Table 15 summarizes the estimated haul costs for the four case study configurations. The conventional 5 axle pole trailer and tri-axle trailer appear to be the least cost alternatives. The 'B' train with a typical load increased the cost by 6%.

TABLE 15. Estimated Case Study Haul Cost.

	5 Axle NTC 350	6 Axle KT 450	7 Axle NTC 400	7 Axle KT 450
In-use cost/haul day ($)	324	357	385	389
Travel cost/trip ($)	182	220	253	256
Total cost/trip ($)	506	577	638	645
Haul cost/m^3 ($)	13.01	12.94	13.63	13.78
Annual haul cost ($ x 1,000)	976	971	1,023	1,034

'B' Train at Maximum Capacity

The case study 'B' train only operated at 88% payload factor. This would adversely affect the estimated haul cost of this vehicle. For comparison purposes the fleet size and haul cost was also calculated at 100% payload factor.

Actual payload : 37 496 kg = 46.8 m^3

Maximum payload: 42 472 kg = 53.0 m^3

Therefore, the fleet required for the case study would be 7.9 instead of 8.9 trucks per day. This reduces the annual number of loads from 1,603 to 1,415 (a reduction of 27% over the standard pole trailer).

The in-use cost per haul day was considered to be the same as Table 13 while the travelling cost estimate was increased in the same proportion as the increase in GCW. This would mean an increase of 9% from 57 167 kg to 62 143 kg.

At an estimated trip cost of $668, the haul cost is $12.60 per m^3. Thus a fully utilized 'B' train could reduce the haul cost by 3% compared to the conventional 5 axle pole trailer.

Summary of Fleet Size and Haul Cost

Table 16 compares the fleet size and haul cost for the four case study combinations plus a fully loaded 'B' train. The table uses the conventional pole trailer (5 axle) as a base of 100. The other configurations are expressed relative to this.

TABLE 16. Summary of Annual Trips, Fleet Size and Haul Cost.

Configuration	Annual Trips & Fleet Size	Trucking Cost
Pole Trailer - 5 axle - NTC 350	100	100
Tri-Axle - 6 axle - KT 450	87	100
'B' Train - 7 axle - NTC 400	83	105
'B' Train - 7 axle - KT 450	83	106
'B' Train - 7 axle - KT 450 (100% payload)	73	97

In this case study the use of higher GCW vehicles than the standard 5 axle pole trailer reduces the number of trucks required at the loading site per day significantly. Depending upon circumstances, this could have real benefit by:

- reducing road traffic and delays
- reducing truck queueing
- increasing time for loader to sort and deck logs
- allowing skidders time to bring in full truck load--eliminating hot loading

However, these larger vehicles do not appear to have any significant potential to reduce the direct haul cost below that of the conventional 5 axle pole trailer.

4. CONCLUSIONS

The purposes of this study have been to demonstrate the use of road digitization and truck performance simulation as practical techniques for analyzing existing and planning future log hauls; and to compare the highway performance of three different truck configurations over a case study haul route.

The case study provided the opportunity to digitize an actual haul route and use it as an input to Cummins' Vehicle Mission Simulation. The model was used to evaluate the over-the-road performance of a 5 axle pole trailer, 6 axle tri-axle trailer and a 7 axle 'B' train, three configurations representative of the range of highway logging trucks in use in the Central Interior of British Columbia.

Road Recorder--B.C. Forest Service

Overall, the B.C. Forest Service road recorder is a convenient and efficient method for digitizing an entire haul road system. This contemporary road surveying system is the basis for:

- producing accurate plan and profile maps of existing haul routes
- evaluating vehicle operation
- predicting the impact of road modifications on the truck fleet
- planning future roads

Vehicle Mission Simulation--Cummins Engine Company

Truck performance simulation has been shown to be a powerful technique for evaluating existing and planning future haul systems. However, a useful simulation is both time consuming and expensive to make, maintain and operate. The Cummins Engine Company's Vehicle Mission Simulation is in daily use predicting the over-the-road performance of highway freight trucks. Preliminary work with VMS highlighted its recognized limitations for logging use, because it cannot handle the very steep grades and soft surfaces of the extraction road system. The very heavy slower-moving coastal off-highway logging trucks, while not part of this project, likely could not be simulated with VMS. However, the simulation is suitable for the highway legal log trucks and higher standard main haul roads of the Interior of British Columbia.

Cummins wrote an interface program to allow the output of the road recorder to be used directly in the VMS system. This permits, for the first time, the simulation of specified vehicles on a detailed representation of the actual haul road. These results could then be compared to measured truck performance data.

Evaluation of the Case Study Vehicles

The results of the road performance, vehicle productivity and haul cost analysis indicate that even with considerable information available, the choice of highway log haul vehicle is not a straightforward decision.

The over-the-road performance capability of the case study vehicles with different GCW ratings (43 623, 51 152 and 62 143 kg) and mechanical specifications (261, 298 and 336 kW) was quite similar. While the high installed power makes the vehicle easier to drive (less shifting required) it is largely unused (relatively low load factor). The lower powered vehicles required only a few percent greater travel time in the total haul which included significant stretches of adverse.

The payload capability varied from 39 m^3 to 53 m^3; thus the fleet size and the annual number of loads by each vehicle type varied considerably. The tri-axle and a 'B' train with an average load and with a full load could reduce truck fleet requirements by 13%, 17% and 27% respectively.

The reduction in fleet size and trips can have significant secondary savings such as reducing truck delays at the landing and traffic on the road. However, these savings can be offset by increased landing and road construction standards or the potential need for a central reload yard when using larger vehicles. The estimation of the overall cost impact of these consequences is beyond the scope of this study.

While the productivity of the case study vehicles is significantly different, the haul cost per m^3 is not. The calculated variation of up to 6% for the higher GCW configurations is within the limits of accuracy of the estimates, therefore they do not necessarily represent real cost differences. The similarity of road performance and haul cost per unit volume must mean that other factors play a significant role in vehicle selection.

The 5 axle standard pole trailer has the smallest payload but the greatest operational flexibility. This employs the greatest number of trucks and drivers and gives them the freedom to haul for the largest number of companies.

The 'B' train with its large payload has the least flexibility in use. Efficient loading can best be accomplished in a reload yard. Any potential saving in direct trucking cost may be lost due to reduced payload utilization.

The tri-axle trailer appears to offer the best trade-off between payload size and haul cost. It can be loaded in a typical woods landing, handle rough extraction roads and still carry an average payload approaching that of the 'B' train.

The estimated costs used in this study indicate little potential for the user to reduce the costs associated with any vehicle. The greatest opportunity appears to lie in extending the operating life of the truck as much as possible to reduce capital depreciation and finance charges. Repair and maintenance is a significant item. Careful regular service could keep this factor to a minimum.

This study illustrated a technique for choosing a tractor and trailer for use on an existing haul route. The road recorder and truck simulation could also be used to determine the benefit of improvements to road location, grades, curves and surface. It would then be possible to study a haul route and to recommend the best road standard and vehicle type.

REFERENCES

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APPENDIX I

ROAD RECORDER--B.C. FOREST SERVICE

The B.C. Forest Service road recorder is an instrumented van outfitted with a front wheel odometer, gyro compass, gyro inclinometer and data recorder.

These instruments detect and record the slope and bearing of the road automatically at a preset (and adjustable) intervals. Notes can be made manually on the tape by pushing the proper button to record the location of specific features, such as road turnoff, culvert or bridge. In this manner the entire haul route can be digitized in one pass.

An interpretive computer program accumulates the sample point data into segments of uniform grade. The plan and profile maps can be made on a plotter from this information. A card deck and listing are also made of the segments noting the segment length, grade and degree of curve as input to truck simulation programs.

APPENDIX II

Sample VMS Output--Tri-Axle Trailer

VEHICLE MISSION SIMULATION

VEHICLE PERFORMANCE REPORT FOR LOG TRUCK PROJECT   PAGE NO -- 1
DATE - APR 02,'81
VMS USER - FERIC   SIMULATION NO - 002   SERIAL NO --23488

****

VEHICLE DESCRIPTION

MANUFACTURER ------- W.WESTRNSTAR   VEHICLE HEIGHT (FT)- 10.5
MODEL --------------- 4900-SERIES   VEHICLE WIDTH (FT)- 8.5
CAB TYPE ----------- CONVENTIONAL
BODY/TRAILER TYPE - POLE TRAILER
CONFIGURATION ------ 6X4-3S   3 AXLE TRACTOR(6X4),3 AXLE SEMITRLR
TIRES --------------11.00R24.5-STD TREAD,RADIAL,TUBELESS

****

ENGINE DESCRIPTION

ENGINE MODEL - CUMMINS   ENGINE POWER -- 450 AT 2100 RPM
KT-450   ENGINE DATA SOURCE - C-3562-B
** SAE STANDARD **   ******* STEADY STATE *******
*** CONDITIONS ***   ******* CONDITIONS *******

ENGINE SPEED (RPM)	STANDARD TORQUE (LB-FT)	ENGINE POWER (HP)	ACCESSORY POWER (HP)	INSTALLED POWER (HP)	INSTALLED SPECIFIC FUEL CONSUMPTION (PCT)
800	725	110.4	1.53	108.9	102
1200	1208	276.0	2.11	273.9	97
1300	1303	322.5	2.26	320.3	96
1400	1340	357.2	2.41	354.8	95
1500	1350	385.6	2.56	383.0	94
1600	1335	406.7	2.71	404.0	95
1700	1300	420.8	2.86	417.9	95
1800	1260	431.8	3.01	428.8	96
1900	1218	440.6	3.17	437.5	97
2000	1173	446.7	3.32	443.4	98
2100	1125	449.8	3.48	446.3	100
2247	743	317.7	3.71	314.0	110

ACCESSORIES ----------	COOLING FAN	POWER STEERING	AIR COND	ENGINE P-T-O	TRANS P-T-O
POWER(HP) AT 2100. RPM	.1	3.0	.0	.0	.0

ALTERNATOR/GENERATOR - 10 AMPS AT 14 VOLTS

****

THIS SIMULATION USES THE STANDARD DRIVER.

S1.3

****

VEHICLE MISSION SIMULATION

VEHICLE PERFORMANCE REPORT FOR LOG TRUCK PROJECT | PAGE NO -- 2 | DATE - APR 02,'81

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DRIVETRAIN DESCRIPTION

MAIN TRANSMISSION - - - - FULLER RTO-12513
AUXILIARY TRANSMISSION -- TWO SPEED AXLE, 36 PCT SPLIT
DRIVE AXLE - - - - - - - - EATON DT400-P
AXLE RATIO - - - - - - - - 5.370

STEADY STATE SUMMARY

*************************** CONDITIONS ****************************

- VEHICLE WEIGHT - 112800 LB GVW/GCW
- ROAD SURFACE - SMOOTH MACADAM, ROUGH CONCRETE OR ASPHALT
- ALTITUDE - 6850 FT ABOVE SEA LEVEL
- AMBIENT TEMP - 60 DEGREES F
- WIND SPEED - 0 MPH
- WIND DIRECTION - 0 DEG (ASSUMES VEHICLE DIRECTION IS NORTH.)

GEAR NO.	GEAR DESC	TRANS GEAR RATIO	OVERALL GEAR RATIO	STARTING GRADE (PCT) MAX	STARTING GRADE (PCT) RECOMD	AT 1500 RPM VEH SPEED (MPH)	AT 1500 RPM MAX GRADE (PCT)	AT 2100 RPM VEH SPEED (MPH)	AT 2100 RPM MAX GRADE (PCT)
1	LL	17.04	91.49	25.3	17.3	2.1	64.7	2.9	50.2
2	L	12.50	67.12	18.4	10.4	2.8	44.4	3.9	35.5
3	1L	11.38	61.12	16.6	8.6	3.1	38.7	4.3	31.1
4	1	8.35	44.84	12.0	4.0	4.2	27.9	5.9	22.7
5	2	6.12	32.86	8.6	.6	5.8	19.9	8.1	16.2
6	3	4.56	24.49			7.7	14.5	10.8	11.8
7	4	3.38	18.15			10.4	10.5	14.6	8.5
8	5	2.47	13.26			14.3	7.6	20.0	6.1
9	50	2.14	11.49			16.5	6.4	23.0	5.1
10	6	1.81	9.72			19.5	5.4	27.2	4.2
11	60	1.57	8.43			22.4	4.4	31.4	3.4
12	7	1.35	7.25			26.1	3.7	36.5	2.8
13	70	1.17	6.28			30.1	3.0	42.1	2.2
14	8	1.00	5.37			35.2	2.5	49.3	1.7
15	80	.87	4.67			40.5	2.0	56.7	1.2

MAXIMUM LEVEL ROAD SPEED IS 61.2 MPH AT 2268 RPM IN GEAR 15.

ROUTE DESCRIPTION

****** NAME ******	WIND SPEED (MPH)	WIND DIR (DEG)	TEMP (DEG)	CRUS SPD (MPH)	GCW/GVW (LBS)
WILLIAMS LAKE,BC-TATLAYOKO LAKE,BC (HWY20)	0	0	60	55	34000
TATLAYOKO LAKE,BC-WILLIAMS LAKE,BC (HWY20)	0	0	60	55	112800

VEHICLE MISSION SIMULATION

VEHICLE PERFORMANCE REPORT FOR LOG TRUCK PROJECT   PAGE NO -- 3
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SIMULATED VEHICLE LOG

DIST (MI)	TIME (H-M)	VEH SPEED (MPH)	DESIRED SPEED (MPH)	ENGINE SPEED (RPM)	GEAR NO	GRADE (PCT)	FUEL CONSPT (GAL)	COMMENTS,LANDMARK
*******	*****	*****	*******	******	****	*****	******	******************
.0	0- 0	.1	64.6	800.	7	999.0	.00	WILLIAMS LAKE
5.0	0- 6	48.3	65.0	1790.	15	7.1	1.12	5 MILES
10.1	0-12	61.9	65.0	2295.	15	-5.0	2.69	10 MILES
15.0	0-17	54.4	65.0	2018.	15	1.8	3.19	15 MILES
20.1	0-23	41.8	65.0	1782.	14	6.0	4.07	20 MILES
25.0	0-29	54.9	65.0	2036.	15	2.0	6.17	25 MILES
30.1	0-35	54.2	65.0	2010.	15	-2.0	7.06	30 MILES
35.1	0-40	54.5	65.0	2018.	15	.9	8.00	35 MILES
40.1	0-46	55.7	65.0	2063.	15	.0	9.23	40 MILES
45.0	0-51	55.3	65.0	2051.	15	-1.0	10.32	45 MILES
50.2	0-57	55.8	65.0	2069.	15	-1.0	11.28	50 MILES
55.0	1- 2	54.1	65.0	2007.	15	-1.0	11.79	55 MILES
60.1	1- 7	54.3	65.0	2014.	15	5.1	12.33	60 MILES
65.0	1-13	54.1	65.0	2005.	15	1.9	13.19	65 MILES
70.0	1-18	55.8	65.0	2066.	15	.0	14.37	70 MILES
75.0	1-23	54.9	65.0	2036.	15	.0	15.44	75 MILES
80.1	1-29	55.8	65.0	2069.	15	.9	16.34	80 MILES
85.0	1-34	54.6	65.0	2023.	15	4.7	17.40	85 MILES
90.0	1-40	54.8	65.0	2032.	15	.0	18.41	90 MILES
95.0	1-45	54.3	65.0	2014.	15	1.0	19.44	95 MILES
100.2	1-51	54.4	65.0	2016.	15	1.0	20.50	100 MILES
105.1	1-56	55.8	65.0	2067.	15	-1.2	21.49	105 MILES
110.0	2- 2	54.9	65.0	2034.	15	.6	22.43	110 MILES
115.1	2- 7	55.7	65.0	2066.	15	.0	23.41	115 MILES
120.0	2-13	55.5	65.0	2058.	15	.0	24.77	120 MILES
125.3	2-18	55.4	65.0	2055.	15	-1.0	25.59	125 MILES
130.1	2-24	55.7	65.0	2065.	15	-1.0	26.29	130 MILES
135.0	2-29	54.2	65.0	2007.	15	.8	27.28	135 MILES
140.0	2-34	50.3	65.0	1866.	15	6.1	28.16	140 MILES
145.0	2-40	55.1	65.0	2043.	15	-1.2	29.42	145 MILES
150.0	2-45	55.2	65.0	2048.	15	.0	30.13	150 MILES
155.0	2-51	55.9	65.0	2073.	15	-3.1	30.83	155 MILES
160.0	2-56	58.6	65.0	2173.	15	-4.9	31.62	160 MILES
162.3	2-59	53.6	65.0	1986.	15	9.5	32.07	TATLAYOKO LAKE
END OF ROUTE 1 - WILLIAMS LAKE,BC-TATLAYOKO LAKE,BC (HWY20)								
162.3	2-59	54.1	53.5	2006.	15	999.0	32.08	TATLAYOKO LAKE
162.8	2-59	44.6	65.0	1653.	15	-3.2	32.08	BEGIN GRADE
162.8	2-59	44.4	65.0	1645.	15	.0	32.08	
162.9	2-59	44.4	65.0	1645.	15	1.5	32.09	
162.9	2-59	43.5	65.0	1612.	15	3.9	32.10	
162.9	2-59	42.6	65.0	1579.	15	5.8	32.10	
162.9	2-59	43.6	65.0	1616.	15	.8	32.13	
163.0	2-59	42.7	65.0	1581.	15	6.3	32.13	

VEHICLE MISSION SIMULATION

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SIMULATION SUMMARY

ROUTE 1 - WILLIAMS LAKE,BC-TATLAYOKO LAKE,BC (HWY20)
ROUTE 2 - TATLAYOKO LAKE,BC-WILLIAMS LAKE,BC (HWY20)

	ROUTE ONE	ROUTE TWO	TOTAL ROUTE
GCW OR GVW (LBS)	34000.	112800.	
CRUISE SPEED (MPH)	55	55	
WIND SPEED (MPH)	0	0	
WIND DIRECTION (DEG)	0	0	
TEMPERATURE (DEG F)	60	60	

****

	ROUTE ONE	ROUTE TWO	TOTAL ROUTE
DISTANCE (MILES)	162.3	162.3	324.7
DRIVING TIME(HRS)	2.98	3.49	6.46
IDLE TIME(MIN-SEC)	0- 0	0- 0	0- 0
AVERAGE SPEED(MPH)	54.6	46.5	50.2
FUEL USED (GAL)	32.1	38.9	70.9
FUEL MILEAGE(MPG)	5.06	4.18	4.58
TIME AT FULL THROTTLE(PCT)	9.6	39.5	25.7
AVG ENGINE SPEED (REVS/MILE)	2229	2436	2333
ENG LOAD FACTOR(PCT)	45	46	46
TOTAL GEAR SHIFTS	20	156	176
TIME ON BRAKES(MIN)	3.6	38.4	42.0

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ENGINE STATISTICS

********************* ENGINE LOAD DISTRIBUTION *********************

TORQUE RANGES (LB-FT)	ENGINE SPEED (RPM) UNDER 1100	1100 TO 1300	1300 TO 1500	1500 TO 1700	1700 TO 1900	1900 TO 2100	OVER 2100	TOTAL
	DRIVING TIME (PCT)							
	.0	.0	.0	.0	.0	.0	.0	.0
-400.								
	.0	.0	.0	9.6	.6	11.1	6.3	27.6
0.								
	.0	.0	.1	.8	.5	5.7	.1	7.1
150.								
	.0	.0	.0	.1	.0	7.5	.0	7.6
300.								
	.0	.0	.0	.1	.0	4.6	.0	4.8
375.								
	.0	.0	.0	.1	.0	4.3	.0	4.4
450.								
	.0	.0	.0	.1	.0	5.2	.0	5.3
525.								
	.0	.0	.0	.0	.0	5.1	.0	5.2
600.								
	.0	.0	.0	.0	.0	2.7	.0	2.7
675.								
	.0	.0	.0	.0	.0	2.6	.0	2.6
750.								
	.0	.0	.0	.0	.0	1.9	.0	1.9
825.								
	.0	.0	.0	.0	.0	1.9	.0	2.0
900.								
	.0	.0	.0	.1	.0	1.2	.0	1.3
975.								
	.0	.0	.0	.0	.0	1.5	.0	1.5
1050.								
	.0	.0	.0	.0	.0	.9	.5	1.4
1125.								
	.0	.0	.0	.0	.0	8.0	.0	8.0
1200.								
	.0	.0	.0	.0	5.5	1.8	.0	7.3
1275.								
	.0	.0	.6	6.3	2.7	.0	.0	9.5
1350.								
TOTAL	.0	.0	.7	17.3	9.3	65.9	7.0	

VEHICLE MISSION SIMULATION

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****

ENGINE STATISTICS

****

LOAD CYCLE DURATION			*	VEHICLE SPEED STATISTICS		*	THROTTLE DISTRIBUTION	
PCT FULL LOAD	AVG (M-S)	MAX (M-S)	*	RANGE (MPH)	TIME (PCT)	*	PCT FULL THROTTLE	TIME (PCT)
90 -100	0-12	3-22	*	0 - 5	.0	*	90 -100	27.6
80 - 90	0- 6	4- 0	*	5 - 10	.0	*	80 - 90	2.8
70 - 80	0- 2	0-25	*	10 - 15	.8	*	70 - 80	4.0
60 - 70	0- 2	1- 9	*	15 - 20	2.5	*	60 - 70	5.7
50 - 60	0- 2	0-58	*	20 - 25	1.7	*	50 - 60	9.9
40 - 50	0- 3	1-28	*	25 - 30	1.5	*	40 - 50	7.9
30 - 40	0- 2	0-59	*	30 - 35	2.4	*	30 - 40	8.1
20 - 30	0- 2	1-10	*	35 - 40	2.4	*	20 - 30	5.4
10 - 20	0- 2	0-37	*	40 - 45	9.2	*	10 - 20	4.1
0 - 10	0-17	7- 9	*	45 - 50	9.9	*	0 - 10	13.7
			*	50 - 55	33.5	*		
			*	55 - 60	33.6	*		
			*	60 - 65	2.7	*		

VEHICLE MISSION SIMULATION

VEHICLE PERFORMANCE REPORT FOR LOG TRUCK PROJECT PAGE NO -- 17
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****

TRANSMISSION STATISTICS

GEAR	NO. START	UP SHIFTS	DOWN SHIFTS	TIME IN GEAR (PCT) RT 1	RT 2	RT 3	RT 4	RT 5	TOTAL
1			0	.0	.0				.0
2		0	0	.0	.0				.0
3		0	0	.0	.0				.0
4		0	0	.0	.0				.0
5		0	0	.0	.0				.0
6		0	0	.0	.0				.0
7	1	0	1	.1	1.3				.7
8		7	5	.0	2.0				1.1
9		7	3	.0	5.0				2.7
10		7	6	.0	.7				.4
11		8	8	.0	1.3				.7
12		9	10	.0	3.7				2.0
13		10	20	.8	4.3				2.7
14		20	27	.9	4.5				2.9
15		28		98.1	77.2				86.8

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VMS USER - FERIC

SIMULATION NO - 002

****

VEHICLE ACCELERATION

VEHICLE SPEED (MPH)	LEVEL ROAD ELAPSED TIME (MIN-SEC)	LEVEL ROAD DISTANCE TRAVELED (MILES)	ONE PERCENT ELAPSED TIME (MIN-SEC)	ONE PERCENT DISTANCE TRAVELED (MILES)	TWO PERCENT ELAPSED TIME (MIN-SEC)	TWO PERCENT DISTANCE TRAVELED (MILES)
20	0-17	.052	0-23	.072	0-23	.069
25	0-26	.104	0-31	.124	0-37	.152
30	0-33	.164	0-41	.204	0-52	.273
35	0-42	.248	0-55	.325	1-16	.489
40	0-54	.365	1-13	.514	2- 4	1.000
45	1- 7	.522	1-37	.805		
50	1-22	.729	2-12	1.279		
55	1-38	.972	3- 7	2.091		
60	1-60	1.314				

VEHICLE SPEED (MPH)	THREE PERCENT ELAPSED TIME (MIN-SEC)	THREE PERCENT DISTANCE TRAVELED (MILES)	FIVE PERCENT ELAPSED TIME (MIN-SEC)	FIVE PERCENT DISTANCE TRAVELED (MILES)	SEVEN PERCENT ELAPSED TIME (MIN-SEC)	SEVEN PERCENT DISTANCE TRAVELED (MILES)
20	0-27	.081	0-42	.141		
25	0-46	.202				
30	1-18	.451				

THE TIME TO ACCELERATE FROM 30 TO 50 MPH ON LEVEL ROAD IS
49 SECONDS.
THE DISTANCE REQUIRED IS 2984 FEET.

GRADE	QUARTER MILE ELAPSED TIME (MIN-SEC)	QUARTER MILE VEHICLE SPEED (MPH)	HALF MILE ELAPSED TIME (MIN-SEC)	HALF MILE VEHICLE SPEED (MPH)	MILE ELAPSED TIME (MIN-SEC)	MILE VEHICLE SPEED (MPH)
LEVEL	0-43	35.1	1- 5	44.2	1-40	55.5
1	0-47	31.3	1-11	39.6	1-52	47.9
2	0-50	29.0	1-17	35.2	2- 4	40.0
3	0-53	26.9	1-24	30.7	2-20	33.3
5	1- 1	21.1	1-41	23.0	3- 2	22.7
7	1-17	16.3	2-10	17.2	3-54	17.2

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POWER REQUIRED AT REAR WHEELS (HP)

VEHICLE SPEED MPH	LEVEL ROAD	0.5 PCT	1.0 PCT	2.0 PCT	3.0 PCT	5.0 PCT	7.0 PCT	10.0 PCT
5	8.1	15.6	23.2	38.2	53.2	83.2	113.1	157.8
10	17.2	32.3	47.3	77.4	107.4	167.4	227.3	316.5
15	27.5	50.1	72.7	117.8	162.8	252.9	342.6	476.5
20	39.3	69.4	99.5	159.6	219.7	339.7	459.4	637.9
25	52.7	90.3	127.9	203.1	278.2	428.2	577.8	801.0
30	68.0	113.1	158.3	248.5	338.6	518.7	698.2	965.9
35	85.4	138.1	190.7	296.0	401.1	611.2	820.6	1133.0
40	105.2	165.4	225.5	345.8	466.0	706.0	945.4	1302.4
45	127.5	195.2	262.9	398.2	533.4	803.5	1072.7	1474.4
50	152.6	227.8	303.0	453.4	603.6	903.7	1202.9	1649.2
55	180.8	263.5	346.2	511.6	676.9	1006.9	1336.0	1827.0
60	212.2	302.4	392.6	573.1	753.4	1113.4	1472.4	2008.0
65	247.0	344.8	442.5	638.0	833.3	1223.4	1612.3	2192.5

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PERFORMANCE IN GEAR 1,TRANSMISSION GEAR RATIO = 17.04
OVERALL GEAR RATIO = 91.49

VEHICLE SPEED (MPH)	ENGINE SPEED (RPM)	DRV TRN EFF (PCT)	POWER AVAIL AT WHEELS (HP)	GRADE-ABILITY (PCT)
1.7	1200	89.0	243.8	55.48
1.8	1300	89.1	285.3	61.58
1.9	1400	89.1	316.0	64.07
2.1	1500	89.0	341.0	64.73
2.2	1600	89.0	359.5	63.65
2.3	1700	88.9	371.5	61.22
2.5	1800	88.8	380.8	58.55
2.6	1900	88.7	388.0	55.84
2.8	2000	88.6	392.7	53.04
2.9	2100	88.4	394.7	50.15

PERFORMANCE IN GEAR 2,TRANSMISSION GEAR RATIO = 12.50
OVERALL GEAR RATIO = 67.12

VEHICLE SPEED (MPH)	ENGINE SPEED (RPM)	DRV TRN EFF (PCT)	POWER AVAIL AT WHEELS (HP)	GRADE-ABILITY (PCT)
2.3	1200	90.9	248.9	38.84
2.4	1300	90.9	291.3	42.53
2.6	1400	90.9	322.6	44.00
2.8	1500	90.9	348.2	44.38
3.0	1600	90.8	367.0	43.75
3.2	1700	90.8	379.3	42.32
3.4	1800	90.7	388.8	40.72
3.6	1900	90.6	396.2	39.06
3.8	2000	90.4	401.0	37.31
3.9	2100	90.3	403.0	35.49

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PERFORMANCE IN GEAR 15,TRANSMISSION GEAR RATIO = .87
OVERALL GEAR RATIO = 4.67

VEHICLE SPEED (MPH)	ENGINE SPEED (RPM)	DRV TRN EFF (PCT)	POWER AVAIL AT WHEELS (HP)	GRADE-ABILITY (PCT)
32.4	1200	89.8	246.1	1.75
35.1	1300	90.1	288.6	1.92
37.8	1400	90.2	319.9	1.97
40.5	1500	90.1	345.2	1.96
43.2	1600	90.0	363.7	1.88
45.9	1700	89.9	375.6	1.77
48.6	1800	89.7	384.5	1.64
51.3	1900	89.4	391.2	1.50
54.0	2000	89.2	395.3	1.36
56.7	2100	88.9	396.6	1.21

APPENDIX III

Conversion Factors

mile (mi)	x 1.6093 =	kilometre (km)
U.S. gallon	x 0.8327 =	Imperial gallon
Imperial gallon	x 4.5461 =	litre (ℓ)
miles per hour (mph)	x 1.6093 =	kilometre per hour (km/h)
pound (lb)	x 0.4536 =	kilogram (kg)
horsepower (hp)	x 0.7457 =	kilowatt (kW)
cunit	x 2.8327 =	cubic metre (m^3)