A PRODUCTION AND COST ANALYSIS OF LOG TRANSPORTATION BY FLATBED TRUCKS IN THE CENTRAL JUNGLE REGION OF PERU

by

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ABSTRACT

This thesis reports a study of the productivity and cost of hauling logs by flatbed trucks, observed during 1985 at Belho Horizonte S.C.R. Ltd. sawmill, in Pichanaki, Peru. This operation typifies many similar hauling operations in the Peruvian tropical mountain forests.

In order to investigate means of improving productivity and decreasing hauling costs in the hauling operations of the Forest companies in the Central Jungle Region of Peru, the productivity and cost trade-offs of truck hauling by diesel-powered trucks and gasoline-powered trucks was evaluated. Furthermore, the overall hauling system was also examined to identify the main factors that govern productivity and costs of the flatbed trucks.

The truck activities during the entire hauling cycle were recorded using Servis Recorders. The haul distance, the number of logs and the volume hauled per trip were also recorded on a survey form. Complementary information regarding truck cost parameters was also obtained.

The results show that there is no significant difference in performance between gasoline-powered trucks and diesel-powered trucks when they are compared for the following operating variables: velocity empty, velocity loaded, delay, loading and unloading time. Significantly greater payloads per trip have been found for diesel-powered trucks.

Very low productivity and very expensive hauling costs have been found for both types of truck as a result of low truck speed caused by the poor conditions of the forest roads, low productivity of the manual loading method, and excessive delay time per trip. Substantial productivity increases and haul cost reductions can be obtained by upgrading the forest roads, mechanizing the loading operation, reducing the delay time, and loading the vehicles to their capacity every trip.

Under the existing operating conditions, hauling logs with used (17-18 yr-old) gasoline-powered trucks was more cost efficient for the most frequent one-way haul distance (30-50 km) in the Central Jungle Region of Peru.

The information provided in this study can be applied for planning purposes and to examine the feasibility of using trucks of greater payload capacity, and new loading and unloading equipment. In addition, the actual configuration of the forest roads can be compared to the requirements of future trucking equipment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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INTRODUCTION

Hauling costs are the major expense of logging operations of the forest companies in the Central Jungle Region of Peru, but little is known about the relative importance of the various factors affecting hauling costs. The forest companies of this important region of Peru must improve hauling productivity and costs. In order to assist them, the productivity and cost of hauling logs by flatbed trucks of different engine types are discussed and analysed in this thesis. Furthermore, a cost sensitivity analysis of the hauling operation is carried out to determine the impact on the productivity and haul cost of variations in the major operating variables. Finally, the physical characteristics of the forest roads where the hauling operation takes place is described and analysed.

The Central Jungle region of Peru is located on the steep slopes of the eastern flanks of the Andes, and contains the following wood product centers: San Ramon, La Merced, Oxapampa, Villa Rica, Pichanaki, and Satipo. The forest resources of this region are very important as a result of its proximity to Lima, the capital of Peru, which is the main consumption center of wood products in the country. The total forest area of this region is 8,987,000 ha, which represents 12% of the total Peruvian forest land.

Sawmilling is the main forest industry in the Central Jungle region. Truck hauling is the only method of log transportation from the bush landings to the mills. Logging companies generally use old, small gasoline-powered flatbed trucks with a payload capacity of 8,000 to 12,000 kg. Some logging companies have recently introduced new trucks powered by diesel engines of similar payload capacity. The most frequent one-way hauling distance in this region is in the range of 30 to 50 km, although there are some cases where the hauling distance is greater than 90 km (David, 1983; Frisk, 1978).

The problems of the log transportation system have always worried the forest operators of the Central Jungle region, and the problems are intensifying as logging operations occur further away from the sawmills. The forest industry in this zone is experiencing higher hauling costs as a result of the longer hauling distance, low road standards, low load capacity of the trucks, age of the trucks and the method used for loading and unloading trucks (David, 1983).

Forest companies need a way of decreasing hauling costs in this region. This can be accomplished by investigating the truck hauling operation in a systems context. This means that all phases of the truck cycle: traveling, queueing, loading, unloading and the multitude of operational delays must be studied before the overall productivity and costs can be estimated (Smith and Tse, 1977a).

The first objective of this study is to investigate the productivity and cost trade-offs of truck hauling by gasoline powered flatbed trucks with 8,000 kg payload capacity and diesel powered trucks of 8,260 kg payload capacity, under similar operating conditions such as road quality and weather. This comparison will allow the selection of the more effective truck to perform the log hauling operation that takes place in the Central Jungle region of Peru.

In this study the following hypothesis will be tested: the cost of hauling logs expressed in dollars per cubic metre ($\$/m^3$) with diesel powered trucks with 8,260 kg payload capacity is less than with gasoline powered trucks of 8,000 kg payload capacity for the most frequent one-way hauling distance (30-50 km) in the Central Jungle region of Peru. Consequently, diesel powered trucks should be better suited for hauling operations in this region.

The second objective of this study is to examine the overall hauling system in order to identify the main factors that govern productivity and costs of the flatbed trucks evaluated. This information will show where improvements or changes can be made to increase productivity and reduce costs of trucking logs to the sawmills.

The original intention of this work was to investigate the productivity and cost trade-offs of truck hauling of gasoline powered flatbed trucks with 8,000 kg payload capacity and diesel powered trucks of 12,000 or 15,000 kg payload capacity. This original idea was not accomplished because the logging company which cooperated in this study did not own any diesel powered flatbed trucks with this payload capacity.

The thesis is divided into five chapters. Chapter 1 presents as background information a brief description of the geography and climate, physiographic and forest characteristics, and the forest industry and the current harvesting systems in the Central Jungle region of Peru. Chapter 2 describes the main factors that affect log-trucking productivity and costs. Chapter 3 describes the study methodology which has been used in this truck hauling study. Chapter 4 gives the study findings and discusses the results. Chapter 5 contains the summary and the conclusions of this study, as well as some specific recommendations.

CHAPTER 1

THE CENTRAL JUNGLE REGION OF PERU: BACKGROUND INFORMATION

1.1 Geography and Climate

The Central Jungle region of Peru is located in the eastern and central part of Peru between 8° and 12° 20' latitude south and 70° 30' and 76° longitude west. The territory involves the zones of Pachitea, Oxapampa, Chanchamayo, Satipo and Atalaya. The total area of this region is 12,454,900 hectares. This truck hauling study was carried out in the forest harvesting area of Pichanaki which is located in the province of Chanchamayo of the Department of Junin. It typifies many similar operations in this region. Figure 1. shows the geographic location of this region.

The climatic conditions in this region are typical of tropical mountain rain forests: humid and hot. Rainfall is very heavy from November to April, and the annual precipitation ranges between 1,500 and 3,000 mm. The temperature is quite uniform throughout the year. The average temperature ranges between 18°C and 25°C (Brack, 1977; Romero, 1983).

1.2 Physiographic Characteristics

The forests of this region are located between 700 and 2,000 metres above sea level and the topography is broken with very steep slopes (Malleux, 1982). Silt and clay soils dominate in this region although coarse-grained soils are common. Good road-building material is abundant in this zone.

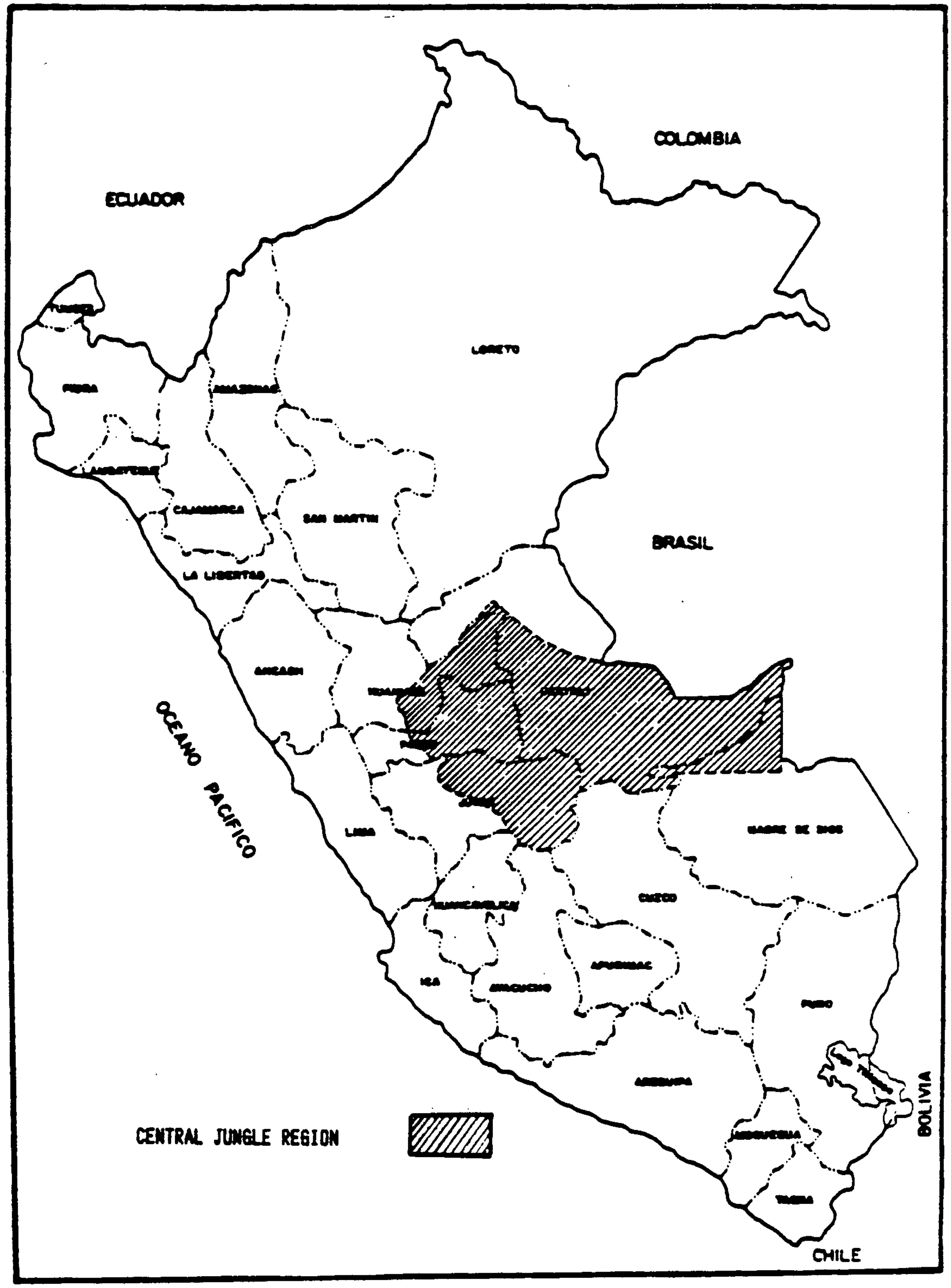
1.3 Forest Characteristics

The Central Jungle Region of Peru has an area of 8,987,000 hectares which represents 12% of the total Peruvian forest land base. The forests of this region, like the forests of the Amazon lowlands, have an extremely heterogeneous species composition. Many forest inventory studies have been carried out in this region. They reveal a total standing merchantable volume between 66 and 140 m^3/ha (Romero, 1983). A forest inventory carried out in the provinces of Chanchamayo and Satipo of the Department of Junin reports a total standing merchantable volume between 78 and 138 m^3/ha with 40 and 63 trees per hectare. The average stem volume was between 1.6 and 2.3 m^3 (U.N.A., 1982).

1.4 Forest Industry

The forest industry in this region is mainly sawmilling. Sawmills produce lumber as a major product. However, railroad crossties, fruit boxes, and broom sticks are also produced on a minor scale. The sawmills are located in the forest districts of San Ramon, Oxapampa, Villa Rica, and Satipo. The lumber production of these mills in 1981

FIGURE 1. Central Jungle Region in Peru.



SOURCE : Instituto Nacional de Planificacion. 1981, Programa de desarrollo de la Selva Central.

represented 19% of the total Peruvian lumber production. The number of sawmills and the lumber production in 1981 are shown in Table 1.

Logs are supplied to the sawmills from their own harvesting operations. Logging operations are adapted to selective harvesting practices; and the volume harvested per hectare is estimated at 30 m^3/ha (Frisk, 1978). The forest companies harvest primarily moena (*Nectandra spp.*), tornillo (*Cedrelinga catenaeformis*), alcanfor (*Ocotea spp.*), cedro (*Cedrela spp.*), diablo fuerte (*Podocarpus spp.*), and congona (*Brosimun spp.*) (Romero, 1983).

Table 1. Sawmills in the Central Jungle Region of Peru.

Forest District	Number of Sawmills	Lumber Annual Capacity (m^3)	Lumber Annual Production (m^3)
San Ramon	16	45,200	43,800
Oxapampa	12	39,500	15,800
Villa Rica	18	37,700	15,300
Satipo	31	60,500	48,000
Total	71	182,900	122,900

Source: David, E. 1983, El transporte terrestre de la madera en la Selva Central. Lima.

1.5 Current Harvesting Systems

Felling and bucking operations in this region are carried out with chainsaws. Felled trees are bucked at the stump site mainly into logs 2.45 to 3.10 metres long, although in some cases the stem is bucked into logs of 4.30

to 4.90 metres. The daily production of a two man crew (chainsaw operator and helper) is estimated in the range of 14 to 28 m^3 for the felling and bucking operation (David, 1983).

Primary transportation in this zone is either manual or mechanized. Manual (with the aid of gravity) is the main method used to skid logs downhill to roadside. This method is used only when the logs are to be skidded down a slope steep enough to allow their free movement without the application of any power. The logs are skidded down by rolling them with the help of peavies. The peavy is extensively used in this zone not only to roll the logs during the skidding operation but also to assist in loading and unloading the trucks. On the other hand, when there are favorable topographic conditions, chutes are constructed in gullies to slide logs downhill to roadside. The construction of a chute consists of clearing a gully and placing small logs to act as ramps in the difficult parts of the track. Campos (cited in Leigh, 1984) indicates that the lengths of the chutes vary up to a maximum of 800 to 1,000 metres.

Mechanized yarding is carried out with a home-made jammer. This method is used to yard logs uphill. The home-made jammer (Figure 2) consists of an one-drum hoist and a boom mounted on an old truck. The hoist is operated through a power take-off from the truck drive line, or by a separate engine, and the boom is an A-frame mounted on the rear end of the truck. The maximum yarding distance with this system is

150 metres, and the estimated production is up to 20 m^3 per day under the best operating conditions. Moreover, the jammer is sometimes used to perform the loading operation (Frisk, 1979). Besides, some logging companies have recently introduced line skidders in this region. The methods used in loading, hauling, and unloading operation are described in detail in Chapter 4 of this thesis.

FIGURE 2. Home-made Jammer.

CHAPTER 2

MAIN FACTORS THAT AFFECT LOG-TRUCKING PRODUCTIVITY AND COSTS

The productivity and cost of hauling logs by truck are mainly determined by the hauling distance, physical characteristics and conditions of the road, loading and unloading equipment, and with the truck type and payload size (Conway, 1982; FAO, 1974; Stenzel et al.,1985). In this chapter, the influences of the main factors on the productivity and hauling costs are discussed.

2.1 Physical Characteristics of Logging Roads

Several authors have pointed out that the proper planning, design, construction and maintenance of logging roads are closely related to the efficiency of the hauling operation. Detailed information on these topics can be found in the references by Adams (1983), Fisher and Taber (1975), Garland (1983a,1983b,1983c), Haussman and Pruett (1973), Heinrich (1976), Jonhson and Wheeler (1978), McNally (1977), and Stenzel et al.(1985).

Byrne et al.(1960) in his study for west coast conditions of U.S.A. found that the travel time of logging trucks, and consequently the hauling cost is affected by grade, road surface, alignment, width of roadway, turnout spacing and density of traffic. Baumgrass (1970) states that the physical characteristics of logging roads such as grade, curvature, length, width, and surface conditions all determine trucking efficiency. When road characteristics become adverse to trucking, production delays increase, truck size and thus payloads are limited, truck wear accelerates, and travel time increases.

Silversides (1981) explains that the truck fleet and road are equally important components of a transport system. In order to optimize transport costs, there must be a balance between investment in road construction and maintenance, and the money spent on vehicles.

2.2 Hauling Distance

The cost of trucking logs varies with the length of haul, and this cost is higher when the haul distance is longer. Moreover, the haul distance determines the number of trips and therefore the volume that can be hauled in a day (Conway, 1982). On the other hand, the most economical size of transport vehicle is found to vary with the length of the haul and the loading and unloading methods used; and for longer hauling distances diesel-powered trucks should be considered for use instead of gasoline-powered trucks (FAO, 1974).

2.3 Loading and Unloading Operation

The terminal functions of loading and unloading have a direct influence on hauling productivity. When the hauling distance is short, the terminal times should be short, otherwise they will become too large a part of the total round-trip time. On the other hand, small volumes of timber can only support low capital-cost loading equipment and vice versa (FAO, 1974). Conway (1982) indicates that hauling is the most costly component in the total harvesting system, therefore trucks should not lose time waiting at the landings for logs or because the loading operation is slow.

2.4 Truck Type and Payload Size

Trucks used in logging vary widely in size and load-carrying capability. This depends on many factors such as size of operation, haul distances, road conditions, volumes available, and the product to be hauled. They vary from single-axle vehicles with 100- to 135-horsepower engines that carry a payload of up 8,172 kg, to custom-built vehicles that can pull a load in excess of 90,800 kg and are powered by 400 to 500 horsepower engines (Conway, 1982).

Stenzel et al.(1985) states that production line vehicles, which are small trucks fitted with a flatbed and necessary accessories, might haul a reasonable load, but they are not designed for hauling. These small trucks may be lacking in power, braking capacity, proper framing, and adequate spring assemblies because they were not designed to serve as logging trucks. Moreover, this author indicates that there are custom-built vehicles that are designed for hauling. These logging trucks are classed as either on-highway or off-highway trucks.

Byrne *et al*. (1960) found that there is little difference between the cost of hauling logs with gasoline powered trucks when compared with diesel powered trucks. The advantage of lower cost of diesel fuel is offset by higher repair, lubrication, and fixed costs.

CHAPTER 3

STUDY METHODOLOGY

This truck hauling study was carried out in the wood products center of Pichanaki, which is located 365 km from Lima, during the dry (June-August) haul season in 1985. A private forest company (Belho Horizonte S.C.R. Ltd. sawmill) cooperated in this study. This company hauls up to 11,250 solid m^3 of hardwoods per year with a fleet of 10 small flatbed trucks.

3.1 Survey Procedure

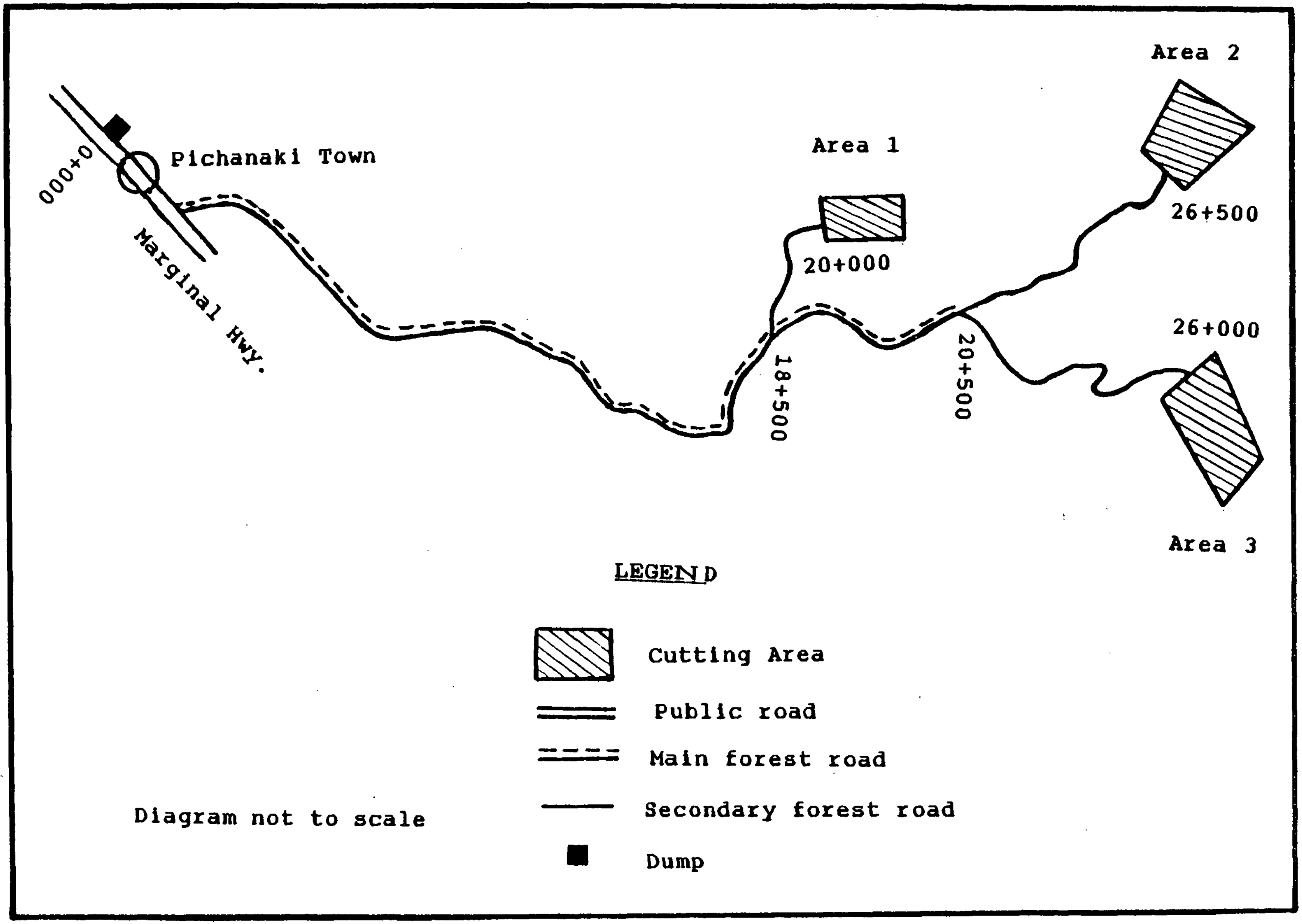
3.1.1 Selection of Cutting Areas and Survey Vehicles

Cutting Areas

Three cutting areas were selected at the extreme end of the secondary road (Figure 3) in the "Alto Cuyani" logging area. Diesel-powered and gasoline-powered trucks hauling from these areas travelled over much the same route. The common road was required so that differences in performance and productivity could be related directly to the differences in the trucks rather than the operating conditions.

Felling, bucking and primary transportation were carried out by contractors. Felled trees were bucked at the stump site with chainsaws into logs of 2.45 , 3.10 , 4.30, and 4.90 metres. Both the manual method with the aid of gravity and

FIGURE 3. Study Area : Road Network.



the mechanized method using home-made jammers, were used in primary transportation of logs. A typical crew of one winch operator and one choker setter was observed in the yarding system. Contractors were paid an average rate[1] of CND\$2.87/m^3 for the felling, bucking, skidding, and for helping during the loading operation. When contractors performed the yarding operation with the company-owned jammer, the Belho Horizonte S.C.R. Ltd. company paid an average of CND\$1.62/m^3 for the felling, bucking, and yarding operation. Generally, each truck hauled from only one cutting area, and the dump site was at the mill yard. The origin of each trip was identified by the cutting area number and by the contractor name.

Road Network

Three road classes were recognized in the haul route (Figure 3). One kilometre of public highway was used as part of the main haul road. This road was of compacted gravel with two lanes and with dense traffic. The remainder of the hauling route consisted of private forest roads. The length of the main road was 19.50 km and the length of the secondary road ranged from 1.5 to 6.0 km.

Truck Fleet

Six small flatbed trucks (3 gasoline-powered and 3 diesel-powered) with a payload capacity between 8,000 and 8,260 kg were observed in this study. For the remainder of

1 An exchange rate of 1 CND\$=9,975.25 Peruvian soles was used to express this cost in current dollars of August 1985.

this thesis, the truck classes are identified by the names of gasoline-powered and diesel-powered trucks. The small flatbed trucks used by this private company are the same type of trucks widely used by most of the logging companies in the Central Jungle region of Peru. The basic unit (Figure 4 and 5) consists of a conventional two-axle truck, one steering axle and one driving axle with dual wheels. It is designed to carry the load directly on its body structure.

3.1.2 Measurement of Machine Time and Productivity

A continuous time study method (Luissier, 1961; Stenzel et al., 1985) was used in the data collection to evaluate the productivity of the trucks. A model DSR servis recorder was attached to each of the trucks under study to record its activities during the entire trip cycle. The servis recorder is an instrument for recording the activity of a vehicle throughout a given work period. It consists of a spring wound clock that drives a disk under a stylus on a pendulum. The vibration of the machine activates the pendulum, which scribes the disk (Nelson, 1974; Berlyn and Keen, 1964).

The servis recorder was installed on the truck following the installation technique described by Berlyn and Keen (1964). Twelve-hour charts were used in this time study. One or two charts were used and changed each round trip. The

FIGURE 4. Gasoline-powered truck being fitted with a flatbed.

FIGURE 5. Diesel-powered truck loaded at the mill yard.

insertion and removal of the servis recorder charts was carried out by following the procedure described by Nelson (1974). Each chart was identified by labelling it with truck No., cutting area, and date. The activities of a sample of 54 truck trips were recorded using this instrument.

In order to recognize the hauling cycle and to establish a correlation between servis recorder traces and work cycle elements, the author was required to ride the trucks for some trips and to record trip data with a wrist watch (to the nearest minute) and a survey form (Appendix 1). The survey form used by Smith and Tse (1977b) to record trip data was used as a basis for this survey form. It was modified to fit to this particular time study.

The hauling cycle was divided into working elements, which were recognized and measured on each chart. These time elements are:

1. Travel empty
2. Loading
3. Travel loaded
4. Unloading
5. Delay

These hauling cycle elements are defined below:

Travel empty

Travel empty begins when the truck leaves the parking area or the unloading area at the mill and ends when the truck arrives at the bush landing.

Loading

Loading begins when the truck arrives at the bush landing and it includes positioning the truck for loading, loading the logs, and preparing the load for hauling. Since it was not possible to recognize on the charts short delays of loading queue and short delays while the truck was waiting for logs, these delay times are included in the loading time.

Travel loaded

Travel loaded begins when the truck leaves the bush landing and ends when it arrives at the unloading area located at the mill yard.

Delay

Delay time consists of the time which the vehicle spends idle. It is composed of mechanical delay and non-mechanical delay. Mechanical delay involves time spent in replacing or repairing a failed part, and service activities such as warm-up time, fueling, lubricating, routine checking and inspection. Non-mechanical delay includes operational lost time due to weather, road conditions, being stuck, waiting for another phase, helping another machine, waiting for supervisor's instructions, etc., and the sum of time spent in long loading and unloading queues. Furthermore, it includes personnel time, such as truck driver's rest and food breaks.

The individual work cycle elements were identified by the type of the trace on the chart. Figure 6 shows the type of trace made by the pendulum stylus in each cycle element.

When the truck is travelling the stylus makes a wide continuous band, when it is idling the stylus makes a thinner band, when it is being loaded or unloaded the stylus makes a discontinuous wide band, and when it is stopped the stylus makes a single thin line.

A chart totaller was used to add up the time elements during a round trip. The procedure described by Nelson (1974) was followed to measure the hauling cycle elements. Figure 7 shows a servis recorder chart totaller with a chart ready to measure.

3.1.3 Payload per Trip

The payload of the trucks for each trip was measured by stick scaling. This operation was carried out at the dump site just after the unloading operation. The log's diameter at the base and at the top and the length were recorded on a form which is shown in the Appendix 1. The volume of each log was calculated in the office with Smalian's formula (Hush et al.,1982):

$$V = L/2\ (A_b + A_u)$$

Where: V = Log volume in m^3

L = Log length in m

A_b = Cross-sectional area at base of log in m^2

A_u = Cross-sectional area at top of the log in m^2

FIGURE 6. Servis Recorder chart at the end of the trip.

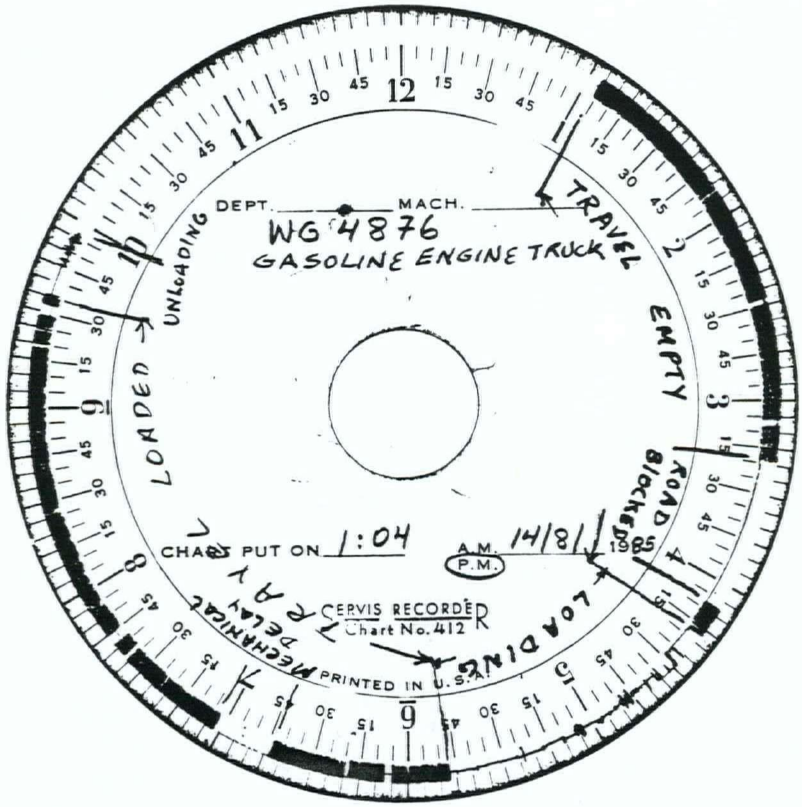


FIGURE 7. Servis Recorder chart totaller with chart in position.

The payload weight was calculated by using the species weight factor. Samples of wood of each forest specie were taken from logs hauled to determine the wood density (green weight-green volume basis). The determination of wood density was carried out at the Wood Technology Laboratory of the Universidad Nacional Agraria La Molina in Lima. The estimated greenwood unit weights of the species harvested in the study area is shown in Table 2.

3.1.4 Complementary Truck Data

In addition to the timing data, complementary information regarding truck specifications and truck cost parameters were obtained by direct observation, personal communication, and from the records of the private company which cooperated in this study.

Truck Specifications

Truck information regarding make, age, engine, front axle and rear axle capacity, tires, flatbed dimensions, tare weight, and maximum payload capacity were collected. Table 3 summarizes the specifications of gasoline-powered and diesel-powered trucks evaluated in this study.

Truck Cost Parameters

The following information was collected for each trucking situation:

- purchase price of truck
- number of trips per year

Table 2. Estimated Density (green weight-green volume basis) of forest species harvested in the study area.

Commom Name	Genus/Species[2,3]	Density (t/m^3)
Manzano	*Battia spp.*	1.17
Congona	*Brosimum spp.*	0.97
Almendro	*Caryocar* spp.	1.24
Cedro	*Cedrela spp.*	0.77
Tornillo	*Cedrelinga catenaeformis*	0.80
Tulpay	*Claricia racemosa*	1.07
Matapalo	*Ficus spp.*	0.78
Catahua	*Hura crepitans*	0.89
Banderilla	*Iryanthera juruensis*	0.78
Nogal	*Juglans neotropica*	1.13
Moena amarilla	*Nectandra spp.*	0.78
Moena negra	*Nectandra spp.*	0.79
Alcanfor	*Ocotea spp.*	0.70
Copal	*Protium puncticulatum*	0.86
Zapote	*Quararibea cordata*	0.83
Nogal amarillo	*Terminalia amazonia*	1.08
Aji	N.I.[4]	1.06
Huamanchilca	N.I.	1.04
Sachahuasca	N.I.	0.99
Vilco	N.I.	0.88

2 Arostegui, A.V. 1982. Recopilacion y analisis de estudios tecnologicos de maderas Peruanas. Proyecto PNUD/FAO/81/002. Documento de trabajo No.2. Lima, Peru. 57pp.

3 Reynel, C. 1984. Un vocabulario para describir y nombrar a los arboles en la lengua Campa-Ashaninca. Revista Forestal del Peru, 12(1-2):81-97.

4 Tree Species not identified.

Table 3. Technical specifications of the trucks.

	Gasoline-powered trucks	Diesel-powered trucks
Truck make	Ford F-600	Dodge DP-500
Engine	Ford 6.1 L(370)2V V-8 BHP-115 @ 2800 RPM	Diesel Perkins C6-354.2 BHP-120 @ 2800 RPM
Transmission	4-speed direct	NP-542 5-speed
Front axle capacity	2,724 kg (6,000 lb)	3,178 kg (7,000 lb)
Rear axle capacity	6,810 kg (15,000 lb)	7,945 kg (17,500 lb)
Tires	9.00X20-12	9.00X20-12
Tare weight	11,123 kg (24,500 lb)	11,123 kg (24,500lb)
Flatbed dimensions	2.70 m X 4.60-4.80 m	2.70 m X 4.60-4.80 m
Age	17-18 years	4-6 years
Maximum Payload	8,000 kg	8,260 kg

- annual opportunity interest rate
- driver wage per trip
- helper wage per trip
- fuel consumption
- fuel price
- oil and lubrication cost
- tire cost and life
- life repair cost of a set of tires
- truck repair and maintenance cost
- truck flatbed cost and life
- manual winch cost and life

3.1.5 Survey of the Haul Route

Representative segments of the different road classes of the haul route were surveyed during the same period that the time study took place. The following physical characteristics of the roads were collected: road grade, subgrade width, curvature, surface conditions and side slope. The maintenance of the haul route was also observed. Suunto clinometer, Suunto compass, and nylon chain were the instruments used in the survey of the haul route and adequate survey forms were used to collect the field data.

3.2 Analysis

The analysis based on the information collected consists of:

- analysis of observed (survey) trips

- truck productivity and cost
- analysis of haul route conditions
- sensitivity analysis
- break-even analysis

3.2.1 Analysis of Observed Trips

A detailed comparative analysis of gasoline-powered versus diesel-powered trucks was undertaken based on the average of each element of the truck working cycle. The operating variables analyzed were :

- travel empty
- travel loaded
- loading time
- unloading time
- delay
- payload volume and weight.

Due to variations between trips as a consequence of the different cutting areas and different hauling distances involved, the comparison between both types of truck was based on the following variables: velocity empty, velocity loaded, loading time, delay time (expressed as a percentage of the productive time of the hauling cycle), payload volume and weight, and unloading time.

3.2.1.1 Statistical Analysis

A descriptive analysis, including calculation of minimum, maximum, average, and standard deviation, was obtained for each work element. In order to determine if there is significant difference in the hauling work elements between gasoline-powered and diesel-powered trucks a test of hypothesis concerning means of the operating variables indicated above was developed. With the mean and standard deviation values obtained from the sample data collected during the time study, a test concerning variances was carried out first, and then a test concerning means was performed. The procedure for testing a hypotheses described by Walpole (1982) was followed. A 0.05 level of significance was used.

A linear correlation and linear regression analyses was performed also to measure the relationship existent between variables involved in the hauling operation. The regression and correlation analyses were accomplished utilizing the ABSTAT statistical package for microcomputers.

3.2.2 Truck Productivity and Cost

The analysis of the surveyed trips provided the basic performance data for each truck type involved in this study. However, because hauling cycles for different cutting areas and different hauling distances were collected, these observations could not be used directly to compare productivity and cost. Consequently, the comparison of productivity and cost between gasoline-powered and diesel-powered trucks was structured around a standard hypothetical haul route, with performance estimated from the actual survey data. The haul route to cutting area number 3, was selected and it includes the following:

Road Segment (Class)	Kilometres
Public highway	1.00
Main forest road	19.50
Secondary forest road	5.50
Total	26.00

The total travel time for this haul length was calculated with the average round trip speed which was determined by using the following formula (FAO, 1974):

$$\text{Average round trip speed (km/hr)} = 2\,(SL \times SE)/(SL + SE)$$

Where : SL = speed loaded (km/hr)

SE = speed empty (km/hr)

3.2.2.1 Truck Productivity

The comparison of the productivity of gasoline-powered trucks versus diesel-powered trucks was carried out based on the following components:

- truck cycle time and trips per day
- daily and annual production
- fleet requirements by vehicle type.

3.2.2.2 Truck Cost Estimate

The estimate of trucking costs is based on the technique proposed by McNally (1975), and on the costing method applied by Smith and Tse (1977b). This method is based on hourly costs but differentiated between in-use hours and travelling hours. This method recognizes that some operating costs accumulate when the unit is standing or travelling, such as depreciation and operator wages, while other costs accumulate only when the vehicle is travelling such as cost of fuel, tires, and servicing and repair.

In-use hours are defined as the time when the truck is ready for duty; that is, operable and with driver. However, 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, accruing for the entire operating time, include:

- capital depreciation
- interest on average investment
- operating labour (wages and fringe benefits)

Travelling hours are defined as the time when the vehicle is in motion and they include productive haul, empty return, and maneuvering. The travelling costs which build up as the vehicle is moved include:

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

The remainder of this section discusses in detail each of these cost items and gives the method and formulae used in calculating the costs. The costs are expressed as either per in-use hour or per travelling hour.

A. In-Use Hour Costs

The in-use costs are based on the truck purchase price data of used gasoline-powered trucks and new diesel-powered trucks, obtained from the records of the cooperating forest company. Original truck purchase price data from 1981 was transformed to the equivalent current Canadian dollars in August 1985 (common base date of this truck study), by removing the effects of inflation from the original purchase price cost data. Calculations are based on increases of the Canadian Consumer Price Index (CPI) reported by Wilson (1985) for the period 1981-1985. Appendix 2 shows truck purchase price information for this study.

Depreciation

Depreciation is a means of recovering the original investment in a machine (McNally, 1977). There are several methods of calculating depreciation depending upon the particular purpose. The straight line method was used to compute the depreciation. This is the simplest method to calculate depreciation, and is generally the accepted method for estimating equipment cost per unit of time (Miyata, 1980). The mathematical formula for straight line depreciation per in-use hour is as follows (Smith and Tse, 1977b):

$$\frac{\text{Depreciation}}{\text{In-use hour}} = \frac{\text{Purchase price - Salvage value}}{\text{Ownership period x In-use hr/yr}}$$

McNally (1977) indicates that there is no way of knowing precisely the economic life of machine because of factors relating to obsolescence, severity of use and quality of maintenance. McNally also points out that for cost estimating purposes it can be assumed that logging trucks which haul short distances and spend an average of 40-60 percent of round trip time at terminal points have a normal life of 20,000 in-use hours or travelling life of 10,000 productive machine hours.

Salvage value is the amount that equipment can be sold for at the time of its disposal. The actual salvage value of equipment is affected by current market demand for used equipment and the condition of the equipment at the time of disposal. However, estimating the future value of equipment is very difficult because it is based on future market conditions, and the unknown condition of the equipment at the time of its disposal (Miyata, 1980). In this thesis, to estimate resale value a 'truck value depreciation scale' suggested by Canadian Kenworth Ltd.(Cited in Smith and Tse, 1977b) was applied to the original value. Following is the resale value (% of purchase price excluding tires) factor as a function of ownership period:

Ownership period (years)	Resale value factor
0	1.00
1	0.70
2	0.56
3	0.45
4	0.36
5	0.29
6	0.23
7	0.18
8	0.15
9	0.10
beyond 10	0.10

An ownership period of 8 years and resale value factor of 15% was assumed for new diesel-powered trucks. While, an ownership period of 4 years and resale value factor of 10% was assumed for used gasoline-powered trucks. An average of 160 trips per year (an estimated 1686 in-use hours) was determined from the cooperating forest company records for both types of truck.

Interest

The charge for interest was computed based on the average value of yearly investment of the machine. The formula used to calculate is as follows (Miyata, 1980) :

$$AVI = \frac{(P - S)\ (N + 1)}{2\ N} + S$$

Where : AVI = average value of yearly investment over its entire economic life

P = initial investment cost

S = salvage value

N = economic life in years.

The interest amount per in-use hour is calculated with an annual opportunity interest rate of 12% as follows:

$$A = (AVI * i)/Y$$

Where : A = Interest amount per in-use hour ($/hr)

i = annual opportunity interest rate (expressed in decimal form)

Y = in-use hours per year

Operating labour

The cost of operating labour is comprised of the direct wages of truck driver and his helper together with the indirect cost of labour fringe benefits (McNally, 1977). The author observed that a truck driver generally works with a helper, and they are paid on a per-trip basis. The cost of labour fringe benefits of 30% indicated by Campos (1983) for the Peruvian workers is used in this study.

Since in-use time is equal to the number of hours the driver is allocated to the truck and paid as a driver, the operating labour cost per in-use hour is obtained as follows:

$$\text{Operating labour (\$/hr)} = \frac{\text{labour cost per trip} * (1 + f)}{\text{In-use hours per cycle}}$$

Where : f = cost of labour fringe benefits expressed in decimal form of direct labour cost

The in-use hours per cycle is equal to the total hauling cycle time excluding driver food time.

B. Travelling Hour Costs

The average operating cost of the trucks selected for the time study was used as a basis to calculate the travelling costs for each type of truck under comparison.

Fuel

The basic fuel consumption, expressed in kilometres per litre, was calculated from monthly fuel consumption records of the vehicles kept for the cooperating private company. The average consumption rate was calculated with the information on the number of trips per month, the origin of the trips, and data on lengths of trips. The fuel per travelling hour is calculated as follows:

Fuel cost/per travelling hour = Kilometres/trip X fuel price($)/litre X 1 litre/number of kilometres X 1 trip/number of travelling hours

Oil and lubrication

Oil and lubrication costs include the cost of engine oil, final drive oil, transmission oil, and grease. Based on records of oil and lubrication costs for the hauling period of 8 months (January to August of 1985) was calculated an average oil and lubrication costs per travelling hour for each type of truck involved in this study. The cost data for these items have been corrected to current dollars of August 1985 for this analysis, so they do not include inflation.

Tires

The original tires were depreciated with the vehicle. Thus, tire costs cover repairs to the original tires and the cost of, and repairs to, replacement tires during the life of the truck. The following tire cost formula (McNally, 1977) is used to calculate the tire cost per travelling hour :

$$TCTH = \frac{B}{Y * Z} + \frac{(T + B)\ (Y * Z - A)}{A * Y * Z}$$

Where : TCTH = tire cost per travelling hour

B = life repair cost of a set of tires

Y = life of truck in years

Z = travelling hours per year

A = life of a set of tires expressed in travelling hours

Data were obtained regarding tire purchase cost (including tube), and repair cost of a set of tires obtained from the records of those vehicles surveyed. With information about tire life for 8 months provided by the owners of the Belho Horizonte S.C.R. Ltd. sawmill, the tire cost per travelling hour for both types of truck was estimated. The life of a set of tires is assumed to be 900 travelling hours for the trucks analysed in this hauling study.

Repair and Maintenance

Repair and maintenance cost includes everything from simple maintenance to the periodic overhaul of engine, transmission, clutch, brakes, and other major equipment components; and maintenance and repair cost are mainly affected by the severity of working conditions, maintenance and repair policies, and the basic equipment design and quality (Miyata, 1980). Moreover, repair and maintenance cost of a machine increases with increasing age of the machine (McNally, 1977).

Truck repair and maintenance cost data obtained from the records of the surveyed trucks for the hauling period of 8 months (January to August of 1985) were used to estimate the repair and maintenance cost for this study. However; this cost is underestimated because it includes the value of all parts, materials used to repair and maintain, and operating labour when the trucks were taken to a particular repair shop; but it does not include operating labour and equipment cost when the trucks were repaired and maintained by the company's mechanics. The cost data for this item has been corrected to current dollars of August 1985 for this analysis, so it does not include inflation.

3.2.3 Analysis of the Haul Route

A plan and a longitudinal profile of each segment of road surveyed were drawn to an appropriate scale. Then the design elements of each road class were analyzed by comparing with the forest road dimensions proposed by Frisk (1979) to be applied in Peruvian forest operations. Furthermore, the maintenance of these forest roads was analysed. Table 4 shows the forest roads design specifications for forest operations in Peru proposed by Frisk (1979).

3.2.4 Sensitivity Analysis

The basic purpose of sensitivity analysis is to find out how the results of a model change when the data, parameters, or assumptions of the model change (Martin, 1971). A cost sensitivity analysis was conducted to evaluate the impact of variations in the major operating parameters on the productivity and haul cost. The effect of the following factors was evaluated in this analysis: delay time, loading time, travelling time, hauling distance, vehicle ownership period, annual in-use hours, and payload volume. To facilitate rapid computation of hauling cost and provide a medium for exploring the impact of changes in the cost factors indicated above, a hauling cost model was developed on an IBM PC microcomputer using the Symphony[5] spreadsheet Software package.

Table 4. Design characteristics for forest roads in Peruvian forest operations.

Design element	Road Types		
	Main road	Secondary road	skidding road
Design speed (km/hr)			
Flat terrain	40-45	30-35	20-25
Rolling terrain	30-40	25-30	15-20
Hilly terrain	20-30	15-25	10-15
Mountainous terrain	15-20	10-15	5-10
Surface width (m)	5-6	4-5	3.5
Minimum curve radius (m)	30	15	10
Crown (%)	2-3	3	3
Turnouts	no	yes	yes
Ditches	yes	yes	no
Culverts	yes	yes	no
Surface type	gravel road	gravel or dirt road	dirt road

3.2.5 Break-even Analysis

A break-even analysis was carried out in order to calculate the one-way hauling distance (km) at which the total hauling costs of gasoline-powered trucks are equal to diesel-powered trucks. The break-even point at which the

5 Symphony is an integrated Software package from Lotus Development Corporation.

total hauling cost (\$/m3) of each alternative are equal is calculated as follows (Stenzel et al., 1985):

$$STd + Td\ (X) = STg + Tg\ (X)$$

$$X = \frac{STd - STg}{Tg - Td}$$

Where: STd = Standing cost/m^3 - Diesel-powered trucks

Td = Travelling cost/m^3 per kilometre

STg = Standing cost/m3 - Gasoline-powered trucks

Tg = Travelling cost/m^3 per kilometre

X = Break-even distance in kilometres

CHAPTER 4

STUDY RESULTS AND DISCUSSION

4.1 Analysis of Observed Trips

Data of 54 round trips were collected during June to August of 1985. Table 5 and Table 6 summarize the field data collected during this period on diesel-powered trucks and gasoline-powered trucks respectively.

4.1.1 Loading Time

The conditions of the loading operation is described here in order to understand this time element of the vehicle working cycle. Trucks were loaded either by hand rolling method or by crosshaul method. In some cases a combination of both loading methods was observed.

Hand Rolling Method

Logs decked at the upper side of the road were mainly loaded by the hand rolling method. To perform the log loading operation, the truck was positioned on the downhill side of the log deck, and the logs were rolled onto the truck bed using a peavy. On sloping ground, a pair of pole skids was laid from the ground to the truck flatbed, and then the logs were rolled onto the vehicle. Figure 8 shows this loading method. The truck driver, the helper and the contractor who accomplished the felling, bucking and manual skidding operation were in charge of the loading operation. It was

Table 5. Field data summary of diesel-powered trucks.

Trip No.	Hauling distance (km)	Travel empty (hr)	Velocity empty (km/hr)	Travel loaded (hr)	Velocity loaded (km/hr)	Loading time (hr)	Unloading time (hr)	Tot.Prod time (hr)	Delay time (hr)	Delay % Prod. time	Total cycle time (hr)	Logs (#)	Payload Volume (m3)	Weight (kg)
1	26.00	2.43	10.70	3.25	8.00	2.83	0.33	8.84	4.65	52.60	13.49	8	6.05	4870
2	26.00	2.75	9.45	3.67	7.08	2.25	0.25	8.92	2.75	30.83	11.67	11	6.82	5790
3	26.00	2.58	10.08	4.33	6.00	1.58	0.42	8.91	4.17	46.80	13.08	13	7.89	6300
4	26.00	2.58	10.08	3.42	7.60	2.00	0.35	8.35	1.50	17.96	9.85	15	6.50	5140
5	19.50	1.57	12.42	2.58	7.56	2.00	0.43	6.58	0.60	9.12	7.18	11	6.98	5580
6	26.00	2.30	11.30	3.25	8.00	1.83	0.18	7.56	3.27	43.25	10.83	10	6.39	6260
7	26.00	2.75	9.45	3.83	6.79	1.83	0.23	8.64	1.95	22.57	10.59	5	6.62	5280
8	26.00	3.05	8.52	3.67	7.08	1.62	0.37	8.71	4.22	48.45	12.93	13	9.40	8650
9	26.00	2.57	10.12	3.97	6.55	2.08	0.58	9.20	2.55	27.72	11.75	6	8.04	7770
10	20.55	2.08	9.88	2.30	8.93	3.17	0.37	7.92	3.42	43.18	11.34	14	6.58	7720
11	20.55	2.28	9.01	2.80	7.34	1.45	0.27	6.80	5.13	75.44	11.93	4	12.29	9950
12	26.00	2.13	12.21	3.13	8.31	1.25	0.22	6.73	1.35	20.06	8.08	10	5.58	4350
13	26.00	2.58	10.08	3.58	7.26	2.17	0.25	8.58	2.34	27.27	10.92	8	6.47	5050
14	26.00	2.17	11.98	3.08	8.44	2.33	0.25	7.83	2.67	34.10	10.50	5	7.72	6140
15	26.00	2.22	11.71	3.25	8.00	2.50	0.27	8.24	1.76	21.36	10.00	5	7.45	5810
16	26.00	2.17	11.98	3.17	8.20	2.08	0.33	7.75	2.92	37.68	10.67	14	4.95	4260
17	26.00	2.53	10.28	3.27	7.95	2.00	0.58	8.38	2.12	25.30	10.50	10	7.54	5960
18	19.70	1.83	10.77	2.83	6.96	1.92	0.28	6.86	3.47	50.58	10.33	11	8.81	6870
19	19.50	1.83	10.66	2.67	7.30	2.62	0.31	7.43	2.17	29.21	9.60	8	7.36	5940
20	19.70	2.25	8.76	2.42	8.14	1.33	0.25	6.25	1.92	30.72	8.17	7	7.23	5640
21	19.50	1.67	11.68	2.30	8.48	1.00	0.27	5.24	1.18	22.52	6.42	9	7.25	5710
22	26.00	2.67	9.74	3.67	7.08	2.08	0.30	8.72	2.28	26.15	11.00	6	7.68	8600
23	26.00	2.42	10.74	3.58	7.26	2.08	0.35	8.43	3.23	38.32	11.66	11	7.80	6410
24	26.00	2.75	9.45	3.53	7.37	2.27	0.38	8.93	1.37	15.34	10.30	8	8.24	6430
25	20.55	1.50	13.70	2.63	7.81	3.23	0.25	7.61	3.55	46.65	11.16	5	8.18	7280
MIN. =	19.50	1.50	8.52	2.30	6.00	1.00	0.18	5.24	0.60	9.12	6.42	4.00	4.95	4260.00
MAX. =	26.00	3.05	13.70	4.33	8.93	3.23	0.58	9.20	5.13	75.44	13.49	15.00	12.29	9950.00
MEAN =			10.59		7.58	2.06	0.32			33.73		9.08	7.43	6310.40
VARIANCE =			1.6189		0.4587	0.2964	0.0100			215.76		10.4933	1.9950	1902337
STD. DEV. =			1.2724		0.6773	0.5444	0.0999			14.69		3.2393	1.4124	1379.25

Table 6. Field data summary of gasoline-powered trucks.

Trip No.	Hauling distance (km)	Travel empty (hr)	Velocity empty (km/hr)	Travel loaded (hr)	Velocity loaded (km/hr)	Loading time (hr)	Unloading time (hr)	Tot.Prod time (hr)	Delay time (hr)	Delay % Prod. time	Total cycle time (hr)	Logs (#)	Payload Volume (m3)	Weight (kg)
1	26.50	2.25	11.78	3.08	8.60	0.78	0.17	6.28	2.05	32.64	8.33	9	5.01	4910
2	26.50	2.50	10.60	3.08	8.60	1.92	0.25	7.75	3.17	40.90	10.92	15	4.66	3740
3	26.50	2.13	12.44	3.70	7.16	1.83	0.62	8.28	5.55	67.03	13.83	9	8.59	6780
4	20.00	2.05	9.76	3.18	6.29	1.70	0.30	7.23	2.58	35.68	9.81	13	7.74	6250
5	26.50	2.25	11.78	3.33	7.96	2.20	0.33	8.11	2.97	36.62	11.08	16	6.86	5360
6	20.00	1.83	10.93	2.78	7.19	2.17	0.27	7.05	1.55	21.99	8.60	13	5.66	5460
7	20.00	2.18	9.17	3.25	6.15	2.75	0.32	8.50	1.67	19.65	10.17	11	5.59	5810
8	20.00	2.25	8.89	2.75	7.27	1.92	0.33	7.25	2.17	29.93	9.42	11	4.77	4900
9	20.00	2.12	9.43	3.03	6.60	1.75	0.42	7.32	1.86	25.41	9.18	17	7.21	6160
10	20.00	2.17	9.22	3.28	6.10	1.13	0.38	6.96	1.70	24.43	8.66	15	6.51	5760
11	20.00	2.12	9.43	2.85	7.02	1.83	0.22	7.02	2.84	40.46	9.86	8	5.44	5600
12	20.00	2.08	9.62	3.28	6.10	2.12	0.33	7.81	1.02	13.06	8.83	16	6.89	6450
13	20.00	2.08	9.62	3.12	6.41	1.67	0.25	7.12	4.40	61.80	11.52	9	5.48	4740
14	26.50	2.50	10.60	3.58	7.40	2.08	0.37	8.53	2.52	29.54	11.05	20	7.82	7660
15	20.00	2.65	7.55	2.70	7.41	2.45	0.22	8.02	2.73	34.04	10.75	14	5.5	5680
16	20.00	1.90	10.53	2.68	7.46	2.37	0.28	7.23	1.24	17.15	8.47	6	6.56	6500
17	20.00	1.90	10.53	2.50	8.00	1.25	0.35	6.00	0.69	11.50	6.69	17	6.5	5410
18	20.00	2.08	9.62	3.00	6.67	1.83	0.33	7.24	2.94	40.61	10.18	15	6.84	6100
19	20.00	2.05	9.76	2.57	7.78	1.75	0.25	6.62	0.93	14.05	7.55	7	6.32	6340
20	20.00	2.58	7.75	2.63	7.60	1.67	0.30	7.18	3.20	44.57	10.38	11	6.5	5160
21	20.00	2.00	10.00	2.33	8.58	1.25	0.33	5.91	1.29	21.83	7.20	16	5.53	4310
22	20.00	1.95	10.26	2.42	8.26	2.17	0.28	6.82	1.21	17.74	8.03	12	5.45	4400
23	26.50	2.50	10.60	4.17	6.35	2.17	0.27	9.11	2.50	27.44	11.61	15	7.65	6100
24	26.50	2.58	10.27	4.05	6.54	1.83	0.28	8.74	2.29	26.20	11.03	14	6.41	5080
25	26.50	2.58	10.27	3.33	7.96	2.25	0.30	8.46	1.67	19.74	10.13	12	6.77	5890
26	26.50	2.75	9.64	4.00	6.63	2.00	0.25	9.00	2.50	27.78	11.50	12	6.31	6310
27	26.50	2.70	9.81	3.83	6.92	2.42	0.37	9.32	2.10	22.53	11.42	3	7.21	6990
28	19.00	1.50	12.67	2.30	8.26	2.62	0.28	6.70	3.40	50.75	10.10	14	7.29	6700
29	26.00	2.42	10.74	3.42	7.60	1.50	0.37	7.71	1.17	15.18	8.88	13	9.07	6740
MIN. =	19.00	1.50	7.55	2.30	6.10	0.78	0.17	5.91	0.69	11.50	6.69	3.00	4.66	3740.00
MAX. =	26.50	2.75	12.67	4.17	8.60	2.75	0.62	9.32	5.55	67.03	13.83	20.00	9.07	7660
MEAN =			10.11		7.27	1.91	0.31			30.01		12.52	6.49	5768.62
VARIANCE =			1.3308		0.6352	0.2006	0.0066			191.4782		14.0443	1.1819	788583.7
STD. DEV. =			1.1536		0.7970	0.4479	0.0813			13.8376		3.7476	1.0872	888.0223

observed that generally the loading crew consisted of four people.

Crosshaul Method

Logs decked along the road were loaded using the crosshaul method. In this log loading method (Figure 9) two pole skids were placed between the ground and the truck flatbed. A rope or chain anchored at the rear end of the flatbed was passed around the log to be loaded, and then hooked to a single rope leading to a power source on the front part of the flatbed. A manual Tirfor winch was the power source used in this method. This manual winch rolled the log up the skids and onto the truck by pulling in the rope. The peavy was used to roll the logs onto the flatbed and also to arrange the layer of logs. The loading operation was mainly carried out by the truck driver and the helper when the crosshaul method was used.

Once the truck had been loaded, the logs were cinched tightly with the two binder lines or chains anchored to the flatbed. The binders were tightened around the load of logs by the manual winch. It must be emphasized that the manual Tirfor winch is a necessary component of the flatbed trucks evaluated. From the records of the cooperating forest company it was found that each Tirfor winch had a purchase cost of CND$600 and average expected life of three years.

FIGURE 8. Loading logs by hand rolling method.

FIGURE 9. Loading logs by crosshaul method.

Table 5 and Table 6 show the loading time for each trip for diesel engine trucks and gasoline engine trucks respectively. These tables also show the minimum, maximum, and average loading time of the trucks under comparison. The test concerning means ($H_o:\mu_1-\mu_2=0$) of the loading time (Appendix 3) indicates that there is no significant difference in loading time between diesel-powered trucks and gasoline-powered trucks. Based on this statistical result the loading time data of the 54 truck trips were used to calculate the average loading time for the mixed truck fleet (Table 7). A summary of loading time for the entire truck fleet is shown in Table 8. The correlation analysis indicates a weak linear relationship between loading time and the variables:number of logs, volume, and weight of the payload.

The average time to load a flatbed truck (1.98 hr), whatever manual loading method is used, reveals that the loading method is not efficient. This situation indicates the necessity to examine the introduction of mechanized loading equipment to make the hauling operation more efficient. However, small logging operations, like the cooperating forest company in this study, cannot afford high capital investment in modern loaders such as front-end loaders. The home-made jammer, which requires a capital investment between CND$5,000 and CND$8,000, could be used as a mobile loader to improve the efficiency of the loading operation. Moreover, by proper planning and good supervision of the hauling operation

Table 7. Field data summary of mixed truck fleet.

Trip No.	Hauling distance (km)	Travel empty (hr)	Velocity empty (km/hr)	Travel loaded (hr)	Velocity loaded (km/hr)	Loading time (hr)	Unloading time (hr)	Tot.Prod time (hr)	Delay time (hr)	Delay % Prod. time	Total cycle time (hr)
1	26.50	2.25	11.78	3.08	8.60	0.78	0.17	6.28	2.05	32.64	8.33
2	26.50	2.50	10.60	3.08	8.60	1.92	0.25	7.75	3.17	40.90	10.92
3	26.50	2.13	12.44	3.70	7.16	1.83	0.62	8.28	5.55	67.03	13.83
4	20.00	2.05	9.76	3.18	6.29	1.70	0.30	7.23	2.58	35.68	9.81
5	26.50	2.25	11.78	3.33	7.96	2.20	0.33	8.11	2.97	36.62	11.08
6	20.00	1.83	10.93	2.78	7.19	2.17	0.27	7.05	1.55	21.99	8.60
7	20.00	2.18	9.17	3.25	6.15	2.75	0.32	8.50	1.67	19.65	10.17
8	20.00	2.25	8.89	2.75	7.27	1.92	0.33	7.25	2.17	29.93	9.42
9	20.00	2.12	9.43	3.03	6.60	1.75	0.42	7.32	1.86	25.41	9.18
10	20.00	2.17	9.22	3.28	6.10	1.13	0.38	6.96	1.70	24.43	8.66
11	20.00	2.12	9.43	2.85	7.02	1.83	0.22	7.02	2.84	40.46	9.86
12	20.00	2.08	9.62	3.28	6.10	2.12	0.33	7.81	1.02	13.06	8.83
13	20.00	2.08	9.62	3.12	6.41	1.67	0.25	7.12	4.40	61.80	11.52
14	26.50	2.50	10.60	3.58	7.40	2.08	0.37	8.53	2.52	29.54	11.05
15	20.00	2.65	7.55	2.70	7.41	2.45	0.22	8.02	2.73	34.04	10.75
16	20.00	1.90	10.53	2.68	7.46	2.37	0.28	7.23	1.24	17.15	8.47
17	20.00	1.90	10.53	2.50	8.00	1.25	0.35	6.00	0.69	11.50	6.69
18	20.00	2.08	9.62	3.00	6.67	1.83	0.33	7.24	2.94	40.61	10.18
19	20.00	2.05	9.76	2.57	7.78	1.75	0.25	6.62	0.93	14.05	7.55
20	20.00	2.58	7.75	2.63	7.60	1.67	0.30	7.18	3.20	44.57	10.38
21	20.00	2.00	10.00	2.33	8.58	1.25	0.33	5.91	1.29	21.83	7.20
22	20.00	1.95	10.26	2.42	8.26	2.17	0.28	6.82	1.21	17.74	8.03
23	26.50	2.50	10.60	4.17	6.35	2.17	0.27	9.11	2.50	27.44	11.61
24	26.50	2.58	10.27	4.05	6.54	1.83	0.28	8.74	2.29	26.20	11.03
25	26.50	2.58	10.27	3.33	7.96	2.25	0.30	8.46	1.67	19.74	10.13
26	26.50	2.75	9.64	4.00	6.63	2.00	0.25	9.00	2.50	27.78	11.50
27	26.50	2.70	9.81	3.83	6.92	2.42	0.37	9.32	2.10	22.53	11.42
28	19.00	1.50	12.67	2.30	8.26	2.62	0.28	6.70	3.40	50.75	10.10
29	26.00	2.42	10.74	3.42	7.60	1.50	0.37	7.71	1.17	15.18	8.88
30	26.00	2.43	10.70	3.25	8.00	2.83	0.33	8.84	4.65	52.60	13.49
31	26.00	2.75	9.45	3.67	7.08	2.25	0.25	8.92	2.75	30.83	11.67
32	26.00	2.58	10.08	4.33	6.00	1.58	0.42	8.91	4.17	46.80	13.08
33	26.00	2.58	10.08	3.42	7.60	2.00	0.35	8.35	1.50	17.96	9.85
34	19.50	1.57	12.42	2.58	7.56	2.00	0.43	6.58	0.60	9.12	7.18
35	26.00	2.30	11.30	3.25	8.00	1.83	0.18	7.56	3.27	43.25	10.83
36	26.00	2.75	9.45	3.83	6.79	1.83	0.23	8.64	1.95	22.57	10.59
37	26.00	3.05	8.52	3.67	7.08	1.62	0.37	8.71	4.22	48.45	12.93
38	26.00	2.57	10.12	3.97	6.55	2.08	0.58	9.20	2.55	27.72	11.75
39	20.55	2.08	9.88	2.30	8.93	3.17	0.37	7.92	3.42	43.18	11.34
40	20.55	2.28	9.01	2.80	7.34	1.45	0.27	6.80	5.13	75.44	11.93
41	26.00	2.13	12.21	3.13	8.31	1.25	0.22	6.73	1.35	20.06	8.08
42	26.00	2.58	10.08	3.58	7.26	2.17	0.25	8.58	2.34	27.27	10.92
43	26.00	2.17	11.98	3.08	8.44	2.33	0.25	7.83	2.67	34.10	10.50
44	26.00	2.22	11.71	3.25	8.00	2.50	0.27	8.24	1.76	21.36	10.00
45	26.00	2.17	11.98	3.17	8.20	2.08	0.33	7.75	2.92	37.68	10.67
46	26.00	2.53	10.28	3.27	7.95	2.00	0.58	8.38	2.12	25.30	10.50
47	19.70	1.83	10.77	2.83	6.96	1.92	0.28	6.86	3.47	50.58	10.33
48	19.50	1.83	10.66	2.67	7.30	2.62	0.31	7.43	2.17	29.21	9.60
49	19.70	2.25	8.76	2.42	8.14	1.33	0.25	6.25	1.92	30.72	8.17
50	19.50	1.67	11.68	2.30	8.48	1.00	0.27	5.24	1.18	22.52	6.42
51	26.00	2.67	9.74	3.67	7.08	2.08	0.30	8.72	2.28	26.15	11.00
52	26.00	2.42	10.74	3.58	7.26	2.08	0.35	8.43	3.23	38.32	11.66
53	26.00	2.75	9.45	3.53	7.37	2.27	0.38	8.93	1.37	15.34	10.30
54	20.55	1.50	13.70	2.63	7.81	3.23	0.25	7.61	3.55	46.65	11.16
MIN. =	19.00	1.50	7.55	2.30	6.00	0.78	0.17	5.24	0.60	9.12	6.42
MAX. =	26.50	3.05	13.70	4.33	8.93	3.23	0.62	9.32	5.55	75.44	13.83
MEAN =			10.33		7.42	1.98	0.32			31.73	
VARIANCE =			1.4941		0.5674	0.2459	0.0080			202.36	
STD. DEV. =			1.2223		0.7533	0.4959	0.0897			14.23	

delays at the landings could be reduced, in particular queueing for loading and waiting for logs.

Table 8. Summary of loading time for diesel-powered trucks and gasoline-powered trucks.

Sample size	54
Minimum loading time (hr)	0.78
Maximum loading time (hr)	3.23
Average loading time (hr)	1.98
Sample standard deviation (s)	0.4959

Source : Data extracted from Table 7.

4.1.2 Unloading Time

All the trucks were unloaded at the sawmill yard. The unloading method was side dumping; either by pulling with a rope powered by an electric winch which is used to feed logs into the main saw or by rolling the logs off the truck with a peavy. Figure 10 and 11 illustrate the unloading operation at the mill yard. Table 5 and Table 6 summarize the unloading time of each truck type of this study. The test concerning means ($H_0:\mu_1-\mu_2=0$) of the unloading time (Appendix 3) indicates that there is no significant difference in unloading time between diesel-powered trucks and gasoline-powered trucks. Table 9 summarizes the unloading time for the mixed fleet. It has been found that a positive but low correlation exists between unloading time and the variables: number of logs, volume, and weight of the payload.

FIGURE 10. Unloading flatbed truck at the mill yard.

FIGURE 11. Unloading truck by side dumping.

Table 9. Summary of unloading time for diesel-powered trucks and gasoline-powered trucks.

Sample size	54
Minimum unloading time (hr)	0.17
Maximum unloading time (hr)	0.62
Average unloading time (hr)	0.32
Sample standard deviation (s)	0.0897

Source: Data extracted from Table 7.

4.1.3 Travel Time Empty

Empty travel time obtained from the Servis Recorder charts for each trip is shown in Table 5 and Table 6 for diesel-powered and gasoline-powered trucks respectively. This original data were used to calculate the velocity empty (km/hr) for each trip in order to compare both types of truck. The minimum, maximum, and average velocity when empty for each type of truck can also be observed in Tables 5 and 6. The test concerning means ($H_o:\mu_1-\mu_2=0$) of the empty velocities (Appendix 3) indicates that there is no significant difference in velocity empty between diesel-powered trucks and gasoline-powered trucks. Finally, the average velocity for the mixed fleet was computed (Table 7). The velocity empty for the mixed fleet is summarized in Table 10.

Empty truck speed for each road class was not possible to obtain in this study because on the service recorder traces could not be differentiated by road class. However, the travel time obtained from the survey trip reports when the truck was ridden indicated that there is no significant difference in the velocity empty between the different road classes.

Table 10. Summary of Velocity empty for diesel-powered trucks and gasoline-powered trucks.

Number of observations	54
Minimum velocity empty (km/hr)	7.55
Maximum velocity empty (km/hr)	13.70
Average velocity empty (km/hr)	10.33
Sample standard deviation (s)	1.2223

Source: Data extracted from Table 7.

Travel time empty was found to be dependent on the hauling distance (one way). A simple linear regression carried out with this variable indicates that the following equation may be used to predict values of travel time empty on the basis of the one-way hauling distance (km)

$$Y = 0.4825 + 0.0769 X$$

Where: Y = predicted value of travel time empty in hours

X = One-way hauling distance in kilometres

The analysis of variance for this regression is summarized in Appendix 3. The F test indicates that the calculated F (49.3792) is greater than the $F_{0.05}$ critical (4.03) with 1,52 degrees of freedom; consequently the computed regression equation is significant at the 0.05 probability level. The coefficient of determination (r^2) of this equation shows that the haul distance explained 48.7% of the variation in travel time empty. The reader is cautioned that this regression equation can not be used to predict travel time empty beyond the range of hauling distances used to fit this equation.

4.1.4 Travel Time Loaded

Table 5 and 6 summarize the travel time loaded expressed in hours for each trip for diesel-powered trucks and gasoline-powered trucks respectively. The velocity loaded (km/hr) for each trip has been computed with this original data to compare both types of truck. The minimum, maximum, and average velocity loaded of each truck type can also be observed in the tables indicated above. The test concerning means ($H_o:\mu_1-\mu_2=0$) of this variable (Appendix 3) indicates that the average velocity loaded of diesel-powered trucks is not significantly different from the average velocity loaded of gasoline-powered trucks. Therefore, the average velocity loaded for the mixed fleet was computed (Table 7). A summary of velocity loaded for the trucks under comparison is shown in Table 11.

Table 11. Summary of Velocity loaded for diesel-powered trucks and gasoline-powered trucks.

Number of observations	54
Minimum velocity loaded (km/hr)	6.00
Maximum velocity loaded (km/hr)	8.93
Average velocity loaded (km/hr)	7.42
Sample standard deviation (s)	0.7533

Source: Data extracted from Table 7.

Travel time loaded on each segment of road class was not possible to recognize on the servis record chart either. However, the data obtained when the trip was ridden revealed no significant difference in velocity loaded (km) between the different road classes.

A high positive correlation ($r=0.7838$) was found between travel time loaded (hr) and one-way hauling distance (km). The simple linear regression analysis of travel time loaded on hauling distance indicated that the following equation may be used to predict travel time loaded (hr) on the basis of one-way hauling distance (km).

$$Y = 0.1436 + 0.1299\ X$$

where: Y = predicted value of travel time loaded in hours

X = one-way hauling distance in kilometres

The analysis of variance for this regression is shown in Appendix 3. The F test indicates that the calculated F (82.8575) is greater than the $F_{0.05}$ critical (4.03) with 1,52 degrees of freedom; therefore the computed regression equation is significant at the 0.05 probability level. The coefficient of determination for this equation shows that the haul distance explained 61.4% of the variation in travel time loaded. The reader is cautioned that this regression equation cannot be used to predict travel time loaded beyond the range of hauling distances used to fit this equation.

The low truck speed either empty or loaded found during the time study, reveals that the existing forest roads require upgrading. Trucks should develop average round trip speed above 15 km/hr, if the main and secondary forest road are built following the design specifications given by Frisk

(1979). In contrast, the flatbed trucks evaluated performed at a very low average round trip speed (8.64 km/hr).

4.1.5 Delay

Total delay time (hr) for each round trip can be observed in Table 5 and 6 for diesel-powered trucks and gasoline-powered trucks respectively. In order to compare the delay time of both types of truck, the original data were expressed as a percentage of the total productive time (loading, unloading, and travelling) of the truck cycle.

The test concerning means ($H_o:\mu_1-\mu_2=0$) of the delay time expressed as percentage of the productive time (Appendix 3) indicates that there is no significant differences in delay time between either type of truck. Consequently, the delay times of the 54 round trips recorded were used to calculate the average delay time for the entire truck fleet (Table 7). It can be observed in Table 7 that the minimum delay time recorded was 0.60 hours (36 minutes) when the hauling distance (one way) was 19.50 km. On the other hand, the maximum delay time recorded was 5.55 hours when the hauling distance was 26.50 km. Table 12 summarizes the delay time for the entire fleet. This table shows that an average delay of 31.73% of the total productive time of the truck cycle has been found for both types of truck.

Positive but low correlation has been found between delay time (hours) and hauling distance, travel time empty, travel time loaded, loading time, and unloading time. A detailed delay analysis (duration, cause, and location) for each truck type was not possible in this study. Although the delay time can be identified by the type of trace on the chart, the cause of the delay in only a few instances was indicated by the truck drivers. However, the author had the opportunity to ride the trucks on some trips and record the cause, location and time of the delay during the hauling cycle by using the survey form shown in Appendix 1.

Table 12. Summary of delay time (expressed as percentage of productive time of the truck cycle) for the entire truck fleet.

Number of observations	54
Minimum delay (%)	9.12
Maximum delay (%)	75.44
Average delay (%)	31.73
Sample standard deviation (s)	14.23

Source: Data extracted from Table 7.

The main delay causes observed in these trips were the following. According to the policy of the forest company which cooperated in this study, each truck driver during the empty travel must transport gravel and rock to maintain the running surface of the main and the secondary forest roads. The gravel was loaded manually with shovels (Figure 12) from a gravel pit located along the main road (km 9+250). It was observed that this operation took between 20 and 35 minutes to perform. The gravel was unloaded by dumping it in the mudholes and wheel ruts of the road (Figure 13). The unloading operation took between 10 and 23 minutes to accomplish.

Other main sources of delay observed in order of importance were the following: road inspection, truck stuck, truck mechanical breakdown, truck run out of fuel, road blocked, waiting for supervisor's instructions, and truck driver's personal time. An average of 25 minutes (0.42 hours) for the truck driver's food and rest was observed during these trips.

4.1.6 Payload

The number of logs, volume, and weight of the payload for each trip are displayed in Table 5 and Table 6 for diesel-powered and gasoline-powered trucks respectively. The payload of the trucks under comparison is summarized in Table 13. This Table shows that the average payload is 7.43 m^3 and 6.49 m^3 for diesel and gasoline-powered trucks respectively.

Table 13. Summary of the payload by truck type.

	Diesel-powered trucks	Gasoline-powered trucks
Number of observations	25	29
Minimum number of logs	4	3
Minimum payload volume (m^3)	4.95	4.66
Maximum payload volume (m^3)	12.2	9.07
Average payload volume (m^3)	7.43	6.49
Minimum payload weight (kg)	4260	3740
Maximum payload weight (kg)	9950	7660
Average payload weight (kg)	6310	5768.6

Source: Data extracted from Table 5 and Table 6

FIGURE 12. Loading gravel and rock manually.

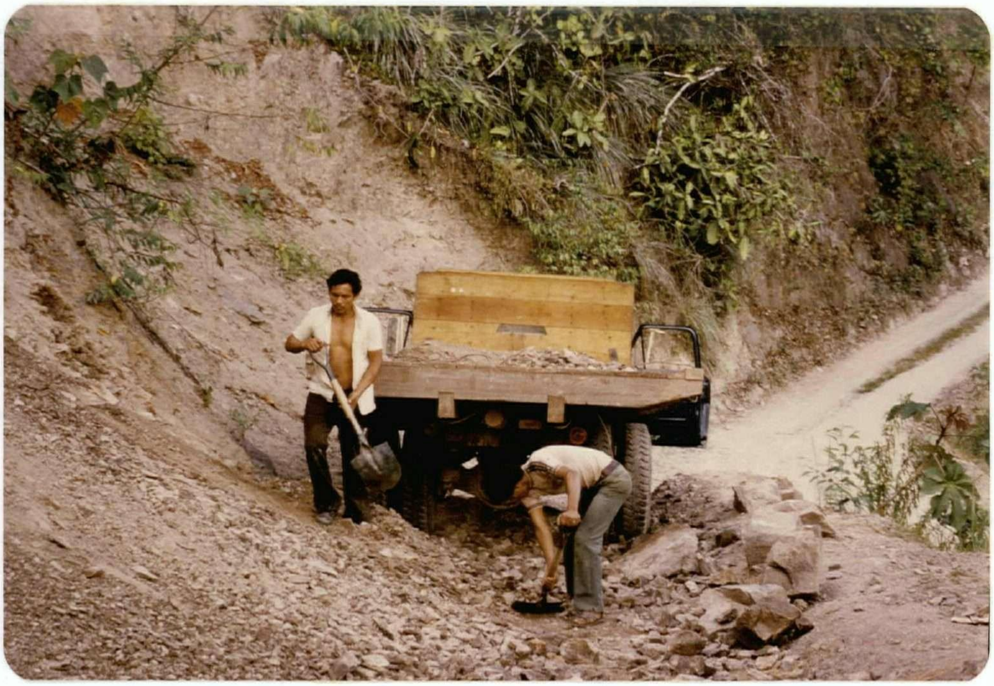


FIGURE 13. Filling in potholes with gravel and rock.

The test concerning means ($H_o:\mu_1-\mu_2=0$) of the payload (Appendix 3) shows that the payload either expressed in volume (m^3) or expressed in weight (kg) of diesel-powered trucks is significantly different from the payload of gasoline-powered trucks.

The average payload weights displayed in Table 13, reveal that flatbed trucks travelled with payload size below their full capacity. This situation happened as a result of lack of knowledge of the unit log weight of the forest species harvested plus the presence of mudholes and ruts on the forest roads of the haul route. Table 5 also shows that only in a few instances the diesel-powered trucks were overloaded. On the contrary, Table 6 shows that gasoline-powered trucks never were overloaded.

4.2 Truck Productivity and Cost

4.2.1 Estimated Truck Cycle Time

In order to predict truck productivity and cost, an estimate of the cycle time was made. Average values of loading time, unloading time, truck velocity empty, truck velocity loaded, and delay time obtained from the actual survey data were used to calculate the total cycle time for both type of trucks under comparison, for the hypothetical common haul route (one way) of 26 km. Table 14 summarizes the total cycle time for diesel-powered trucks and gasoline-powered trucks.

Table 14 demonstrates that delay time is the second largest component after the travelling loaded time. In contrast, the unloading time is the minor element during the truck cycle. Figure 14 generated with data of Table 14 shows the average truck cycle time by element time expressed in percentage. Table 14 shows that the standing time of the trucks is 4.94 hours per round trip, and the trucks spend 6.02 hours travelling the one-way haul route of 26 km. From Figure 15 it can be appreciated that the travelling time (empty and loaded) represents 54.9% of the total cycle time, meanwhile the standing time (loading, unloading, and delay) represents 45.1% of the total cycle time.

Table 14. Estimated cycle time for a 26 km one-way haul for diesel-powered trucks and gasoline-powered trucks.

ELEMENT	TIME PER TRIP (hr)
Travelling - empty	2.52
loading	1.98
Travelling - loaded	3.50
Unloading	0.32
Delay[1]	2.64
Total cycle time	10.96
Paid hours per cycle[2]	10.54

On the other hand, in Table 7 it can be observed that a minimum cycle time of 6.42 hours was obtained for a hauling distance of 19.50 km; and the maximum cycle time was

1 Based on an average delay of 31.73% of productive time obtained from the sample data.

2 Driver's food and rest break of 25 minutes (0.42 hours) was excluded from the total cycle time because this time is not considered paid time.

FIGURE 14. AVERAGE TRUCK CYCLE TIME
for Diesel and Gasoline-powered Trucks

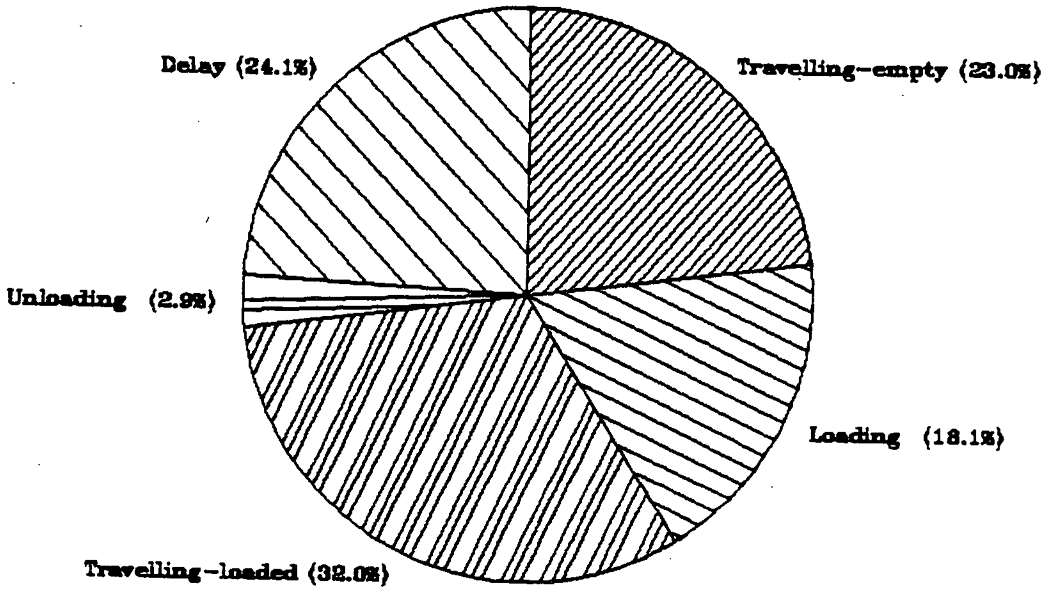
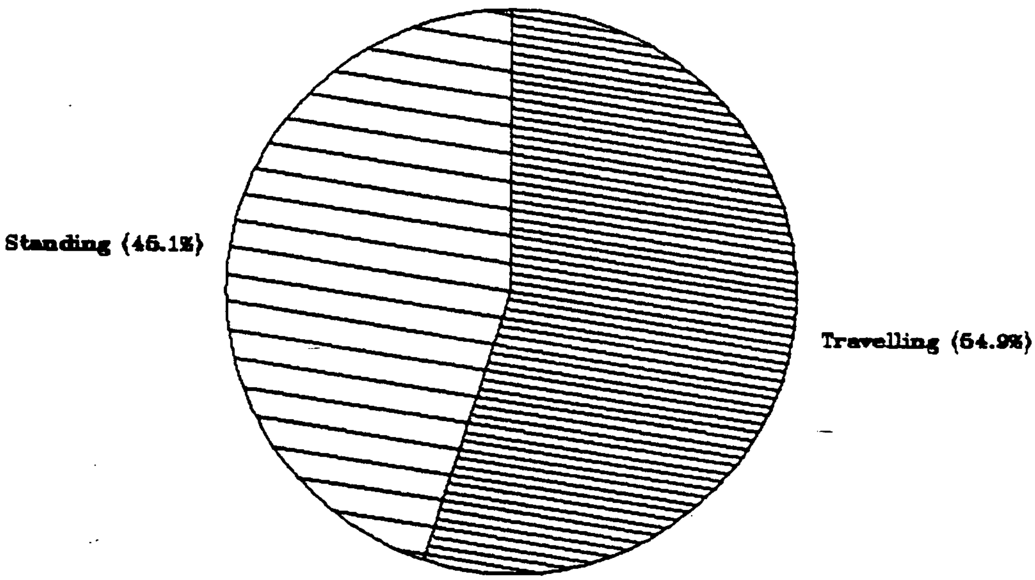


FIGURE 15. Average cycle time expressed as standing and travelling time.



13.83 hours for a hauling distance of 26.50 km. The author observed during the field work of this study that trucks which hauled from cutting area 1 could make two round trips per day on many occasions; but trucks which hauled from cutting area 2 and 3 could only make one round trip per day.

4.2.2 Daily and Annual Production

Considering the average of 160 round trips per year obtained for both types of truck, and considering the average payload (m^3) for each trip for each type of truck, the annual volume which might be hauled with the flatbed trucks analysed was estimated for the hypothetical one-way haul route of 26 km. From the average cycle time obtained in Table 14, it is apparent that the trucks under comparison can make only one round trip per day for the hauling distance indicated above. The productivity of the flatbed trucks analysed is given in Table 15.

4.2.3 Fleet Size

A fleet size of 9.46 and 10.83 for diesel-powered and gasoline-powered trucks respectively was obtained for Belho Horizonte S.C.R. Ltd. sawmill, which hauls 11,250 m^3 of sawlogs per year, considering the annual volume (m^3) which might be hauled with each type truck for the hypothetical one-way haul distance of 26 km.

Table 15. Truck productivity by truck type for a 26-km one-way haul distance.

	Diesel-powered truck	Gasoline-powered truck
Number of trips per day	1	1
Annual truck trips	160	160
Average volume hauled/trip (m^3)	7.43	6.49
Annual volume hauled (m^3)	1189	1038

4.2.4 Truck Cost Estimate and Haul Cost

Economic and physical data obtained during the field work of this study[3] which are summarized in Table 16, were used to estimate costs per in-use hour and per travelling hour for each truck type. The results are shown in Table 17. Finally, haul cost was estimated by each truck type, again based on the hypothetical haul distance of 26 km. The haul cost per trip and per cubic metre for both types of trucks under comparison is summarized in Table 18 and Table 19.

The trip cost breakdown in Table 18 for diesel-powered trucks indicates the dominance of four costs: depreciation, interest, fuel and tires. It can be shown that the main items (depreciation and interest) can be expected to decrease significantly by reducing the standing time per trip in this type of truck.

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3 All the cost parameters are expressed in current dollars of August 1985. An exchange rate of 1 Canadian $ = 9,975.25 Peruvian soles reported by Banco Central de Reserva del Peru for August 1985, was used to express in Canadian dollars the original cost data obtained in Peruvian soles.

Table 16. Hauling cost parameters.

Parameter	Truck Type: Diesel-powered	Truck Type: Gasoline-powered
Initial purchase price of truck ($)	54505	14640
Ownership period in years	8	4
Resale value factor (% purchase price excluding tires)	15	10
Truck salvage value ($)	7586.25	1071
Initial cost of truck's flatbed ($)	570	570
Expected flatbed life (years)	3	3
Opportunity interest rate (%)	12	12
Number of trips per year	160	160
In-use hours per year	1686	1686
Fuel price ($/litre)	0.4300	0.4967
Fuel consumption (km/litre)	1.1449	0.7632
Oil and lubrication cost ($/hour)	0.28	0.32
Oil price ($/litre)	2.44	2.44
Tire price ($/tire)	655	655
Number of tires on truck	6	6
Life of a set of tires in travelling hours	900	900
Life repair cost of a set of tires ($)	200	200
Truck repair and maintenance cost ($/hour)	1.56	1.48
Initial cost of manual winch ($)	600	600
Manual winch life (years)	3	3
Manual winch repair and maintenance cost ($/hour)	0.06	0.06
Hauling distance (km)	26	26
Empty speed (km/hour)	10.33	10.33
Loaded speed (km/hour)	7.42	7.42
Round trip average speed (km/hour)	8.64	8.64
Time required for loading (hour)	1.98	1.98
Time required for unloading (hour)	0.32	0.32
Delay time (% of productive time)	31.73	31.73
Truck driver wage ($/trip)	8.02	8.02
Helper wage ($/trip)	3.01	3.01
Fringe benefits (% of direct wages)	30	30
Average payload (kg)	6310	5768.62
Average payload (m3)	7.43	6.49
Travelling hours per year	963	963
Standing hours per year	723	723

Table 17. Summary of truck costs.

A. Fixed cost per In-use hour ($)

COST FACTOR	TRUCK TYPE			
	Diesel-powered		Gasoline-powered	
Depreciation		3.71		2.24
Truck	3.48		2.01	
Flatbed + Manual winch	0.23		0.23	
Interest		2.47		0.74
Truck	2.41		0.68	
Flatbed + Manual winch	0.06		0.06	
Operating labour(Driver&helper)		1.36		1.36
Wages	1.05		1.05	
Fringes	0.31		0.31	
SUBTOTAL		7.54		4.34

B. Variable cost per travelling hour ($)

COST FACTOR	TRUCK TYPE			
	Diesel-powered		Gasoline-powered	
Fuel		3.24		5.62
Oil and Lubrication		0.28		0.32
Tires		4.08		3.57
Repair and Maintenance		1.62		1.54
Truck	1.56		1.48	
Manual winch	0.06		0.06	
SUBTOTAL		9.22		11.05

Table 18. Estimated haul cost for diesel-powered trucks for 26 km one-way haul distance.

FACTOR	COST ($/hr)	HOURS	TOTAL	$/m3	%
In-use costs:					
Depreciation	3.71	10.54	39.10	5.26	29
Interest	2.47	10.54	26.07	3.51	20
Wages & Fringe	1.36	10.54	14.34	1.93	11
Travelling costs:					
Fuel	3.24	6.02	19.53	2.63	14
Oil & Lubrication	0.28	6.02	1.69	0.23	1
Tires	4.08	6.02	24.55	3.30	18
Repair & Maintenance	1.62	6.02	9.75	1.31	7
Total cost per trip ($):			135.02		
Haul cost/m³ ($):				18.17	

Table 19. Estimated haul cost for gasoline-powered trucks for 26 km one-way haul distance.

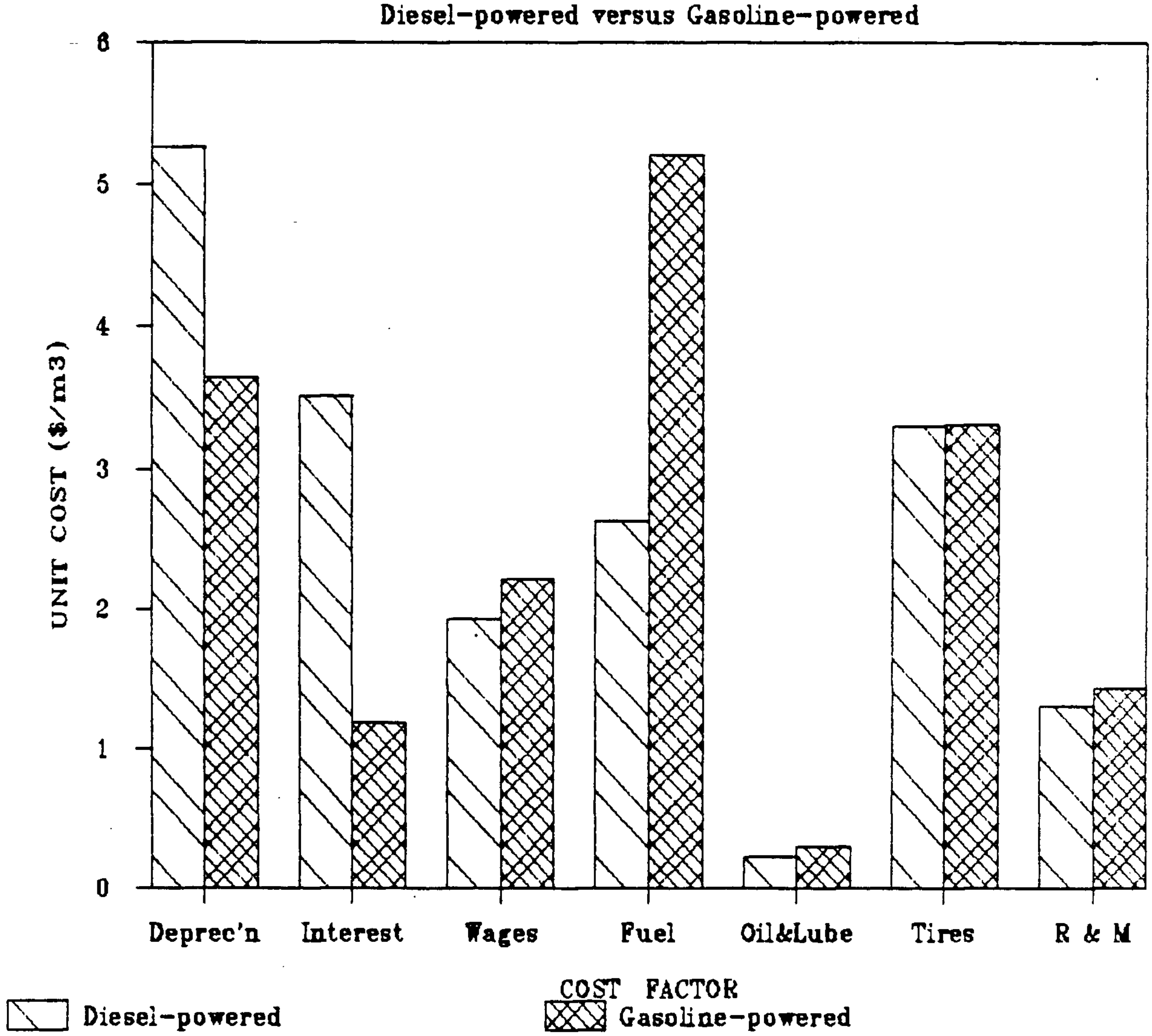
FACTOR	COST ($/hr)	HOURS	TOTAL	$/m3	%
In-use costs:					
Depreciation	2.24	10.54	23.64	3.64	21
Interest	0.74	10.54	7.75	1.19	7
Wages & Fringe	1.36	10.54	14.34	2.21	13
Travelling costs:					
Fuel	5.62	6.02	33.84	5.21	30
Oil & Lubrication	0.32	6.02	1.93	0.30	2
Tires	3.57	6.02	21.48	3.31	19
Repair & Maintenance	1.54	6.02	9.27	1.43	8
Total cost per trip ($):			112.24		
Haul cost/m³ ($):				17.29	

The trip cost breakdown in Table 19 for gasoline-powered trucks reveals the dominance of three costs: fuel, depreciation, and tires. It is apparent that the haul cost cannot be expected to decrease significantly by reducing the standing time per trip, because the main cost factor in this type of truck is fuel.

Table 18 and Table 19 reveal that the cost of hauling logs with gasoline-powered trucks ($17.29/m^3$) is less than with diesel-powered trucks ($18.17/m^3$) for the hypothetical one-way haul route of 26 km. Figure 16 constructed with data of Table 18 and 19 shows the haul cost comparison by cost factors between both types of truck. It can be observed that the higher depreciation and interest cost of diesel-powered trucks counterbalance their advantage of lower fuel cost.

The hauling cost of $17.29/m^3$ or $18.17/m^3$ with flatbed trucks obtained for the short haul distance of 26 km, is extremely expensive if it is compared with haul cost obtained with logging trucks in British Columbia, Canada. For example, in the interior of British Columbia, a haul cost of $13.01/m^3$ with 5 axle-standard pole trailer has been reported by Smith (1981), for a haul route of 261 km (one way). Of this route, 229 km was dual-lane all-weather road (highway) and 32 km was 1 1/2- lane low standard rural access road.

FIGURE 16. HAULING COST COMPARISON



4.3 Analysis of the Haul Route

Considering that travel time and haul cost are affected by road surface, gradient, curvature, road width, etc; in this hauling study, certain design specifications of the existing haul route were collected and analysed. Three road classes were identified in the haul route (Figure 3): public road, main forest road and secondary forest road.

4.3.1 Public Road

One kilometre of "Marginal" public highway was used as part of the main haul road. This short segment of public road runs through the Pichanaki town and has dense traffic. The "Marginal" highway is a double-lane road, and a gravelled road of high speed design. But, because only a short segment of this public road is used and it runs through a town, the travel speed of the trucks analysed was not significantly different than in the forest roads. The design specifications of this short length of public road are as follows: subgrade width, 9.0 m; running surface width, 7.0 m; maximum grade, 3%; and crown, 4%.

4.3.2 Forest Roads

Forest roads built by the Belho Horizonte S.C.R. Ltd. sawmill may be classified in two broad categories with regard to their function: main and secondary road.

Main Road

The main forest road used for the flatbed trucks in this hauling study was a single-lane, undrained dirt road of 19.50 km. This main road may be classified as a permanent road because it is planned to be maintained for traffic for at least 10 years. A traffic density of at least seven log trucks per day was observed in this road. However, the total traffic density that this road supports is higher because it is also used by local farmers to transport their farm crops. This main road is used only during dry periods, as it is unuseable during the rainy season. Therefore, it can also be classified as a "Summer road" (Stenzel et al., 1985).

Secondary Road

The secondary road classification consisted of branch and spur roads. The branch roads connected the spur with the main road, and the spur roads were short roads to landings. The secondary roads surveyed were single-lane, dirt, and undrained roads. They are temporary roads, and usually are abandoned when the area has been logged. A traffic density of 2 or 3 log trucks per day was observed in the branch roads.

All forest roads in the Central Region of Peru like the forest roads evaluated in this study are built by the private forest company with crawler tractor bulldozers.

4.3.3 Forest Roads Design Specifications

In order to know the design characteristics of the forest roads where the hauling operation took place, representative segments of main and secondary road were surveyed. With the field data collected a plan at a scale of 1:1000, and a profile with 1:1500 horizontal scale, and 1:300 vertical scale were drawn. Profile and Plan views of some of the segments surveyed are shown in Appendix 4. The reader is cautioned that the original graphs with the scale indicated above have been reduced by 64%. Table 20 summarizes the field observations collected regarding road grade and curvature in the main and the secondary road.

<u>Road grade</u>

Table 20 reveals that a maximum favorable grade of 16 and 17.5% has been found in the main road and secondary road respectively. The profile of the segments of road Main3 and Sec3C in Appendix 4 show that the highest values of favorable grade is found in long distances. Garland (1983b) indicates that favorable grades may reach 12 to 15% for short distances; and Henrich (1976) recommended in his proposed road classification system for forest operations in tropical high forest, maximum favorable grades of 10 and 12% in steep and difficult terrain for main and secondary road respectively.

Table 20. Summary of curvature and gradient of forest roads sampled.

Road class	Road sample code	Length of road sampled(m)	Max. grade(%)		Curve	
			Favor.	Adverse	#	Radius (m)
	Main1	100	2	4	-	--
	Main2	130	13	-	1	40
Main road	Main3	450	16	-	5	20,35,35,8,25
	Main4	200	12	2	3	20,25,13
	Main5	300	3	6	-	--
	Main6	150	11	10	3	10,20,20
	Main7	150	2	13	3	30,15,30
	Sec1	200	16	--	1	5
	Sec2A	230	--	13	2	35,35
	Sec2B	150	--	12	3	25,35,35
Secondary road	Sec2C	110	9	--	1	10
	Sec3A	170	14	-	2	25,25
	Sec3B	135	14	-	4	25,25,8,15
	Sec3C	200	17.5	-	3	35,30,10
	Sec3D	230	13	4	1	35
Total		2,905				

On the other hand, the highest adverse grade found on the forest roads surveyed was 13% in the main road and in the secondary road. The profiles of the segments of road Main7 and Sec2B, where these highest values of adverse grade have been found, can be observed in Appendix 4. Garland (1983b) and Haussman and Pruett (1973) indicate that adverse grade should be kept below 10%; and Henrich (1976) recommends maximum adverse grade of 8 to 10% for main and secondary road respectively. As can be observed in Table 20, some sections of the forest road surveyed show steeper favorable grade and a little steeper adverse grade than the recommended grade values by the authors indicated above.

Curves

Table 20 shows that most of the road segments surveyed have an abundance of curves, and some of them are very sharp. As it can be observed in this table, the following road segments present very sharp curves: Main3, Main4, Main6, Main7, Sec1, Sec2c, Sec3b, and Sec3c. The radius of each curve was measured in the plan view of the section of road surveyed with a plastic curve templet with a radius at the plan view scale. Plan views of some of the segments of road surveyed, which are given in Appendix 4 show the number of curves in each section and their corresponding curvature. It is apparent in Table 20 that the minimum curve recommended by Frisk (1979) of 30 and 15 metres for curves in the main and secondary road respectively, are not met in many cases. Conway (1982) explains that an abundance of curves on a road slows down traffic, and on single-lane roads with short-radius curves, round-trip time is increased and driving can be hazardous. Besides, Garland (1983b) recommends moderate grades, not greater than 7% in sharp curves.

Road width

Many representative cross sections of each road class were also surveyed. The data collected is summarized as follows:

Road class	Subgrade width (m)	Surface width (m)
Main road	4.50 - 6.50	3.00 - 3.60
Secondary road	4.00 - 5.00	2.90 - 3.20

By comparing these road surface width values with the proposed by Frisk (1979), it can be realized that the surveyed roads are narrow. The author observed that many sections of road in steep terrain were built in full cut with cut slope between 1:0.60 and 1:1 in the main road; and cut slope between 1:0.30 and 1:0.80 in the secondary road. Furthermore, irregular interval of turn-out points constructed in the main forest road, and in the branch roads was also observed.

Road drainage

The surveyed forest roads were without proper drainage structures. Main and secondary roads were built without a crown, ditches, and culverts, which are needed to intercept, collect and remove surface and subsurface runoff from the roads. An adequate drainage system in the construction of any road must be made not only for passage of surface of water from adjacent slopes, but also for rapid drainage of the road bed itself to keep the road in good, serviceable condition (Haussman and Pruett, 1973). Garland (1983b) recommends the design crowned roads with ditches and frequent cross drains in an area of frequent and intense precipitation to drain rainfall off the road quickly.

Many sections of the main road were observed to have severe drainage problems such as mudholes and ruts as a consequence of a lack of a drainage system to prevent water saturation of the road surface and road subgrade. Figure 17,

FIGURE 17. Main forest road without drainage system.

FIGURE 18. Main forest road with mudholes and ruts.

and Figure 18 illustrate sections of main road with drainage problems. Fewer drainage problems in the secondary road were observed as a result of low traffic density and temporary use. Roads broken with chuckholes and ruts force a driver to slow down, and trucks travelling fully loaded on such roads will have higher truck maintenance cost and less production (Conway, 1982).

The design specifications regarding crown, ditches and culverts proposed by Frisk (1979) are not met in the forest roads where the hauling operation took place.

Bridges

Two log bridges with concrete abutments were observed in the main forest road. Guardrails, and shear logs, and proper decking with crossties and planking could improve these bridges. Lack of maintenance of the bridge decking in one of them was noted. Figure 19 shows a log bridge of 10 metres span with concrete abutments over the "Cuyani" river.

Road surface

The main and the secondary road of the haul route evaluated may be classified as dirt road, because only short sections of road with drainage problems were gravelled. However, Frisk (1979) recommends gravelled surface road in the case of the main road. Since natural gravel is available, the main forest road should be gravelled in order to make it permanently open to traffic.

4.3.4 Road Maintenance

Poor maintenance of the forest roads has been observed during the field work of this truck hauling study. As stated in Section 4.1.5 of this chapter, truck drivers must transport rock and gravel on the flatbed of the truck during the empty return trip. Basically, the maintenance of the roads is reduced to fill in the mudholes and ruts with gravel and rock, which are accomplished manually by the truck driver and his helper. Lack of control of overhanging brush, as well brush obstructing visibility on curves in many sections of the main road was also observed. It is well known that too much roadside vegetation creates visibility and safety problems and delays drying of the road surface.

The owner of Belho Horizonte S.C.R. Ltd. company indicated that road grading of the main road is done once a year with bulldozer, but the potholes and ruts are eliminated for only a short time by this activity. According to Stenzel et al.(1985), mudholes in a road are a problem that cannot be eliminated merely by dumping rock in the holes. Mudholes can be repaired most effectively by draining the hole, removing the mud, and filling the hole with high-quality material. Moreover, mudholes occur primarily as a result of poor drainage; therefore, correcting deficiencies in the drainage system oftentimes eliminates the problem.

The physical characteristics of the existing forest roads reveals that they did not have proper planning, design, construction and maintenance. Therefore, the existing road conditions had an adverse effect on log hauling productivity and cost.

FIGURE 19. Log bridge with concrete abutments.

4.4 Sensitivity Analysis

As stated in Section 3.2.4 Chapter 3, a computerized hauling cost model to operate on an IBM PC microcomputer was developed to carry out the sensitivity analysis. The model uses the Symphony spreadsheet development system. It is designed to calculate the average cycle time, the number of trips per year, and the haul cost per trip and per cubic metre for a given one-way haul distance (km) and for a given flatbed truck.

The model was developed in a manner which allows the sensitivity analysis to be accomplished by using the Symphony's "Sheet Range What-if" command (Ewing and LeBlond, 1984). The effects on the cycle time and the haul cost can be explored by altering factors such as truck average round trip speed, loading time, delay time, and haul distance. The effects of varying truck ownership period, in-use hours per year, and payload per trip on the haul cost were also evaluated.

4.4.1 Sensitivity Analysis of Truck Cycle Time

In Section 4.2.1, an average cycle time of 10.96 hours for a haul distance (one way) of 26 km was obtained. A maximum truck cycle time of 6.50 hours for a one-way hauling distance of 26 km must be obtained to allow the trucks to make at least 2 round trips per day.

The effect on the cycle time of increasing the average round trip speed of 8.64 km/hr (obtained from the time study) up to 30 km/hr, and reduction of the average delay time (2.64 hr) from 10 to 80% can be observed in Table 21. This table shows that trucks can start reaching a cycle time of 6.50 hr when the average round trip speed is increased to 15 km/hr and the delay time is reduced by 80% (0.53 hr). Maximum cycle time of 6.50 hr can also be obtained with greater speed than 15 km/hr with less reduction of delay time. Finally, this table shows that even if the round trip could be increased to 30 km/hr, a cycle time of 6.50 hr cannot be reached by the trucks without a reduction in delay time.

The effect on the cycle time of increasing average round trip speed and decreasing the average loading time (1.98 hr) by 10 to 80% are displayed in Table 22. This table reveals that trucks can attain a maximum cycle time of 6.50 hr when the average round trip speed is increased to 17 km/hr and when the loading time is reduced by 80%. Maximum cycle time of 6.50 hr can also be obtained with less reduction of loading time but with higher speeds than 17 km/hr. In addition, in Table 22 can be observed that without reducing the loading time, the cycle time of 6.50 hr cannot be reached despite the round trip speed being increased to 30 km/hr.

The effect of decreasing delay time and loading time on the cycle time can be observed in Table 23. This table shows that although the loading and delay time could be reduced by 80%, the truck cycle time can never be lower than 7.26 hr.

Which means that by only reducing loading and delay time, trucks cannot be expected to make 2 round trips per day in a shift of 13 hours.

Based on the results obtained in Tables 21, 22, and 23, the effects of decreasing delay and loading time on the cycle time when the average round trip speed could be increased up to 12 and 15 km/hr respectively were examined. Table 24 shows that if the average round trip speed is increased to 12 km/hr, a cycle time of 6.50 hr could be obtained by reducing the delay time in the range between 50 to 80% ,and by reducing the loading time in the range between 80 to 40% respectively. Table 25 shows that trucks can obtain a cycle time of 6.50 hr in many combinations of reduction of delay and loading time, if the average round trip speed is increased to 15 km/hr.

The impact of hauling distance and loading time on truck cycle time when the average round trip speed could be increased to 15 km/hr or 30 km/hr, and the delay time could be reduced to 1.00 hr (reduction of 62%) was also examined in Table 26 and Table 27. Table 26 reveals that under the assumed conditions of speed and delay, when the one-way haul distance is not greater than 30 km, trucks could make two round trips per day in many cases by reducing loading time by at least 40%. This table also reveals that even if the loading time could be reduced by 80%, trucks cannot be expected to perform two round trips per day when the hauling distance is greater than 35 km.

On the other hand, Table 27 shows that trucks can make 2 round trips for a hauling distance of 45 km inclusive without any reduction of the loading time. By reducing the delay of at least 60%, trucks could perform 2 round trips for a hauling distance of 65 km. Finally, it can be observed that for a hauling distance greater than 75 km, trucks could only make one round trip per day; but cycle time of less than 10.0 hours could be obtained for a hauling distance of 100 km, inclusive without reducing the loading time.

Table 21. Impact of average round trip speed and delay time on truck cycle time.

	Cycle Time (hr)								
	Delay Time (hr)								
Avg.Speed (km/hr)	-0% 2.64	-10% 2.38	-20% 2.11	-30% 1.85	-40% 1.58	-50% 1.32	-60% 1.06	-70% 0.79	-80% 0.53
8.64	10.96	10.69	10.43	10.17	9.90	9.64	9.37	9.11	8.85
10.00	10.14	9.88	9.61	9.35	9.08	8.82	8.56	8.29	8.03
11.00	9.67	9.40	9.14	8.88	8.61	8.35	8.08	7.82	7.56
12.00	9.27	9.01	8.75	8.48	8.22	7.95	7.69	7.43	7.16
13.00	8.94	8.68	8.41	8.15	7.88	7.62	7.36	7.09	6.83
14.00	8.65	8.39	8.13	7.86	7.60	7.33	7.07	6.81	6.54
15.00	8.41	8.14	7.88	7.61	7.35	7.09	6.82	6.56	6.29
16.00	8.19	7.93	7.66	7.40	7.13	6.87	6.61	6.34	6.08
17.00	8.00	7.73	7.47	7.21	6.94	6.68	6.41	6.15	5.89
18.00	7.83	7.56	7.30	7.04	6.77	6.51	6.24	5.98	5.72
19.00	7.68	7.41	7.15	6.88	6.62	6.36	6.09	5.83	5.56
20.00	7.54	7.28	7.01	6.75	6.48	6.22	5.96	5.69	5.43
21.00	7.42	7.15	6.89	6.62	6.36	6.10	5.83	5.57	5.30
22.00	7.30	7.04	6.78	6.51	6.25	5.98	5.72	5.46	5.19
23.00	7.20	6.94	6.67	6.41	6.14	5.88	5.62	5.35	5.09
24.00	7.11	6.84	6.58	6.31	6.05	5.79	5.52	5.26	4.99
25.00	7.02	6.76	6.49	6.23	5.96	5.70	5.44	5.17	4.91
26.00	6.94	6.68	6.41	6.15	5.88	5.62	5.36	5.09	4.83
27.00	6.87	6.60	6.34	6.07	5.81	5.55	5.28	5.02	4.75
28.00	6.80	6.53	6.27	6.01	5.74	5.48	5.21	4.95	4.69
29.00	6.73	6.47	6.21	5.94	5.68	5.41	5.15	4.89	4.62
30.00	6.67	6.41	6.15	5.88	5.62	5.35	5.09	4.83	4.56

Table 22. Impact of average round trip speed and loading time on truck cycle time.

	Cycle time (hr)								
	Loading Time (hrs)								
Avg.Speed	-0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
(km/hr)	1.98	1.78	1.58	1.39	1.19	0.99	0.79	0.59	0.40
8.64	10.96	10.76	10.56	10.36	10.17	9.97	9.77	9.57	9.37
10.00	10.14	9.94	9.74	9.55	9.35	9.15	8.95	8.75	8.56
11.00	9.67	9.47	9.27	9.07	8.88	8.68	8.48	8.28	8.08
12.00	9.27	9.08	8.88	8.68	8.48	8.28	8.09	7.89	7.69
13.00	8.94	8.74	8.54	8.35	8.15	7.95	7.75	7.55	7.36
14.00	8.65	8.46	8.26	8.06	7.86	7.66	7.47	7.27	7.07
15.00	8.41	8.21	8.01	7.81	7.61	7.42	7.22	7.02	6.82
16.00	8.19	7.99	7.79	7.60	7.40	7.20	7.00	6.80	6.61
17.00	8.00	7.80	7.60	7.40	7.21	7.01	6.81	6.61	6.41
18.00	7.83	7.63	7.43	7.23	7.04	6.84	6.64	6.44	6.24
19.00	7.68	7.48	7.28	7.08	6.88	6.69	6.49	6.29	6.09
20.00	7.54	7.34	7.14	6.95	6.75	6.55	6.35	6.15	5.96
21.00	7.42	7.22	7.02	6.82	6.62	6.43	6.23	6.03	5.83
22.00	7.30	7.11	6.91	6.71	6.51	6.31	6.12	5.92	5.72
23.00	7.20	7.00	6.80	6.61	6.41	6.21	6.01	5.81	5.62
24.00	7.11	6.91	6.71	6.51	6.31	6.12	5.92	5.72	5.52
25.00	7.02	6.82	6.62	6.43	6.23	6.03	5.83	5.63	5.44
26.00	6.94	6.74	6.54	6.35	6.15	5.95	5.75	5.55	5.36
27.00	6.87	6.67	6.47	6.27	6.07	5.88	5.68	5.48	5.28
28.00	6.80	6.60	6.40	6.20	6.01	5.81	5.61	5.41	5.21
29.00	6.73	6.54	6.34	6.14	5.94	5.74	5.55	5.35	5.15
30.00	6.67	6.48	6.28	6.08	5.88	5.68	5.49	5.29	5.09

Table 23. Impact of loading and delay time on truck cycle time.

	Cycle time (hr)								
	Delay Time (hr)								
Loading Time	-0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
(hr)	2.64	2.38	2.11	1.85	1.58	1.32	1.06	0.79	0.53
1.98	10.96	10.69	10.43	10.17	9.90	9.64	9.37	9.11	8.85
1.78	10.76	10.50	10.23	9.97	9.70	9.44	9.18	8.91	8.65
1.58	10.56	10.30	10.03	9.77	9.51	9.24	8.98	8.71	8.45
1.39	10.36	10.10	9.84	9.57	9.31	9.04	8.78	8.52	8.25
1.19	10.17	9.90	9.64	9.37	9.11	8.85	8.58	8.32	8.05
0.99	9.97	9.70	9.44	9.18	8.91	8.65	8.38	8.12	7.86
0.79	9.77	9.51	9.24	8.98	8.71	8.45	8.19	7.92	7.66
0.59	9.57	9.31	9.04	8.78	8.52	8.25	7.99	7.72	7.46
0.40	9.37	9.11	8.85	8.58	8.32	8.05	7.79	7.53	7.26

Table 24. Impact of loading and delay time on truck cycle time when the average round trip speed is increased to 12 km/hr.

	Cycle Time (hr)								
	Delay Time (hr)								
Loading Time	-0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
(hr)	2.64	2.38	2.11	1.85	1.58	1.32	1.06	0.79	0.53
1.98	9.27	9.01	8.75	8.48	8.22	7.95	7.69	7.43	7.16
1.78	9.08	8.81	8.55	8.28	8.02	7.76	7.49	7.23	6.96
1.58	8.88	8.61	8.35	8.09	7.82	7.56	7.29	7.03	6.77
1.39	8.68	8.42	8.15	7.89	7.62	7.36	7.10	6.83	6.57
1.19	8.48	8.22	7.95	7.69	7.43	7.16	6.90	6.63	6.37
0.99	8.28	8.02	7.76	7.49	7.23	6.96	6.70	6.44	6.17
0.79	8.09	7.82	7.56	7.29	7.03	6.77	6.50	6.24	5.97
0.59	7.89	7.62	7.36	7.10	6.83	6.57	6.30	6.04	5.78
0.40	7.69	7.43	7.16	6.90	6.63	6.37	6.11	5.84	5.58

Table 25. Impact of delay and loading time on truck cycle time when the average round trip speed is increased to 15 km/hr.

	Cycle Time (hr)								
	Delay Time (hr)								
Loading Time	-0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
(hr)	2.64	2.38	2.11	1.85	1.58	1.32	1.06	0.79	0.53
1.98	8.41	8.14	7.88	7.61	7.35	7.09	6.82	6.56	6.29
1.78	8.21	7.94	7.68	7.42	7.15	6.89	6.62	6.36	6.10
1.58	8.01	7.75	7.48	7.22	6.95	6.69	6.43	6.16	5.90
1.39	7.81	7.55	7.28	7.02	6.76	6.49	6.23	5.96	5.70
1.19	7.61	7.35	7.09	6.82	6.56	6.29	6.03	5.77	5.50
0.99	7.42	7.15	6.89	6.62	6.36	6.10	5.83	5.57	5.30
0.79	7.22	6.95	6.69	6.43	6.16	5.90	5.63	5.37	5.11
0.59	7.02	6.76	6.49	6.23	5.96	5.70	5.44	5.17	4.91
0.40	6.82	6.56	6.29	6.03	5.77	5.50	5.24	4.97	4.71

Table 26. Impact of hauling distance and loading time on truck cycle time when the average round trip speed is increased to 15 km/hr and delay is reduced to 1.00 hr.

Hauling Distance (km)	Cycle Time (hr)								
	Loading Time (hr)								
	-0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
	1.98	1.78	1.58	1.39	1.19	0.99	0.79	0.59	0.40
20	5.97	5.77	5.57	5.37	5.17	4.98	4.78	4.58	4.38
25	6.63	6.44	6.24	6.04	5.84	5.64	5.45	5.25	5.05
30	7.30	7.10	6.90	6.71	6.51	6.31	6.11	5.91	5.72
35	7.97	7.77	7.57	7.37	7.17	6.98	6.78	6.58	6.38
40	8.63	8.44	8.24	8.04	7.84	7.64	7.45	7.25	7.05
45	9.30	9.10	8.90	8.71	8.51	8.31	8.11	7.91	7.72
50	9.97	9.77	9.57	9.37	9.17	8.98	8.78	8.58	8.38
55	10.63	10.44	10.24	10.04	9.84	9.64	9.45	9.25	9.05
60	11.30	11.10	10.90	10.71	10.51	10.31	10.11	9.91	9.72
65	11.97	11.77	11.57	11.37	11.17	10.98	10.78	10.58	10.38
70	12.63	12.44	12.24	12.04	11.84	11.64	11.45	11.25	11.05
75	13.30	13.10	12.90	12.71	12.51	12.31	12.11	11.91	11.72
80	13.97	13.77	13.57	13.37	13.17	12.98	12.78	12.58	12.38
85	14.63	14.44	14.24	14.04	13.84	13.64	13.45	13.25	13.05
90	15.30	15.10	14.90	14.71	14.51	14.31	14.11	13.91	13.72
95	15.97	15.77	15.57	15.37	15.17	14.98	14.78	14.58	14.38
100	16.63	16.44	16.24	16.04	15.84	15.64	15.45	15.25	15.05

Table 27. Impact of hauling distance and loading time on truck cycle time when the average round trip speed is increased to 30 km/hr and delay is reduced to 1.00 hr.

Hauling Distance (km)	Cycle Time (hr)								
	Loading Time (hr)								
	-0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
	1.98	1.78	1.58	1.39	1.19	0.99	0.79	0.59	0.40
20	4.63	4.44	4.24	4.04	3.84	3.64	3.45	3.25	3.05
25	4.97	4.77	4.57	4.37	4.17	3.98	3.78	3.58	3.38
30	5.30	5.10	4.90	4.71	4.51	4.31	4.11	3.91	3.72
35	5.63	5.44	5.24	5.04	4.84	4.64	4.45	4.25	4.05
40	5.97	5.77	5.57	5.37	5.17	4.98	4.78	4.58	4.38
45	6.30	6.10	5.90	5.71	5.51	5.31	5.11	4.91	4.72
50	6.63	6.44	6.24	6.04	5.84	5.64	5.45	5.25	5.05
55	6.97	6.77	6.57	6.37	6.17	5.98	5.78	5.58	5.38
60	7.30	7.10	6.90	6.71	6.51	6.31	6.11	5.91	5.72
65	7.63	7.44	7.24	7.04	6.84	6.64	6.45	6.25	6.05
70	7.97	7.77	7.57	7.37	7.17	6.98	6.78	6.58	6.38
75	8.30	8.10	7.90	7.71	7.51	7.31	7.11	6.91	6.72
80	8.63	8.44	8.24	8.04	7.84	7.64	7.45	7.25	7.05
85	8.97	8.77	8.57	8.37	8.17	7.98	7.78	7.58	7.38
90	9.30	9.10	8.90	8.71	8.51	8.31	8.11	7.91	7.72
95	9.63	9.44	9.24	9.04	8.84	8.64	8.45	8.25	8.05
100	9.97	9.77	9.57	9.37	9.17	8.98	8.78	8.58	8.38

4.4.2 Sensitivity Analysis of Hauling Cost

A sensitivity analysis was conducted to evaluate the impact on the haul cost of changes of the following main factors that may be controllable to some extent by the logging company: vehicle ownership period, annual in-use time, hauling distance, payload per trip, delay time, loading time, and average round trip speed.

Ownership period

Table 28 summarizes the hauling cost for the assumed common haul distance (one way) of 26 km for different ownership period for diesel and gasoline-powered trucks. In this study, ownnership of 8 and 4 years were assumed for diesel and gasoline-powered trucks respectively. Table 28 shows that by increasing the ownership period from 8 to 12 years for diesel-powered trucks, a cost saving of 8.48% could be obtained. In contrast, by increasing the ownership period from 4 to 8 years of gasoline-powered trucks, a cost saving of 7.23% could be obtained. However, the maintenance and repair cost are expected to rise as the vehicles get old. Therefore, only minimum real cost savings could be expected by retaining the same vehicle for a greater number of years.

Annual operating hours

Increasing annual operating hours amortizes fixed costs over a greater annual production period. Hauling cost for additional annual operating hours than the estimated average of 1686 hours was examined for both types of truck. Table 29 shows how the haul costs change if the flatbed trucks evaluated could work additional annual in-use hours, but under the actual operating conditions. Table 29 reveals that an increase of 25% of the average annual operating hours (1686 hr/yr) could represent a modest cost savings of 9 and 4% for diesel and gasoline-powered trucks respectively.

Table 28. Impact of truck ownership period on haul cost.

	Hauling cost ($/m³)	
Ownership period (years)	Diesel-powered truck	Gasoline-powered truck
2	--	19.81
3	22.46	18.13
4	21.16	17.29
5	20.16	16.76
6	19.38	16.46
7	18.74	16.22
8	18.17	16.04
9	17.71	--
10	17.31	--
11	16.94	--
12	16.63	--

Table 29. Impact of annual operating hours on haul cost.

		Hauling cost ($/m³)	
Annual operating hours	Trips per year	Diesel-powered truck	Gasoline-powered truck
1476	140	19.36	17.85
1581	150	18.73	17.55
1686	160	18.17	17.29
1792	170	17.68	17.06
1897	180	17.24	16.86
2002	190	16.85	16.68
2108	200	16.50	16.52

Average round trip speed

An average round trip speed of 8.64 km/hr was obtained from data collected in the time study for both types of truck under comparison. The effect of increasing this average speed up to 30 km/hr was analysed. Table 30 gives the hauling cost for both types of truck for increased average speed.

Table 30. Impact of average round trip speed on haul cost.

	Hauling cost ($\$/m^3$)	
Average round trip speed (km/hr)	Diesel-powered truck	Gasoline-powered truck
8.64	18.17	17.29
10.00	16.81	16.18
12.00	15.36	15.00
14.00	14.33	14.15
16.00	13.56	13.52
18.00	12.96	13.03
20.00	12.48	12.64
22.00	12.08	12.31
24.00	11.75	12.05
26.00	11.48	11.82
28.00	11.24	11.62
30.00	11.03	11.45

Table 30 shows that by increasing the average round trip speed from 8.64 up to 14 km/hr a cost saving of 21 and 18% could be obtained in diesel and gasoline-powered trucks respectively. In this Table also shows that by increasing the average speed beyond 18 km/hr the cost reduction drops significantly.

Loading time

The effect of reducing loading time from 10 to 80% on the hauling cost is given in Table 31. This table shows that by a drastic reduction of the loading time by 80%, a modest cost saving of 7 and 3% could be obtained in diesel-powered and gasoline-powered trucks respectively.

Table 31. Impact of loading time on hauling cost.

		Hauling cost ($/m³)	
Loading time (hr)		Diesel-powered truck	Gasoline-powered truck
1.98		18.17	17.29
1.78	(-10%)	18.01	17.22
1.58	(-20%)	17.85	17.15
1.39	(-30%)	17.70	17.08
1.19	(-40%)	17.55	17.00
0.99	(-50%)	17.39	16.93
0.79	(-60%)	17.23	16.86
0.59	(-70%)	17.07	16.78
0.40	(-80%)	16.92	16.71

Delay time

The impact of a 10 to 80% reduction in delays on the haul cost was also evaluated. Hauling cost by truck type for decreasing delay time is given in Table 32.

Table 32 illustrates that by eliminating 80% of the average delay time, the hauling cost could be reduced by 9 and 4% in diesel and gasoline-powered trucks respectively.

Haul distance and payload

The effect on the haul cost of increasing haul distance and increasing payload per trip was also evaluated. Table 33 and Table 34 illustrate how the hauling cost of diesel and gasoline-powered trucks respectively, could change if hauling distance and payload increased.

Table 33 shows that for a given one-way haul distance, the haul cost of diesel-powered trucks could be reduced by 17% by increasing the average payload per trip from 7.43 to 9.0 m^3. On the contrary, Table 34 shows that for any given one-way haul distance a reduction of 28% of the haul cost of gasoline-powered trucks could be reached by increasing the payload from 6.49 to 9.0 m^3. Finally, Table 33 and 34 illustrate that an extremely high hauling cost not lower than $54.0/$m^3$ is expected for a haul distance of 100 km with both types of truck, if the existing operating conditions are maintained.

Table 32. Impact of delay time on hauling cost.

	Hauling cost ($/$m^3$)	
Delay time (hr)	Diesel-powered truck	Gasoline-powered truck
2.64	18.17	17.29
2.38 (-10%)	17.97	17.20
2.11 (-20%)	17.75	17.10
1.85 (-30%)	17.55	17.00
1.58 (-40%)	17.33	16.90
1.32 (-50%)	17.13	16.81
1.06 (-60%)	16.92	16.71
0.79 (-70%)	16.71	16.61
0.53 (-80%)	16.50	16.52

<u>Effect of round trip speed, delay, and loading time on haul cost</u>

The sensitivity analysis of the cycle time and the hauling cost have revealed that some factors directly controllable by the logging company, such as average round trip speed, loading time, and delay time, have great influence on the truck productivity and haul cost. Based on these results, a sensitivity analysis was carried out to evaluate the joint effect of increasing average speed, and reducing delay and loading time.

Table 33. Impact of haul distance and payload on haul cost of diesel-powered trucks.

Hauling Distance (km)	Hauling cost ($/m3) Payload (m3) 7.43	7.50	8.00	8.50	9.00	9.50
10	10.38	10.29	9.64	9.08	8.57	8.12
15	12.82	12.70	11.90	11.20	10.58	10.02
20	15.25	15.11	14.16	13.33	12.59	11.93
25	17.69	17.52	16.43	15.46	14.60	13.83
30	20.12	19.93	18.69	17.59	16.61	15.74
35	22.55	22.34	20.95	19.71	18.62	17.64
40	24.99	24.75	23.21	21.84	20.63	19.54
45	27.42	27.17	25.47	23.97	22.64	21.45
50	29.86	29.58	27.73	26.10	24.65	23.35
55	32.29	31.99	29.99	28.23	26.66	25.25
60	34.72	34.40	32.25	30.35	28.67	27.16
65	37.16	36.81	34.51	32.48	30.68	29.06
70	39.59	39.22	36.77	34.61	32.69	30.97
75	42.03	41.63	39.03	36.74	34.70	32.87
80	44.46	44.05	41.29	38.86	36.71	34.77
85	46.90	46.46	43.55	40.99	38.71	36.68
90	49.33	48.87	45.81	43.12	40.72	38.58
95	51.76	51.28	48.08	45.25	42.73	40.48
100	54.20	53.69	50.34	47.38	44.74	42.39

Table 34. Impact of hauling distance and payload on haul cost of gasoline-powered trucks.

Hauling Distance (km)	Hauling cost ($/m3) Payload (m3) 6.49	7.00	7.50	8.00	8.50	9.00
10	9.04	8.38	7.82	7.33	6.90	6.52
15	11.62	10.77	10.05	9.43	8.87	8.38
20	14.20	13.16	12.29	11.52	10.84	10.24
25	16.78	15.56	14.52	13.61	12.81	12.10
30	19.36	17.95	16.75	15.70	14.78	13.96
35	21.94	20.34	18.98	17.80	16.75	15.82
40	24.52	22.73	21.22	19.89	18.72	17.68
45	27.10	25.13	23.45	21.98	20.69	19.54
50	29.68	27.52	25.68	24.08	22.66	21.40
55	32.26	29.91	27.92	26.17	24.63	23.26
60	34.84	32.30	30.15	28.26	26.60	25.12
65	37.42	34.69	32.38	30.36	28.57	26.98
70	40.00	37.09	34.61	32.45	30.54	28.84
75	42.58	39.48	36.85	34.54	32.51	30.71
80	45.16	41.87	39.08	36.64	34.48	32.57
85	47.74	44.26	41.31	38.73	36.45	34.43
90	50.32	46.65	43.54	40.82	38.42	36.29
95	52.90	49.05	45.78	42.92	40.39	38.15
100	55.48	51.44	48.01	45.01	42.36	40.01

The author assumes that the average round trip of 8.64 km/hr of the flatbed trucks evaluated could be increased significantly by improving the existing road standard. The actual road standard of the forest roads could be upgraded by performing the following activities:

- reshaping the road bed and providing a crown
- installing culverts and ditches where needed
- improving the horizontal and vertical alignment where possible
- maintaining properly the forest road

It can be assumed that trucks could perform round trip average speed of 12 or 15 km/hr if the activities indicated above are accomplished.

The average loading time of 1.98 hr could also be reduced significantly by changing the loading method. Since a drastic reduction of 80% in the loading time could represent only a modest saving of 7% in the case of the more expensive truck (diesel-powered), the author believes that the use of a very expensive loading machine such as a front-end loader cannot be justified at this stage. The home-made jammer which is used in the yarding operation could be considered to perform the loading operation in reduced time.

Ogle (1982) indicates that a shop-built cable crane mounted on flatbed Ford which is used to yard and load, can load flatbed trucks in approximately 30 minutes, in a Mexican logging operation. Besides, Corvanich (1979) in his report of logging operations in Thailand points out that a local-made crane truck requires 45 minutes to load a log truck of 12,000 kg payload capacity. Based on these reports, the time required to load a flatbed truck with a home-made jammer is assumed to be 45 minutes.

On the other hand, it is assumed that the forest roads with proper drainage system and proper maintenance will be free of mudholes and ruts, and the gravel required to surface the road or to stabilize the subgrade must be hauled with dump trucks. The author assumes that delay due to loading and unloading gravel, truck stuck, and road reconnaissance, and waiting for logs, can be eliminated. Delay due to mechanical problems can also be reduced if preventive maintenance of the trucks could be implemented. Under these circumstances, only certain delays would remain, such as minor mechanical problems, warm up time, fueling, truck driver's food breaks, personnel time, etc. It is estimated that the average delay time could be reduced by at least 62%, which means that a maximum delay time of 1.00 hour per trip could be expected.

A sensitivity analysis was conducted to evaluate the effect on the hauling cost of the following proposed alternatives:

Factor	Alternative No.1	Alternative No.2
Average round trip speed (km/hr)	12	15
Loading time (hr)	0.75	0.75
Delay (hr)	1.00	1.00

Table 35 and Table 36 show the effect of increasing the travel speed, and reducing delay and loading time on truck productivity and haul cost of diesel and gasoline-powered trucks respectively.

Table 35 shows that in the case of diesel-powered trucks, by increasing the average speed to 12 or 15 km/hr, and reducing the delay and loading time by 62%, a large reduction between 27.96 and 35.94% in the hauling cost could be obtained. On the other hand, Table 36 shows that in the case of gasoline-powered trucks, a reduction of the hauling cost of 19.38 and 26.20% may be expected for alternative No.1 and alternative No.2 respectively. Finally, Tables 35 and 36 show that hauling logs with diesel-powered trucks could be cheaper than with gasoline-powered trucks in both proposed alternatives.

Table 35. Analytical illustration of the effects of varying average round trip speed, delay and loading time on productivity and haul cost of diesel-powered trucks.

	Existing conditions	Alternative No.1	Alternative No.2
Average cycle time (hr)	10.96	6.40	5.5
Number of trips per year	160	282	330
Volume hauled per trip (m^3)	7.43	7.43	7.43
Volume hauled per year (m^3)	1,189	2,095	2,452
Depreciation ($/$m^3$)	5.26	2.99	2.55
Interest ($/$m^3$)	3.51	1.99	1.70
Wages and Fringe ($/$m^3$)	1.93	1.93	1.93
Fuel ($/$m^3$)	2.63	2.63	2.63
Oil and lubrication ($/$m^3$)	0.23	0.16	0.13
Tires ($/$m^3$)	3.30	2.44	1.94
Repair and Maintenance($/$m^3$)	1.31	0.94	0.76
Haul cost ($/$m^3$)	18.17	13.09	11.64

Figure 20 and Figure 21 generated with data of Table 35 and Table 36 respectively, illustrate the effects of varying average round trip speed, delay and loading time on haul cost components of diesel and gasoline-powered trucks. Figure 20 and 21 reveal that a substantial cost saving of depreciation, interest, and tires, is expected in the most costly truck (diesel-powered). Finally, these figures indicate that great cost saving of tires could be obtained under the operating conditions proposed in alternatives No.1 and No.2.

Table 36. Analytical illustration of the effects of varying average round trip speed, delay and loading time on productivity and haul cost of gasoline-powered trucks.

	Existing conditions	Alternative No.1	Alternative No.2
Average cycle time (hr)	10.96	6.40	5.54
Number of trips per year	160	282	330
Volume hauled per trip (m^3)	6.49	6.49	6.49
Volume hauled per year (m^3)	1,038	1,830	2,142
Depreciation ($/$m^3$)	3.64	2.07	1.77
Interest ($/$m^3$)	1.19	0.68	0.58
Wages and Fringe ($/$m^3$)	2.21	2.21	2.21
Fuel ($/$m^3$)	5.21	5.21	5.21
Oil and Lubrication ($/$m^3$)	0.30	0.21	0.17
Tires ($/$m^3$)	3.31	2.53	1.99
Repair and maintenance ($/$m^3$)	1.43	1.03	0.82
Haul cost ($/$m^3$)	17.29	13.94	12.76

It can also be assumed that flatbed trucks travelling over forest roads with smooth surfaces (free of mudholes and ruts), can haul near their full payload capacity. The effect of increasing haul distance and payload per trip was analyzed for diesel and gasoline-powered trucks under the operating conditions proposed in Alternative 1 and 2. Tables 37, 38, 39,and 40 summarizes the results of this analysis.

By comparing hauling cost obtained for diesel-powered trucks in Table 33, 37, and 38, for any given hauling distance, it is apparent that a cost saving between 40 to 46.92% could be reached by increasing the payload from 7.43 to 9.0 m3 per trip in alternative 1 and 2 respectively.

FIGURE 20. HAULING COST COMPARISON

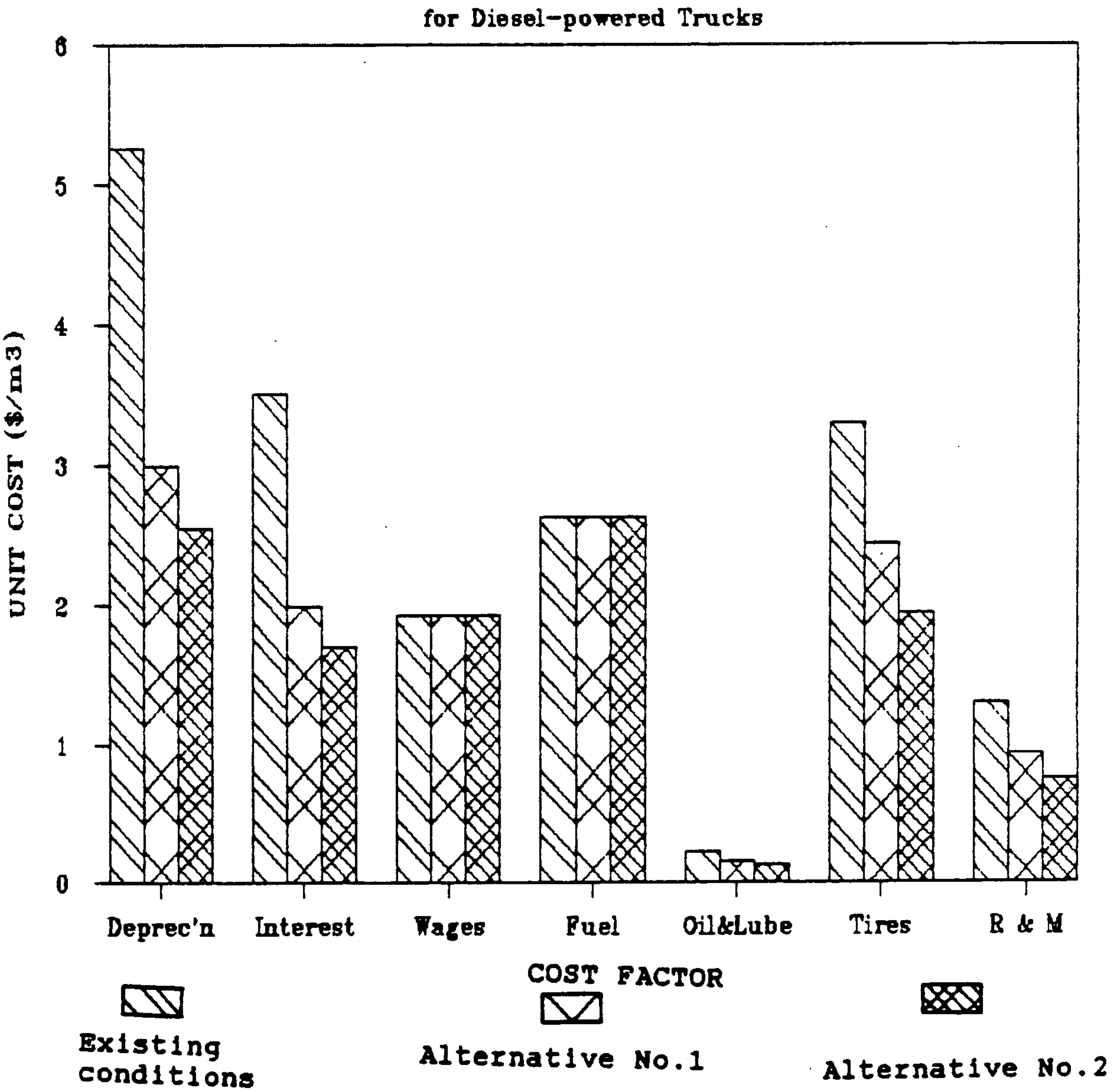


FIGURE 21. HAULING COST COMPARISON

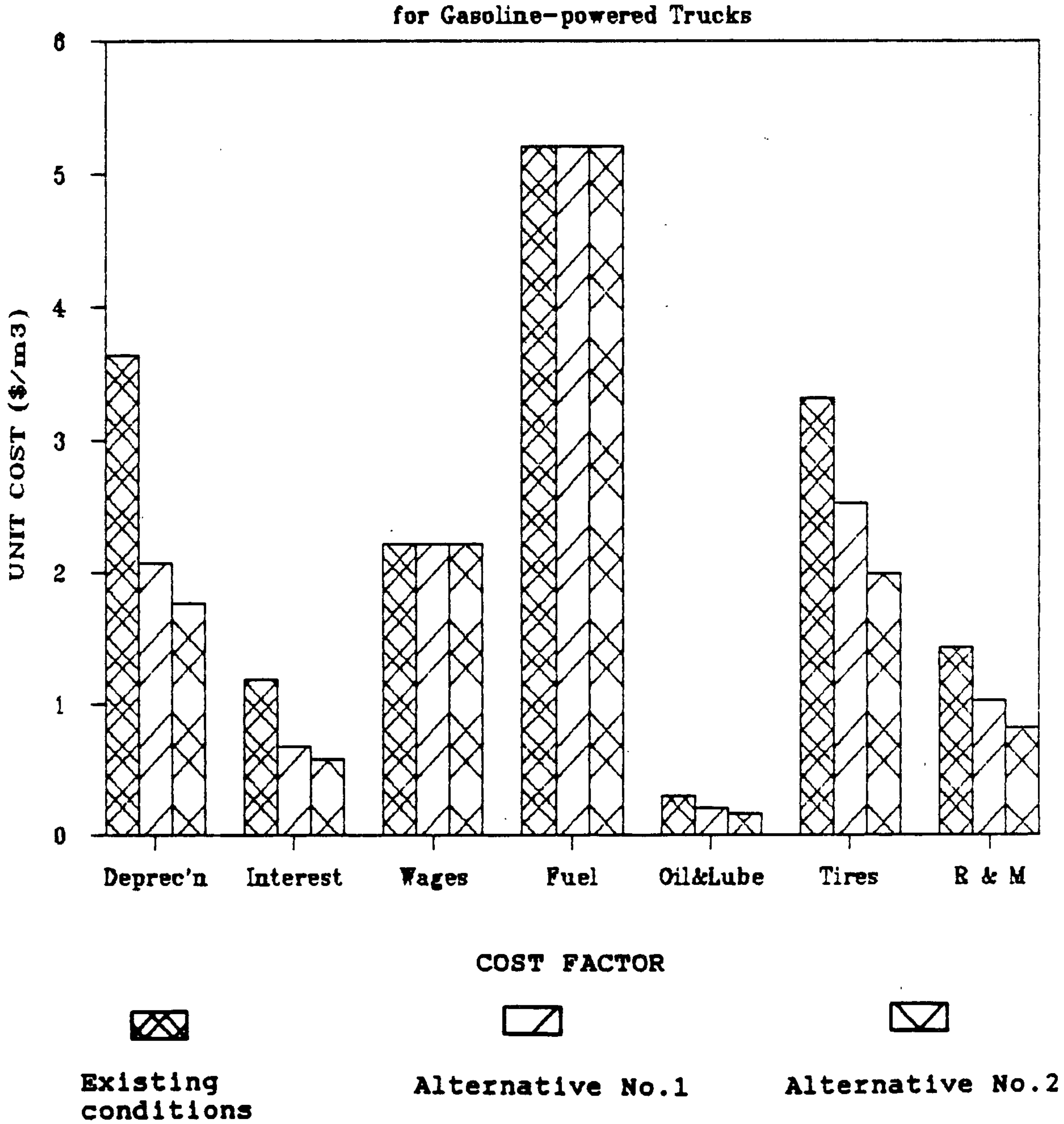


Table 38. Impact of hauling distance and payload on haul cost under Alternative No.2 of diesel-powered trucks.

Hauling Distance (km)	Hauling Cost ($/m3) Payload (m3) 7.43	7.50	8.00	8.50	9.00	9.50
10	6.47	6.41	6.01	5.66	5.34	5.06
15	8.09	8.01	7.51	7.07	6.68	6.33
20	9.70	9.61	9.01	8.48	8.01	7.59
25	11.32	11.21	10.51	9.90	9.35	8.85
30	12.94	12.82	12.02	11.31	10.68	10.12
35	14.55	14.42	13.52	12.72	12.01	11.38
40	16.17	16.02	15.02	14.13	13.35	12.65
45	17.79	17.62	16.52	15.55	14.68	13.91
50	19.40	19.22	18.02	16.96	16.02	15.17
55	21.02	20.82	19.52	18.37	17.35	16.44
60	22.64	22.42	21.02	19.79	18.69	17.70
65	24.25	24.03	22.52	21.20	20.02	18.97
70	25.87	25.63	24.03	22.61	21.36	20.23
75	27.48	27.23	25.53	24.02	22.69	21.50
80	29.10	28.83	27.03	25.44	24.02	22.76
85	30.72	30.43	28.53	26.85	25.36	24.02
90	32.33	32.03	30.03	28.26	26.69	25.29
95	33.95	33.63	31.53	29.68	28.03	26.55
100	35.57	35.23	33.03	31.09	29.36	27.82

Table 37. Impact of hauling distance and payload on haul cost under Alternative No.1 for diesel-powered trucks.

Hauling Distance (km)	Hauling Cost ($/m3) Payload (m3) 7.43	7.50	8.00	8.50	9.00	9.50
10	7.03	6.96	6.53	6.14	5.80	5.50
15	8.92	8.84	8.29	7.80	7.36	6.98
20	10.82	10.71	10.04	9.45	8.93	8.46
25	12.71	12.59	11.80	11.11	10.49	9.94
30	14.60	14.47	13.56	12.77	12.06	11.42
35	16.50	16.34	15.32	14.42	13.62	12.90
40	18.39	18.22	17.08	16.08	15.18	14.38
45	20.29	20.10	18.84	17.73	16.75	15.87
50	22.18	21.97	20.60	19.39	18.31	17.35
55	24.07	23.85	22.36	21.04	19.87	18.83
60	25.97	25.73	24.12	22.70	21.44	20.31
65	27.86	27.60	25.88	24.35	23.00	21.79
70	29.76	29.48	27.64	26.01	24.57	23.27
75	31.65	31.36	29.40	27.67	26.13	24.75
80	33.54	33.23	31.15	29.32	27.69	26.24
85	35.44	35.11	32.91	30.98	29.26	27.72
90	37.33	36.98	34.67	32.63	30.82	29.20
95	39.23	38.86	36.43	34.29	32.38	30.68
100	41.12	40.74	38.19	35.94	33.95	32.16

Table 40. Impact of hauling distance and payload on haul cost under Alternative No.2 of gasoline-powered trucks.

Hauling Distance (km)	Hauling Cost ($/m3) Payload (m3) 6.49	7.00	7.50	8.00	8.50	9.00
10	6.64	6.16	5.75	5.39	5.07	4.79
15	8.55	7.93	7.40	6.94	6.53	6.17
20	10.46	9.70	9.05	8.49	7.99	7.55
25	12.38	11.47	10.71	10.04	9.45	8.92
30	14.29	13.25	12.36	11.59	10.91	10.30
35	16.20	15.02	14.02	13.14	12.37	11.68
40	18.11	16.79	15.67	14.69	13.83	13.06
45	20.02	18.56	17.32	16.24	15.29	14.44
50	21.93	20.33	18.98	17.79	16.75	15.82
55	23.84	22.11	20.63	19.34	18.21	17.19
60	25.75	23.88	22.29	20.89	19.66	18.57
65	27.67	25.65	23.94	22.44	21.12	19.95
70	29.58	27.42	25.59	23.99	22.58	21.33
75	31.49	29.19	27.25	25.55	24.04	22.71
80	33.40	30.97	28.90	27.10	25.50	24.09
85	35.31	32.74	30.56	28.65	26.96	25.46
90	37.22	34.51	32.21	30.20	28.42	26.84
95	39.13	36.28	33.86	31.75	29.88	28.22
100	41.05	38.06	35.52	33.30	31.34	29.60

Table 39. Impact of hauling distance and payload on haul cost under Alternative No.1 of gasoline-powered trucks.

Hauling Distance (km)	Hauling Cost ($/m3) Payload (m3) 6.49	7.00	7.50	8.00	8.50	9.00
10	7.10	6.58	6.14	5.76	5.42	5.12
15	9.23	8.56	7.99	7.49	7.05	6.66
20	11.37	10.54	9.84	9.23	8.68	8.20
25	13.51	12.53	11.69	10.96	10.32	9.74
30	15.65	14.51	13.54	12.70	11.95	11.29
35	17.79	16.49	15.39	14.43	13.58	12.83
40	19.93	18.47	17.24	16.17	15.21	14.37
45	22.06	20.46	19.09	17.90	16.85	15.91
50	24.20	22.44	20.94	19.64	18.48	17.45
55	26.34	24.42	22.79	21.37	20.11	19.00
60	28.48	26.41	24.65	23.10	21.75	20.54
65	30.62	28.39	26.50	24.84	23.38	22.08
70	32.76	30.37	28.35	26.57	25.01	23.62
75	34.90	32.35	30.20	28.31	26.64	25.16
80	37.03	34.34	32.05	30.04	28.28	26.71
85	39.17	36.32	33.90	31.78	29.91	28.25
90	41.31	38.30	35.75	33.51	31.54	29.79
95	43.45	40.28	37.60	35.25	33.18	31.33
100	45.59	42.27	39.45	36.98	34.81	32.87

Figure 22 generated with data from Tables 33, 37, and 38 illustrates a truck cost comparison of diesel-powered trucks, for the existing operating conditions, and proposed alternatives, for increasing hauling distance, but maintaining all the other factors constant.

4.5 Break-even Analysis

Hauling cost as a standing cost per unit volume to cover loading, unloading and delay time, plus a travelling cost per unit volume per unit hauling distance were calculated for both types of trucks under comparison, to determine the break-even distance at which the total hauling cost ($/m3) of both alternatives are equal. In this analysis, standing costs comprise depreciation, interest, operator wages and fringe benefits. While travelling costs comprise the three items indicated above together with fuel, oil and lubrication, tires, and repair and maintenance (McNally, 1974, 1975). Standing and travelling costs were calculated with truck cost estimate data reported in Section 4.2.3 of this Chapter, and they are shown in Table 41 and Table 42.

From the results obtained in Table 41 and 42, the hauling cost per unit volume of each type of truck analysed in this study can be expressed as:

a) Diesel-powered trucks

$$\text{Hauling cost } (\$/m^3) = \$4.59 + (\$0.5224 * HD)$$

b) Gasoline-powered trucks

Hauling cost ($\$/m^3$) = \$3.02 + (\$0.5490 * HD)

Where: HD = one-way hauling distance in kilometres

Table 41. Estimated hauling cost as a standing and travelling cost for diesel-powered trucks.

Item	Standing	Travelling	Total
One-way hauling distance (km)	---	26	26
Hours per trip	4.52	6.02	10.54
Cost: per hour	7.54	16.77	---
per trip	34.10	100.92	135.02
per m^3	4.59	13.58	18.17
per m^3-km	---	0.5224	---

Table 42. Estimated hauling cost as a standing and travelling cost for gasoline-powered trucks.

Item	Standing	Travelling	Total
One-way hauling distance (km)	---	26	26
Hours per trip	4.52	6.02	10.54
Cost: per hour	4.34	15.39	---
per trip	19.61	92.63	112.24
per m^3	3.02	14.27	17.29
per m^3-km	---	0.5490	---

The standing cost ($\$/m^3$) of 4.59 or 3.02 is fixed regardless of hauling distance as long as the standing time (loading, unloading, and delay) of 4.52 hours per trip can be maintained; while the travelling cost ($\$/m^3$-km) of 0.5490 or 0.5224 is expected to decrease in inverse proportion to travelling speed; which means by upgrading the forest roads the travelling cost can be reduced significantly (McNally, 1974).

By applying the formula given in Section 3.2.5, Chapter 3, the break-even point was calculated as follows:

$$X = (4.59-3.02)/(0.5490-0.5224) = 59.0 \text{ km}$$

Where: X = break-even distance in km

The break-even analysis is illustrated in Figure 23. This figure shows that below the equal point (59 km) hauling logs with gasoline-powered trucks is cheaper than with diesel-powered trucks. Above this point the reverse is true.

FIGURE 22. Hauling cost comparison for diesel-powered trucks: existing conditions versus proposed alternatives.

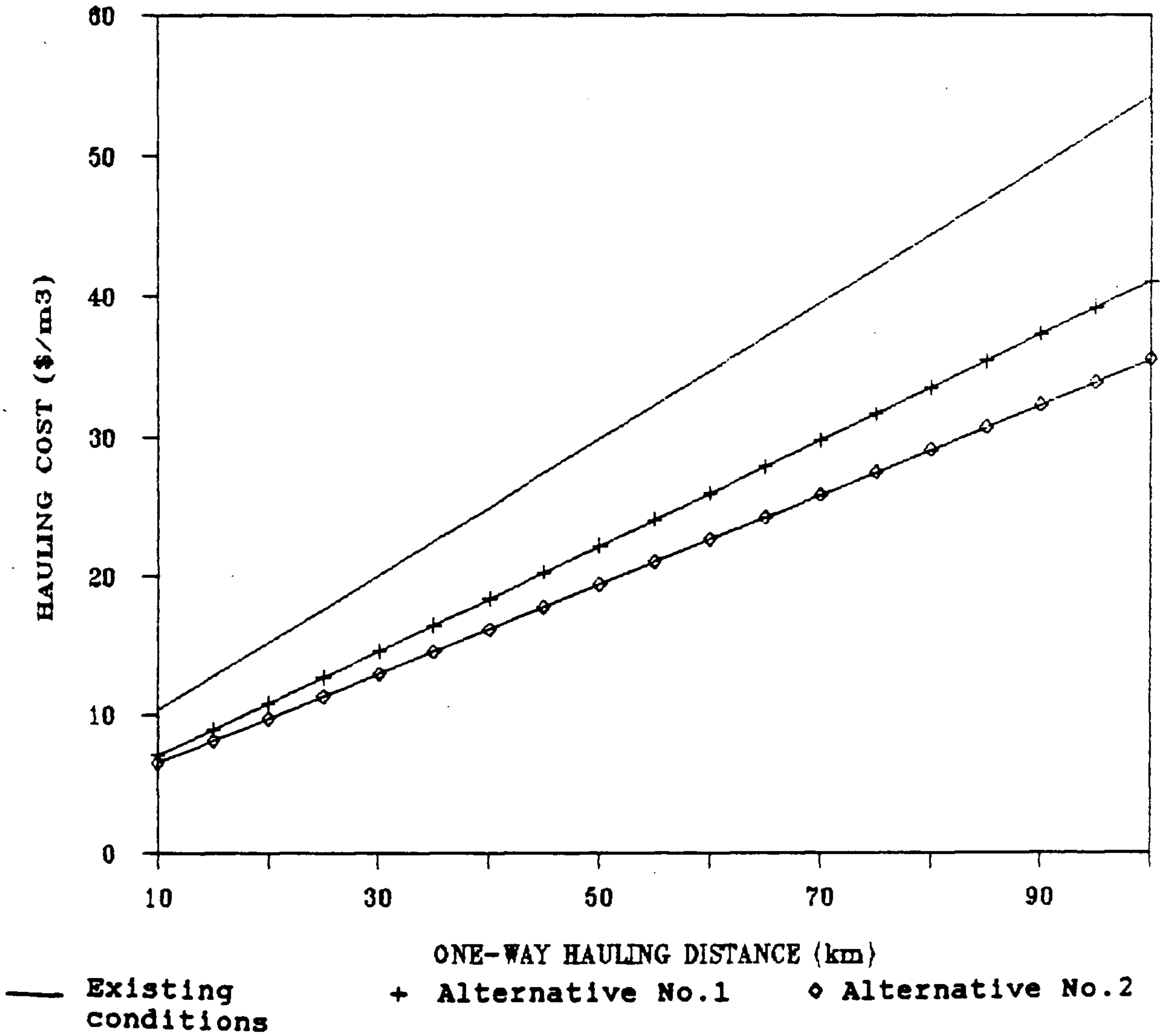
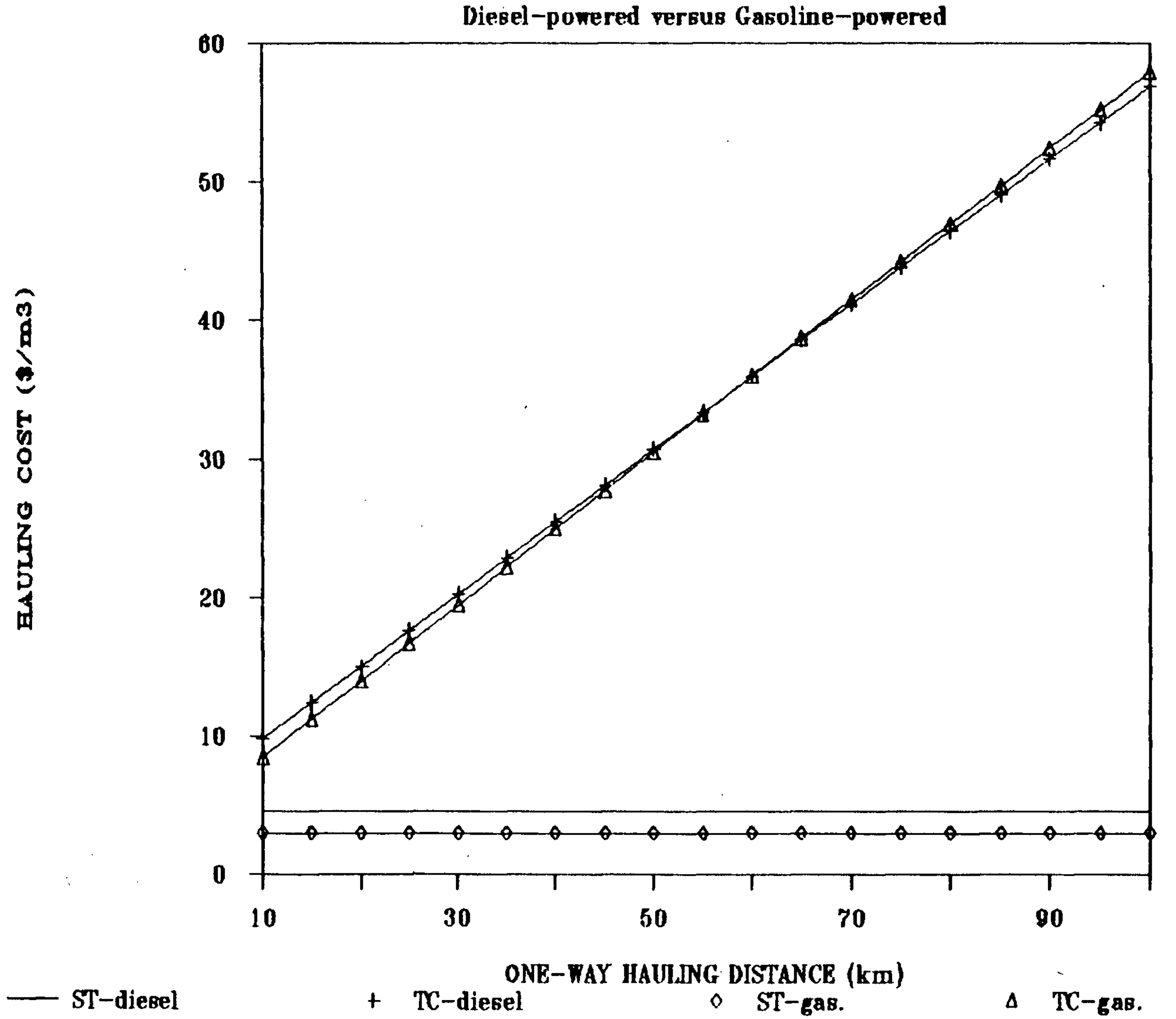


FIGURE 23. BREAK-EVEN CHART-TRUCK COMPARISON



CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This hauling study was carried out in a logging company in the wood products center of Pichanaki, which typifies many similar hauling operations in the Central Jungle region of Peru. The study reveals that the existing physical characteristics and conditions of the forest roads are probably one of the main obstacles to efficient transportation of logs from bush landings to sawmill by flatbed trucks.

Very low average travel speed empty of 10.33 km/hr or loaded of 7.42 km/hr for flatbed trucks was found. This is believed to be primarily as a result of presence of mudholes and ruts on the running surface of many sections of the forest roads. The forest roads had serious drainage problems because they were built without crown, ditches or culverts to prevent water saturation of the road surface and subgrade. Poor alignment is also thought to be a contributing factor to low speed.

Delay time was the second major obstacle to efficient log transportation by flatbed trucks. An average delay time of 2.64 hours, which represents 24.1% of the truck cycle for a haul distance (one way) of 26 km, has been found, as a result of drainage problems on forest roads, inadequate policies for road maintenance, and lack of proper planning and supervision of the hauling operation. Preventive maintenance of the trucks should be implemented to avoid mechanical delays during the hauling operation. Furthermore, dump trucks must be used instead of flatbed trucks to haul gravel required to surface or stabilize the subgrade of the roads.

The average loading time of 1.98 hours, which accounted for 18.1% of the cycle time, shows that the manual loading methods used to load the trucks were not efficient. Therefore, mechanical loading methods should be introduced to improve the productivity of the flatbed trucks evaluated. Small logging companies, however cannot afford the high capital investment required for loading machines such as front-end loaders. The home-made jammer being used in the yarding operation, should therefore also be used in the loading operations in order to reduce loading times.

The average per trip payload of 7.43 and 6.49 m^3 for diesel-powered and gasoline-powered trucks respectively, indicates that the flatbed trucks hauled payload under their full capacity. This situation results from the lack of knowledge about the unit log weight of the species hauled, plus the presence of mudholes and ruts on the forest roads. The sensitivity analysis showed that by loading the truck near its full capacity (9 m^3) for every trip, the haul cost could be reduced by at least 17%. Therefore, upgrading of haul roads would lead to further improvements in hauling efficiency through increased payload capacity of the trucks.

It has been found that there is no significant difference in performance between gasoline-powered and diesel-powered trucks for the following operating variables: velocity empty, velocity loaded, delay, loading and unloading time. Significantly greater payload per trip has been found for diesel-powered trucks than for gasoline-powered trucks.

Very expensive hauling costs, between $18.17/m³ and $17.29/m³ have been found for diesel-powered and gasoline-powered trucks respectively, for the short one-way haul distance of 26 km. Under the existing operating conditions, hauling logs with 17-18 year-old rebuilt, gasoline-powered trucks was less expensive than with diesel-powered trucks from 4 to 6 years-old, for haul distances (one-way) below 59 km. On the other hand, diesel-powered trucks could be more cost efficient on one-way haul distances greater than 59 km. Therefore, for the most current one-way haul distance (30-50 km) on forest roads, the use of old gasoline-powered trucks is recommended.

Fuel plus tire costs amounted to 32% and 49% of the total hauling costs for diesel-powered and gasoline-powered trucks respectively. More efficient engines must be examined and well designed forest roads must be built to reduce these costs.

The sensitivity analysis showed that the low productivity of the flatbed trucks could be increased, and the high haul cost could be decreased substantially by increasing truck speed, reducing the loading time, reducing delay, and loading the vehicle to its capacity in every trip.

The sensitivity analysis also revealed that if the round trip average speed could be increased from 8.64 km/hr to 12 km/hr and the loading and delay time could be reduced by 62%, the trucks would be able to complete two trips per day on a one-way haul of 26 km.

Round trip speeds of 12 km/hr could be obtained through upgrading of existing road conditions. The improvements should be accomplished through reshaping the road bed and providing a crown, installing culverts and ditches where needed, improving horizontal and vertical alignment where possible, and maintaining the forest roads properly. Moreover, proper decking with crossties and planking should be provided to the existing log bridges. It is recommended that future forest roads be built with well designed drainage structures and good horizontal and vertical alignment to improve trucking efficiency.

Future economic feasibility analyses will be necessary to ensure investments in improving existing forest road standards are justified.

Symphony spreadsheet software has proven to be an excellent tool for analysing costs of the complex hauling system. Also in this study, the model DSR Servis Recorder has proven to be a very useful instrument to record truck activities during the trip cycle. The chart interpretation can be done with a little practice and some knowledge of the process elements of the hauling cycle. Servis Recorders with a 24-hr clock mechanism would have been better for this time study, because the truck cycle time on some occasions took more than 12 hours.

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APPENDICES

APPENDIX 1

TRUCK TRIP REPORT

Date....................Forest Company............................

Cutting Area...

Truck-engine type: Gasoline...............Diesel.................

Truck No...............Model.............Trip No................

Hauling Distance (km)...................Rider.................

OPERATION		
Warm up		
Leave parking		
Leave unloading area		
Begin main forest road		
Begin secondary forest road		
Arrive at bush landing		
Leave queue		
Begin loading		
End loading		
Leave bush landing		
Begin main forest road		
Begin public road		
Arrive unloading area		
Leave queue		
Begin unloading		
End unloading		

Page 2.

OTHER DELAYS					
Cause					
Location					
Time:	Begin				
	End				

PAYLOAD							
Log No.	Max.diam. (cm)	Min.diam (cm)	Length (m)	Species	Volume (m^3)	kg/m^3	kg
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
TOTAL							

APPENDIX 2

TRUCK PURCHASE PRICE INFORMATION

A. New Diesel-powered trucks

Truck Model	DODGE DP-500
Truck purchase price in Peruvian soles(January 1981)	11,486,000
Truck purchase price in U.S. dollars (January 1981)	32,539[1]
Truck purchase price in Canadian dollars(January 1981)	38,744[2]
Truck purchase price in current Canadian dollars of August 1985	54,505[3]

B. Old Gasoline-powered trucks

Truck Model	FORD F-600[4]
Truck purchase price in Peruvian soles(December 1981)	5,000,000
Truck purchase price in U.S. dollars (December 1981)	9,878[5]
Truck purchase price in Canadian dollars(December 1981)	11,707[6]
Truck purchase price in current Canadian dollars of August 1985	14,640[3]

1 Based on an exchange rate of 1 US$= 352.99 Peruvian soles in January 1981 reported by International Monetary Fund, 1981. International Financial Statistics, 34(5):315.

2 Based on an exchange rate of 1 US$= 1.1907 Canadian dollars in January 1981 reported by Bank of Canada Review (January 1983).ppS127.

3 Based on increases of the total Consumer Price Index (12.5, 10.8, 5.8, 4.4) for the period 1981-1984 reported by the Honourable Michael H. Wilson Minister of Finance of Canada in Economic Review, April 1985.pp32.

4 Trucks built in 1966

5 Based on an exchange rate of 1 US$= 506.17 Peruvian soles in December 1981 reported by International Monetary Fund, 1982. International Financial Statistics, 35(3):321.

6 Based on an exchange rate of 1 US$= 1.1851 Canadian dollars in December 1981 reported by Bank of Canada Review (January 1983).ppS127.

APPENDIX 3

STATISTICAL ANALYSIS

A. TESTS OF HYPOTHESES

1. VELOCITY EMPTY (km/hr)

Diesel-powered truck	Gasoline-powered truck
$\bar{X}_1 = 10.59$	$\bar{X}_2 = 10.11$
$s_1 = 1.2724$	$s_2 = 1.1536$
$n_1 = 25$	$n_2 = 29$

1.1 Test concerning variances

$H_o : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}\ (24,28) = 2.17$

$f < f_{1-\alpha/2}\ (24,28) = 1/f_{\alpha/2}\ (28,24) = 1/2.1967 = 0.4552$

$f = s_1^2 \;/\; s_2^2$ (1)

$f = 1.6189/1.3308 = 1.2166$

Decision: Accept H_o

1.2 Test concerning means

$H_o : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

Critical region: $t > t_\alpha\ n_1+n_2-2$ $t > 1.645$

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{Sp\sqrt{1/n_1 + 1/n_2}} \quad (2)$$

$$Sp^2 = \frac{(n_1-1)\,s_1^2 + (n_2-1)\,s_2^2}{n_1 + n_2 - 2} \quad (2)$$

$Sp = 1.2099$

$t = 1.4537$

Decision: Accept H_o and conclude that there is not enough evidence that the velocity empty of diesel-powered trucks is significantly different from the velocity empty of gasoline-powered trucks.

2. VELOCITY LOADED (km/hr)

Diesel-powered truck	Gasoline-powered truck
$\bar{X}_1 = 7.58$	$\bar{X}_2 = 7.27$
$s_1 = 0.6773$	$s_2 = 0.7970$
$n_1 = 25$	$n_2 = 29$

2.1 Test concerning variances

$H_o : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}\ (24,28) = 2.17$

$f < f_{1-\alpha/2}\ (24,28) = 1/f_{\alpha/2}\ (28,24) = 1/2.1967 = 0.4552$

$f = s_1^2 \ / \ s_2^2$

$f = 0.4587/0.6352 = 0.7221$

Decision: Accept H_o

2.2 Test concerning means

$H_o : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

Critical region: $t > t_\alpha\ n_1+n_2-2$ $\quad t > 1.645$

$Sp = 0.7441$

$t = 1.5261$

Decision: Accept H_0 and conclude that the velocity loaded of diesel-powered trucks is not significantly different from the velocity loaded of gasoline powered trucks.

3. LOADING TIME (hr)

Diesel-powered truck	Gasoline-powered truck
$\overline{X}_1 = 2.06$	$\overline{X}_2 = 1.91$
$s_1 = 0.5444$	$s_2 = 0.4479$
$n_1 = 25$	$n_2 = 29$

3.1 Test concerning variances

$H_0 : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}\ (24,28) = 2.17$

$f < f_{1-\alpha/2}\ (24,28) = 1/f_{\alpha/2}\ (28,24) = 1/2.1967 = 0.4552$

$f = s_1^2 \ / \ s_2^2$

$f = 0.2964/0.2006 = 1.4776$

Decision: Accept H_0

3.2 Test concerning means

$H_0 : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

Critical region: $t > t_{\alpha}\ n_1+n_2-2$ $\quad t > 1.645$

$Sp = 0.4948$

$t = 1.1108$

Decision: Accept H_0 and conclude that there is not enough evidence that the loading time is significantly different between both types of truck.

4. UNLOADING TIME (hr)

Diesel-powered truck	Gasoline-powered truck
$\bar{X}_1 = 0.32$	$\bar{X}_2 = 0.31$
$s_1 = 0.0999$	$s_2 = 0.0813$
$n_1 = 25$	$n_2 = 29$

4.1 Test concerning variances

$H_0 : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}\ (24,28) = 2.17$

$f < f_{1-\alpha/2}\ (24,28) = 1/f_{\alpha/2}\ (28,24) = 1/2.1967 = 0.4552$

$f = s_1^2 \ / \ s_2^2$

$f = 0.01/0.0066 = 1.5121$

Decision: Accept H_0

4.2 Test concerning means

$H_0 : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

Critical region: $t > t_\alpha\ n_1+n_2-2$ $t > 1.645$

$Sp = 0.0904$

$t = 0.4053$

Decision: Accept H_0 and conclude that unloading time is not significantly different between diesel-powered trucks and gasoline-powered trucks.

5. DELAY (As % of productive time)

Diesel-powered truck	Gasoline-powered truck
$\bar{X}_1 = 33.73$	$\bar{X}_2 = 30.01$
$s_1 = 14.6900$	$s_2 = 13.8376$
$n_1 = 25$	$n_2 = 29$

5.1 Test concerning variances

$H_0 : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}\ (24,28) = 2.17$

$f < f_{1-\alpha/2}\ (24,28) = 1/f_{\alpha/2}\ (28,24) = 1/2.1967 = 0.4552$

$f = s_1^2 \ / \ s_2^2$

$f = 215.7600/191.4782 = 1.13$

Decision: Accept H_0

5.2 Test concerning means

$H_0 : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

Critical region: $t > t_\alpha\ n_1+n_2-2$ $\qquad t > 1.645$

$Sp = 14.2368$

$t = 0.9575$

Decision: Accept H_0 and conclude that there is not enough evidence that the delay is significantly different between both types of truck.

6. PAYLOAD

6.1. PAYLOAD VOLUME (m^3)

Diesel-powered truck	Gasoline-powered truck
$\overline{X}_1 = 7.43$	$\overline{X}_2 = 6.49$
$s_1 = 1.4124$	$s_2 = 1.0872$
$n_1 = 25$	$n_2 = 29$

6.1.1 Test concerning variances

$H_0 : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}$ (24,28) = 2.17

$f < f_{1-\alpha/2}$ (24,28) = $1/f_{\alpha/2}$ (28,24) = 1/2.1967 = 0.4552

$f = s_1^2 / s_2^2$

f = 1.9950/1.1819 = 1.6880

Decision: Accept H_0

6.1.2 Test concerning means

$H_0 : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

Critical region: $t > t_{\alpha}\ n_1+n_2-2$ $\quad t > 1.645$

Sp = 1.2479

t = 2.7603

Decision: Reject H_0 and conclude that the payload volume (m3) of diesel-powered trucks is significantly different from the payload volume of gasoline-powered trucks.

6.2 PAYLOAD WEIGHT (kg)

Diesel-powered truck	Gasoline-powered truck
$\bar{X}_1$ = 6310.40	$\bar{X}_2$ = 5768.62
s_1 = 1379.25	s_2 = 888.0223
n_1 = 25	n_2 = 29

6.2.1 Test concerning variances

$H_0 : \sigma_1^2 = \sigma_2^2$
$H_1 : \sigma_1^2 \neq \sigma_2^2$
$\alpha = 0.05$

Critical region:

$f > f_{\alpha/2}$ (24,28) = 2.17

$f < f_{1-\alpha/2}$ (24,28) = $1/f_{\alpha/2}$ (28,24) = 1/2.1967 = 0.4552

$f = s_1^2 / s_2^2$

f = 1902337/788583 = 2.41

Decision: Reject H_0.

6.2.2 Test concerning means

$H_0 : \mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$
$H_1 : \mu_1 - \mu_2 > 0$
$\alpha = 0.05$

When

$$\text{Degrees of freedom (V)} = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{\dfrac{(s_1^2/n_1)^2}{n_1-1} + \dfrac{(s_2^2/n_2)^2}{n_2-1}} \qquad (2)$$

$$V = 40$$

Critical region: $t' > 1.645$

$$t' = \frac{(\bar{X}1-\bar{X}2) - (\mu_1 - \mu_2)}{\sqrt{(s_1^2/n_1) + (s_2^2/n_2)}} \qquad (2)$$

$t' = 1.6858$

Decision: Reject H_0 and conclude that the payload weight (kg) of diesel-powered trucks is significantly different from the payload weight of gasoline-powered trucks.

B. LINEAR REGRESSION ANALYSIS

1. TRAVEL TIME EMPTY (Y) IN HOURS

Dependent variable: Travel time empty (Y)

Independent variable : one-way hauling distance (X)

Coefficient of determination (r^2): 0.487074

Correlation coefficient (r) : 0.697907

Estimated constant term : 0.482558

Standard error of estimate : 0.251564

Regression coefficient : 0.07690

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN OF SQUARES	F TEST
Regression	1	3.12495	3.12495	49.3792
Residuals	52	3.29080	0.06328	
Total	53	6.41575		

2. TRAVEL TIME LOADED (Y) IN HOURS

Dependent variable: travel time loaded (Y)

Independent variable: one-way hauling distance (X)

Coefficient of determination (r^2) : 0.614408

Correlation coefficient (r) : 0.783842

Estimated constant term : 0.143634

Standard error of estimate : 0.328159

Regression coefficient : 0.129954

ANALYSIS OF VARIANCE FOR THE REGRESSION

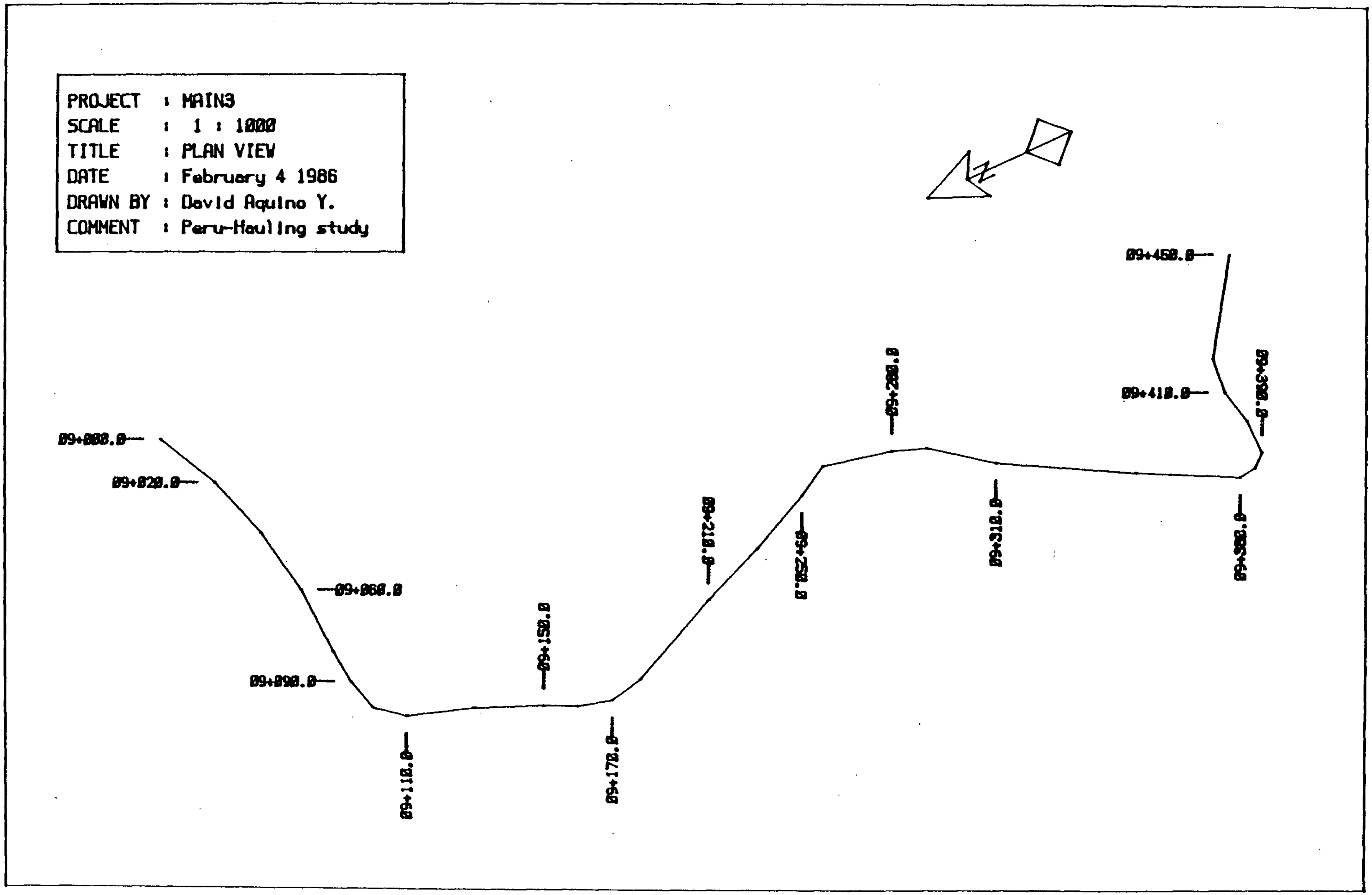
SOURCE OF VARIANCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN OF SQUARES	F TEST
Regression	1	8.92276	8.92276	82.857
Residuals	52	5.59978	0.10768	
Total	53	14.5225		

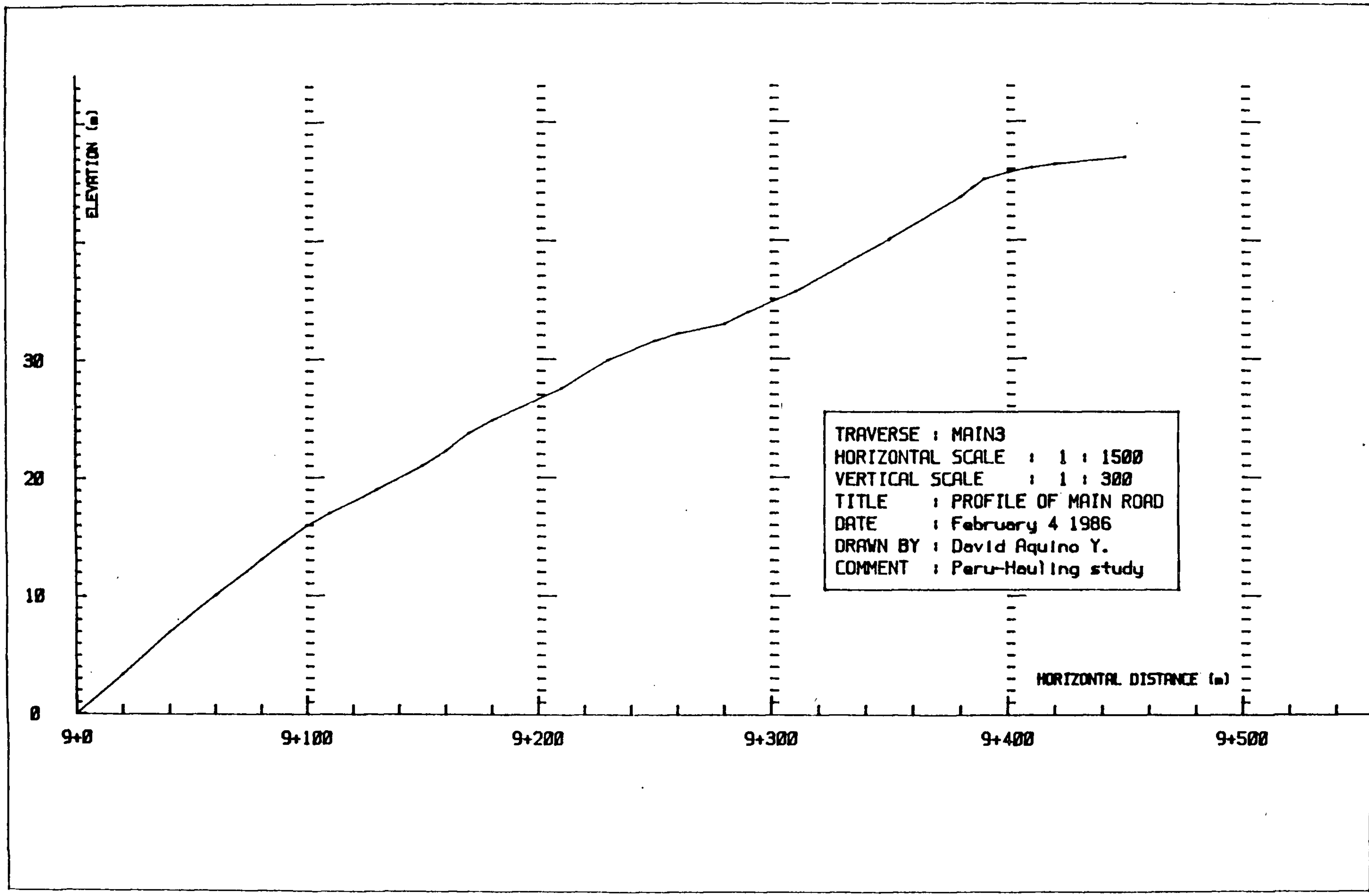
1 Walpole, E.R., 1982. pp.321.

2 Walpole, E.R., 1982. pp.311.

APPENDIX 4

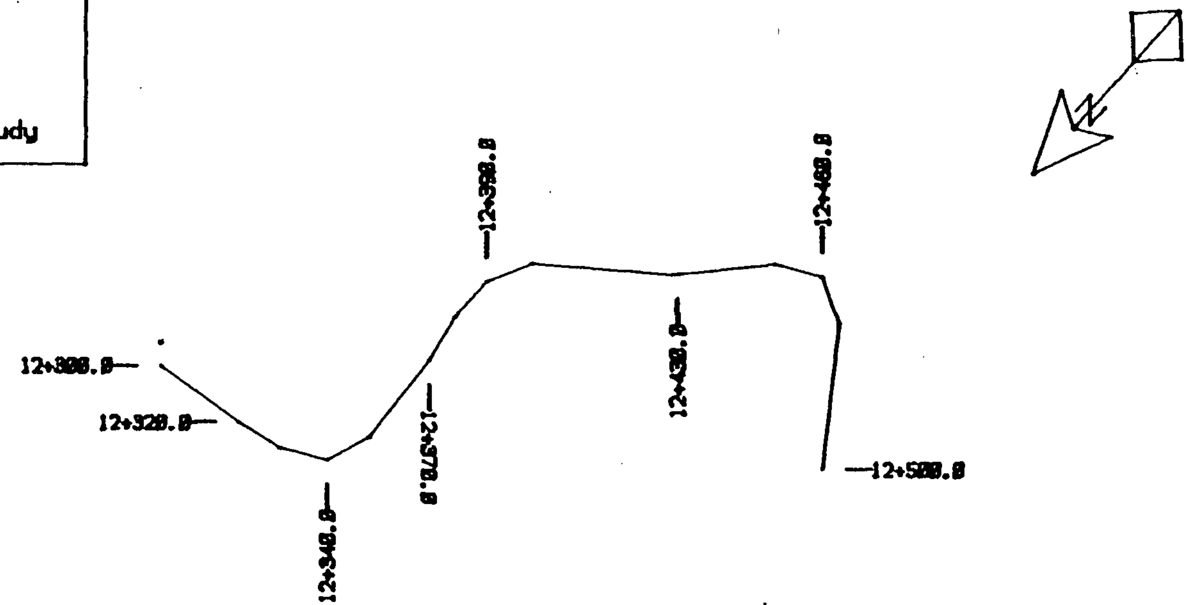
PLAN VIEW AND PROFILE OF FOREST ROADS SURVEYED

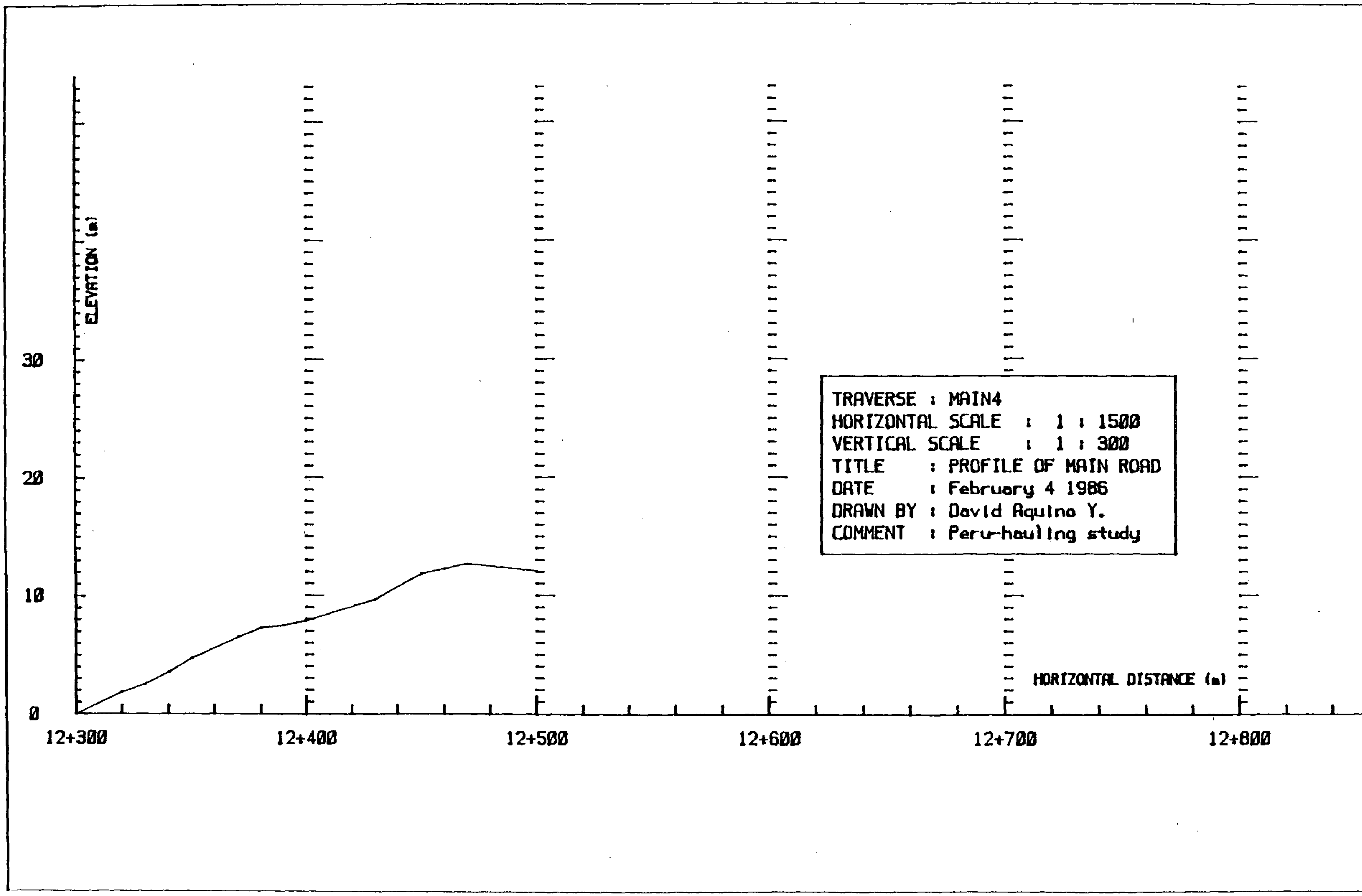

PROJECT : MAIN3
SCALE : 1 : 1000
TITLE : PLAN VIEW
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study
09+000.0
09+020.0
09+060.0
09+090.0
09+110.0
09+150.0
09+170.0
09+210.0
09+280.0
09+310.0
09+410.0
09+450.0

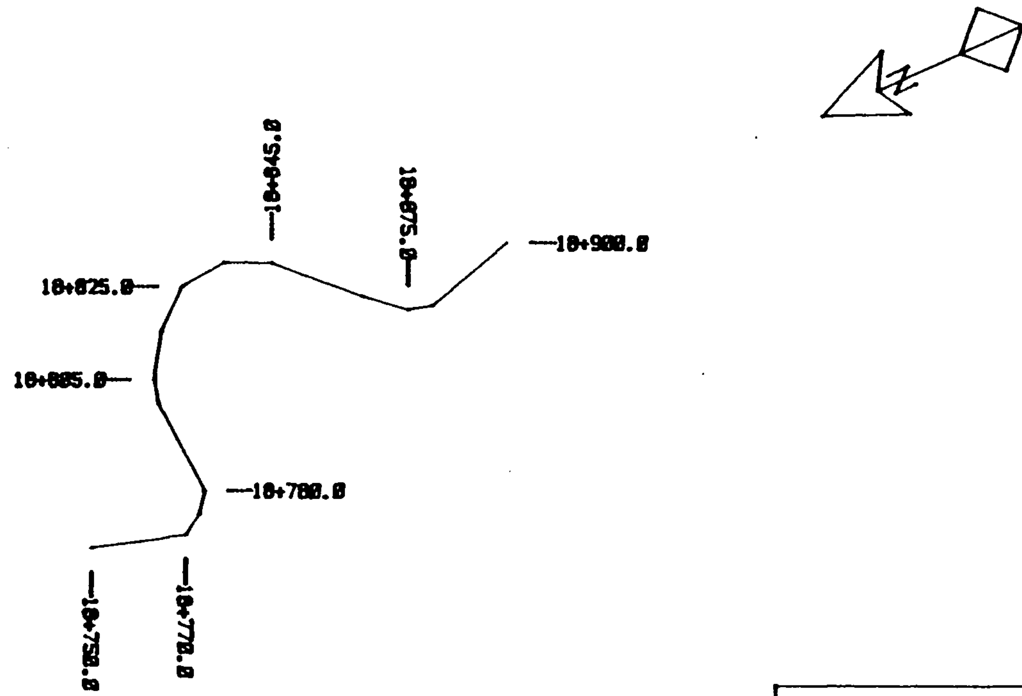


ELEVATION (m)
30
20
10
0
9+0
9+100
9+200
9+300
9+400
9+500
HORIZONTAL DISTANCE (m)
TRAVERSE : MAIN3
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF MAIN ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study

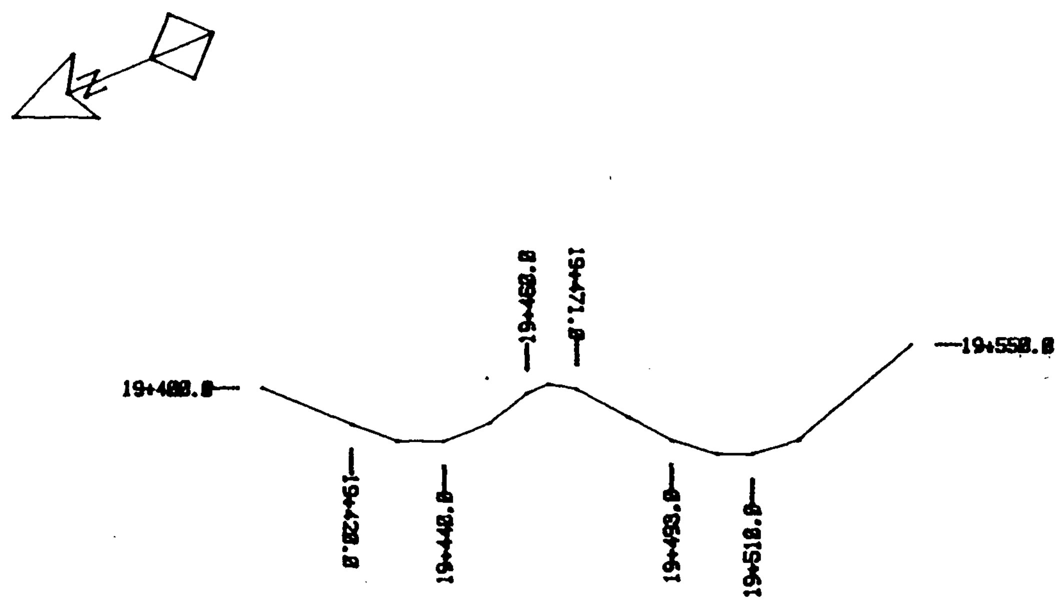
PROJECT : MAIN4
SCALE : 1 : 1000
TITLE : PLAN VIEW
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study



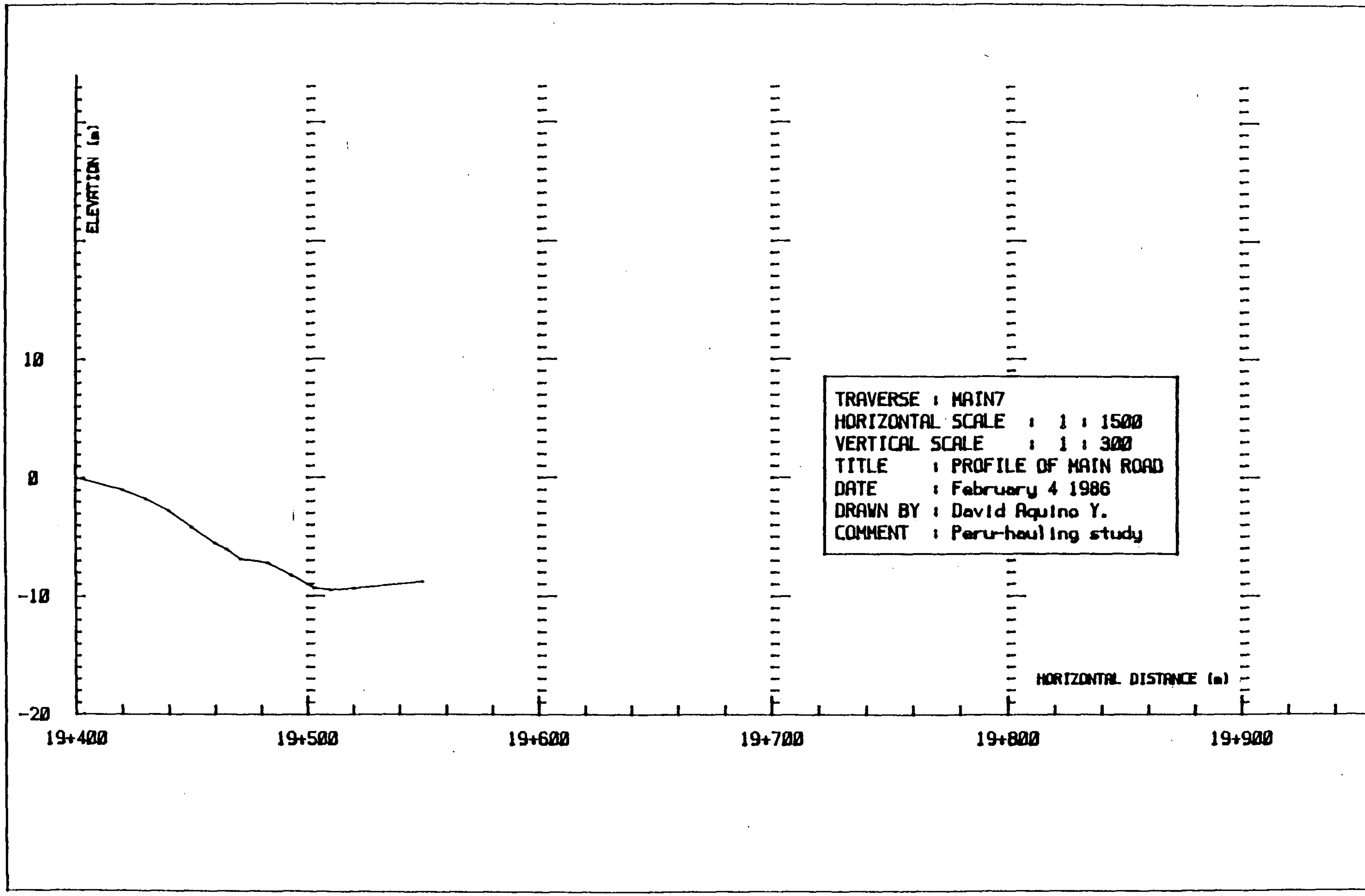

ELEVATION (m)
30
20
10
0
12+300
12+400
12+500
12+600
12+700
12+800
HORIZONTAL DISTANCE (m)
TRAVERSE : MAIN4
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF MAIN ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-hauling study

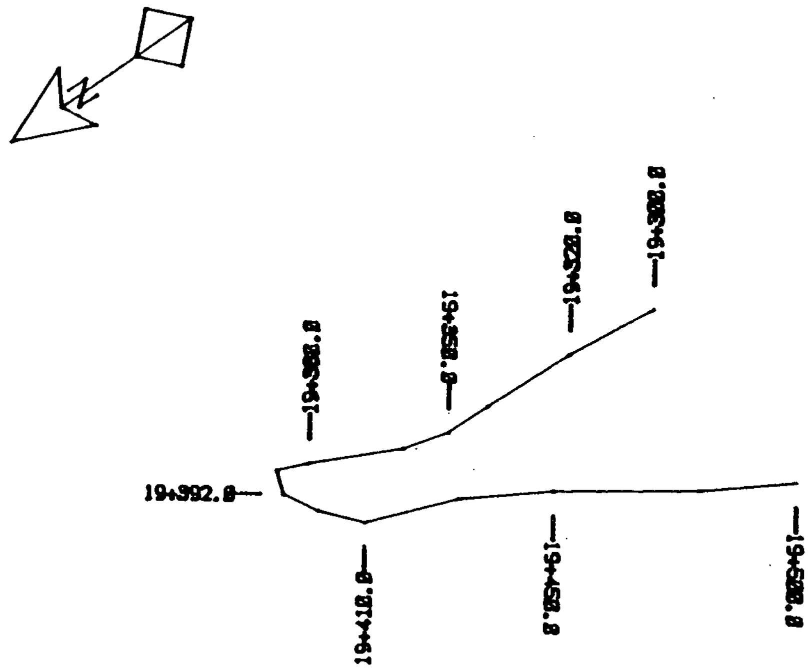


PROJECT : MAIN6
SCALE : 1 : 1000
TITLE : PLAN VIEW
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study

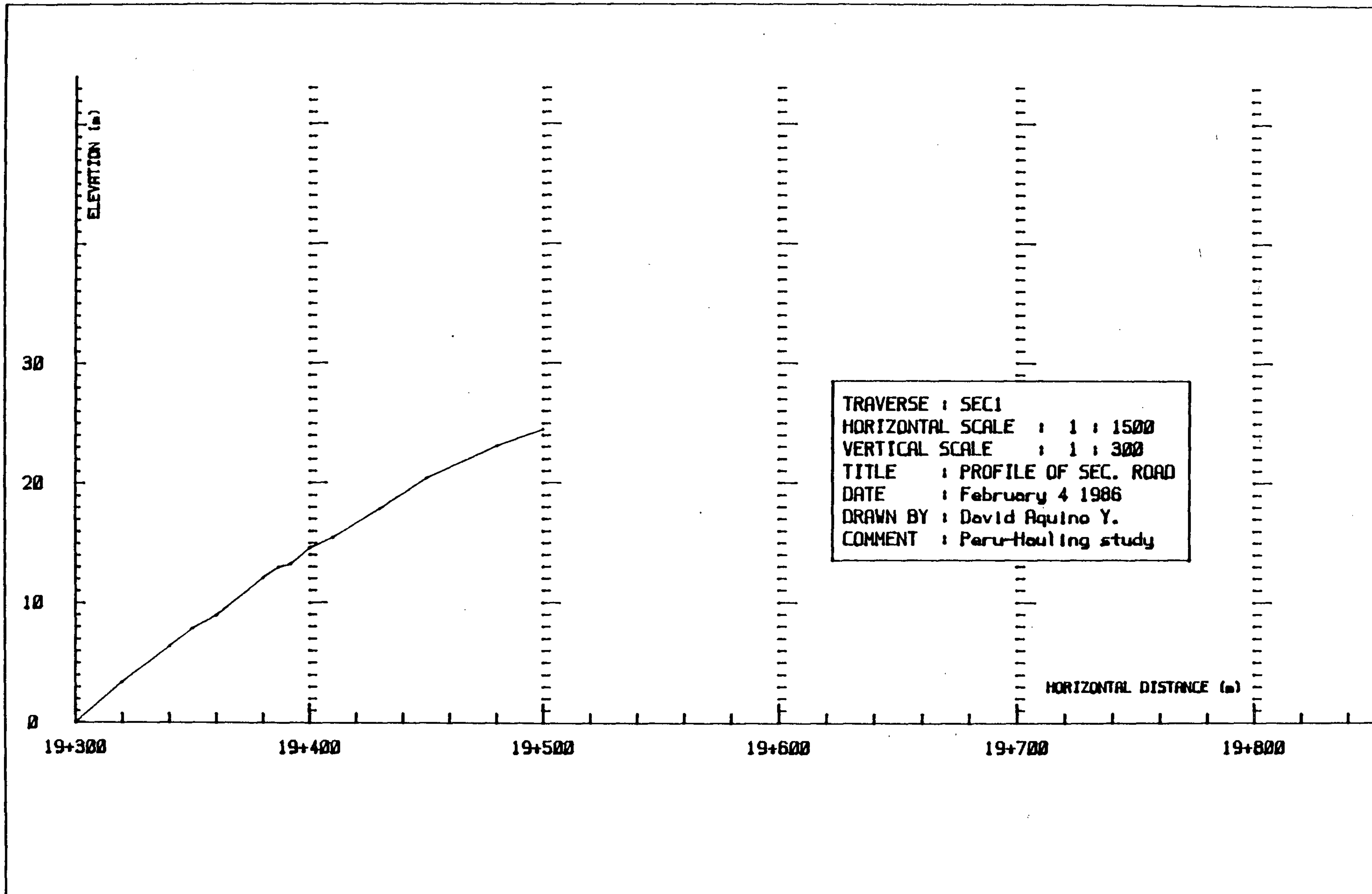


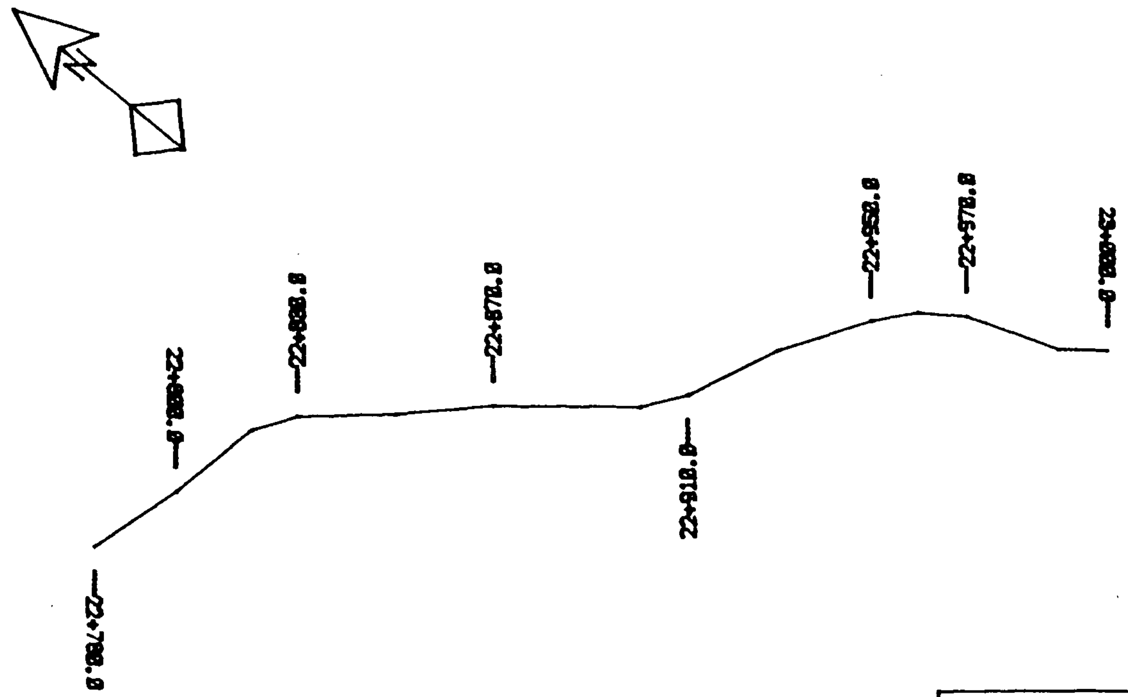
PROJECT	:	MAIN7
SCALE	:	1 : 1000
TITLE	:	PLAN VIEW
DATE	:	February 4 1986
DRAWN BY	:	David Aquino Y.
COMMENT	:	Peru-Hauling study


ELEVATION (m)
10
0
-10
-20
19+400
19+500
19+600
19+700
19+800
19+900
HORIZONTAL DISTANCE (m)
TRAVERSE : MAIN7
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF MAIN ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-hauling study

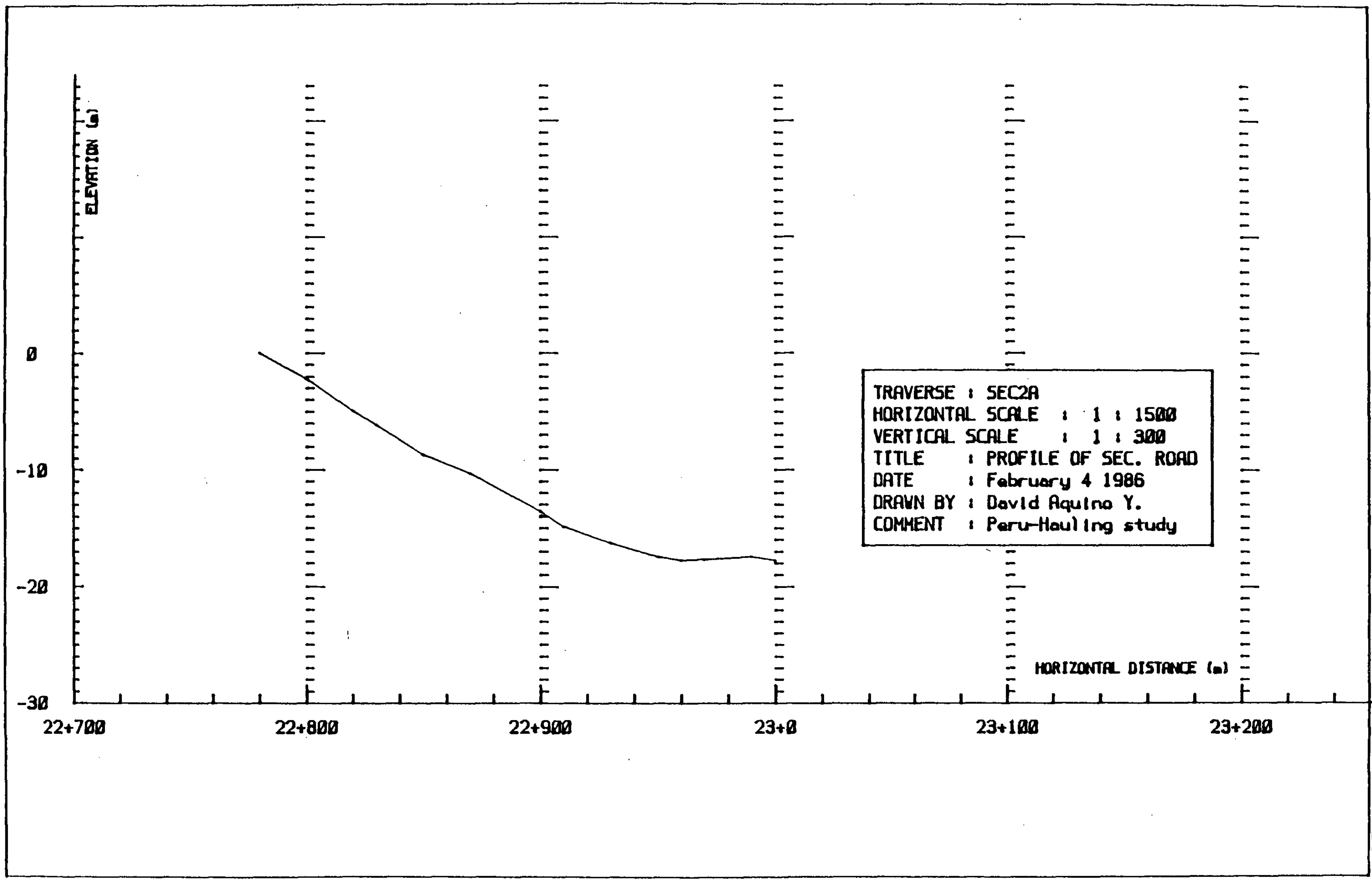


PROJECT	: SEC1
SCALE	: 1 : 1000
TITLE	: PLAN VIEW
DATE	: February 4 1986
DRAWN BY	: David Aquino Y.
COMMENT	: Peru-Hauling study

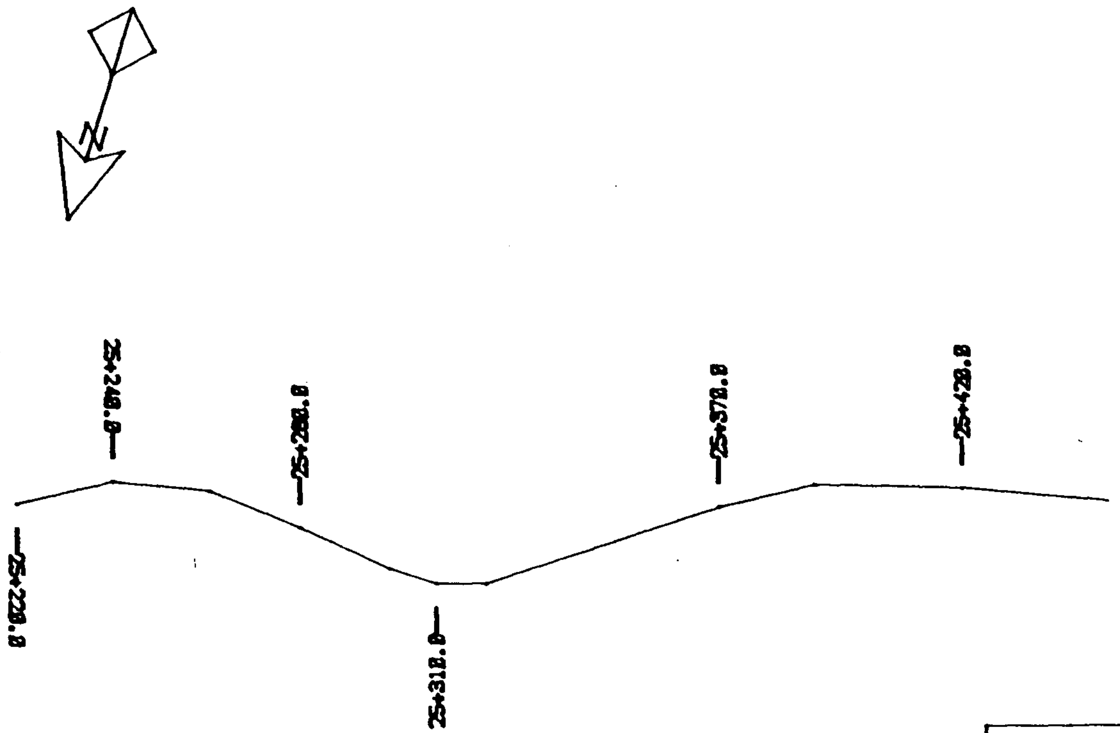

ELEVATION (m)
30
20
10
0
19+300
19+400
19+500
19+600
19+700
19+800
HORIZONTAL DISTANCE (m)
TRAVERSE : SEC1
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF SEC. ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study



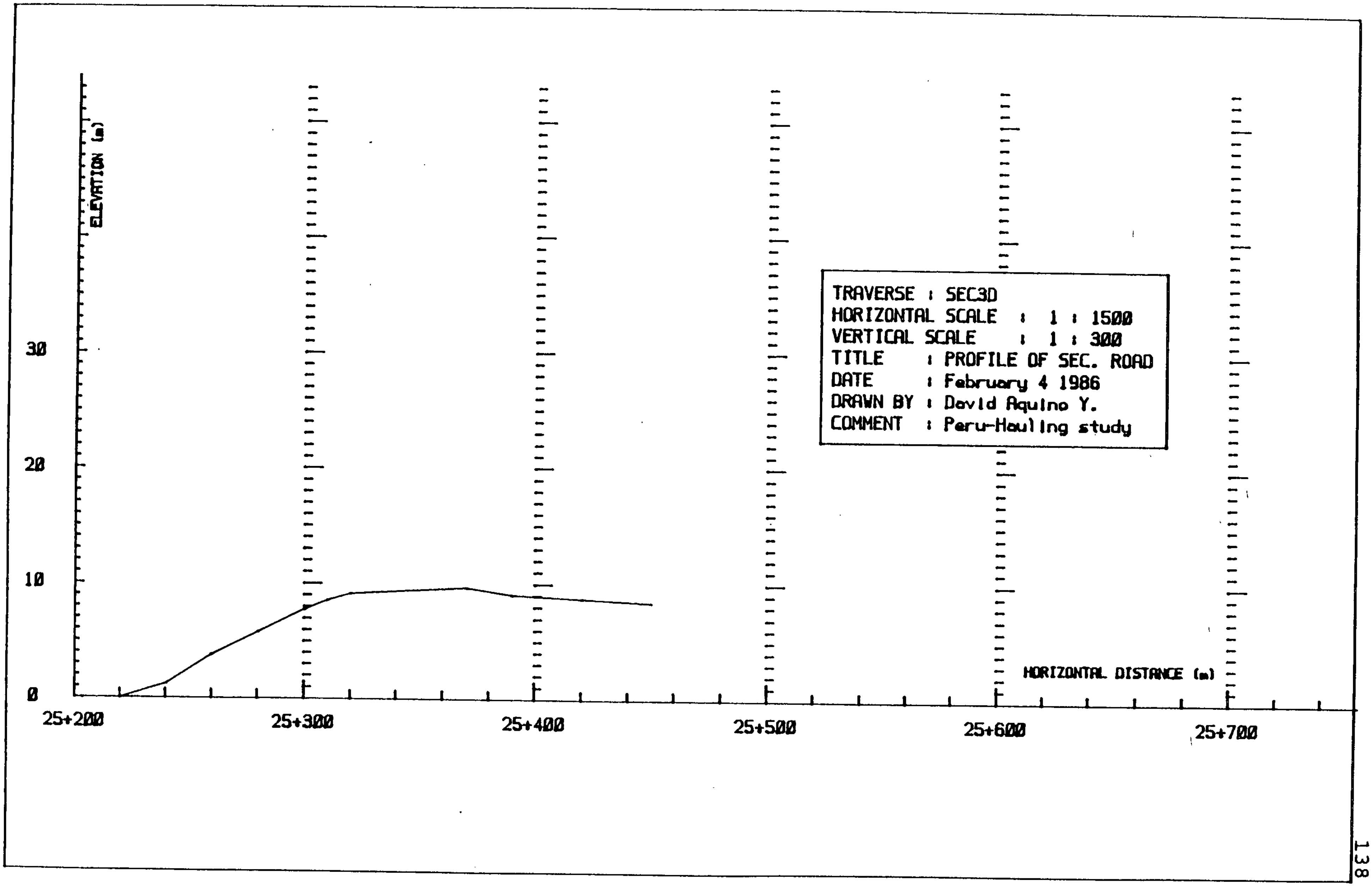
PROJECT : SEC2A
SCALE : 1 : 1000
TITLE : PLAN VIEW
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study

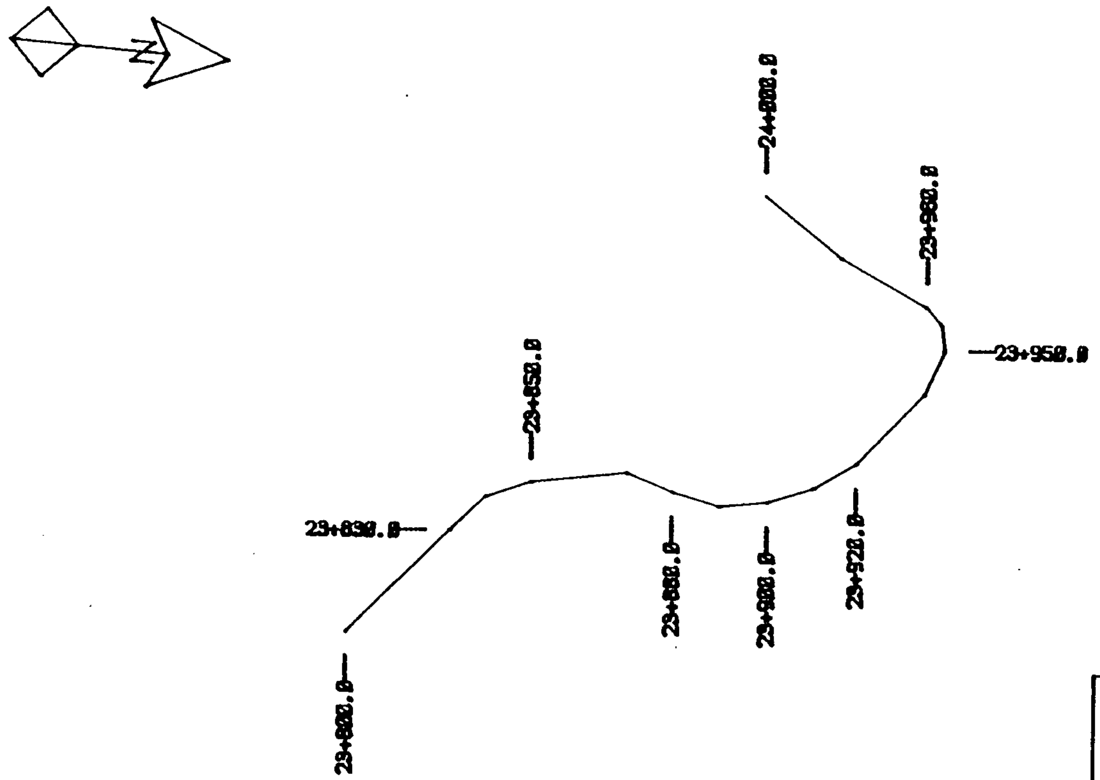


ELEVATION (m)
0
-10
-20
-30
22+700
22+800
22+900
23+0
23+100
23+200
HORIZONTAL DISTANCE (m)
TRAVERSE : SEC2A
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF SEC. ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study

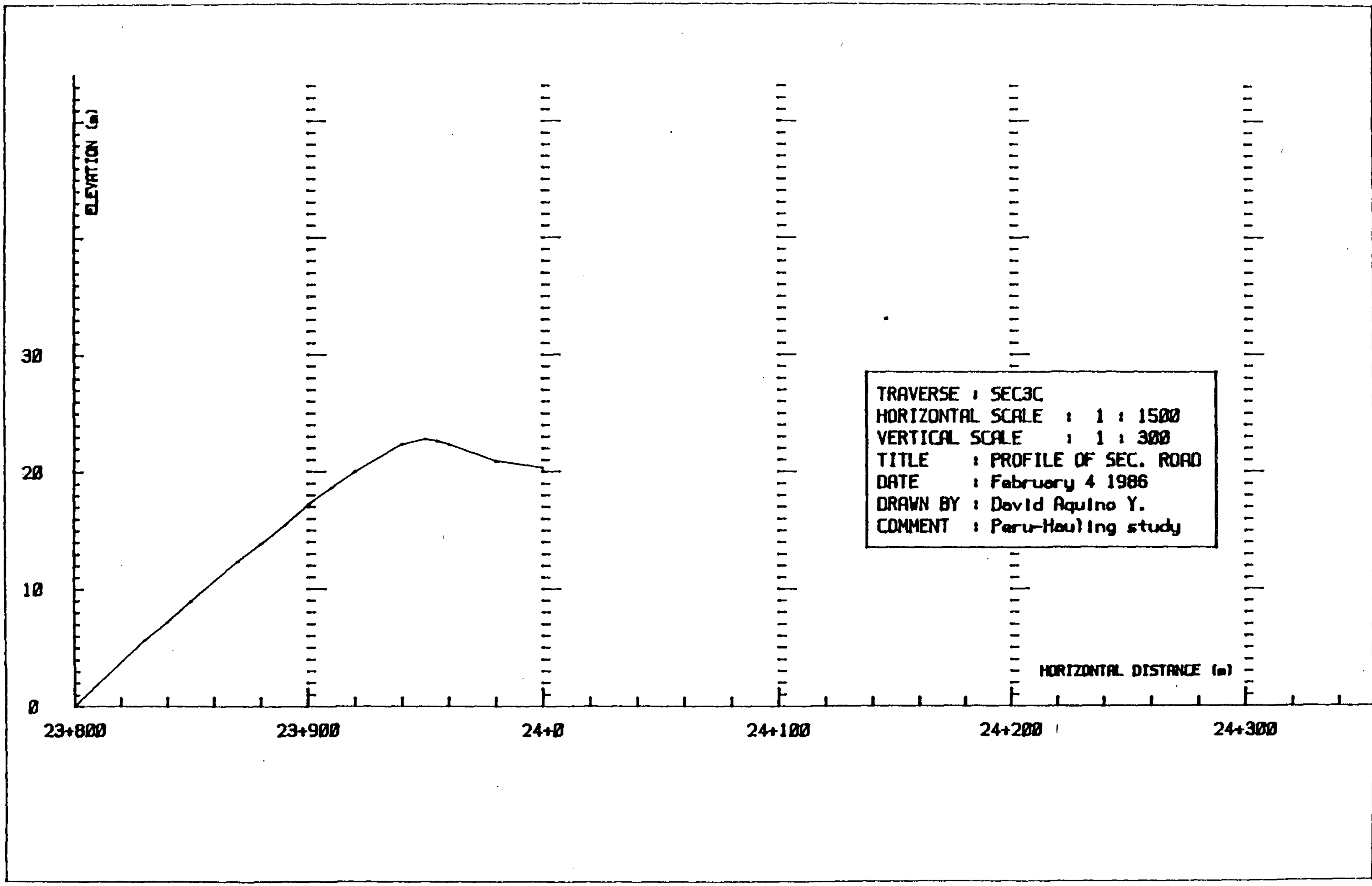


PROJECT : SEC3D
SCALE : 1 : 1000
TITLE : PLAN VIEW
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study


ELEVATION (m)
30
20
10
0
25+200
25+300
25+400
25+500
25+600
25+700
HORIZONTAL DISTANCE (m)
TRAVERSE : SEC3D
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF SEC. ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study



PROJECT	:	SEC3C
SCALE	:	1 : 1000
TITLE	:	PLAN VIEW
DATE	:	February 4 1986
DRAWN BY	:	David Aquino Y.
COMMENT	:	Peru-Hauling study


ELEVATION (m)
30
20
10
0
23+800
23+900
24+0
24+100
24+200
24+300
HORIZONTAL DISTANCE (m)
TRAVERSE : SEC3C
HORIZONTAL SCALE : 1 : 1500
VERTICAL SCALE : 1 : 300
TITLE : PROFILE OF SEC. ROAD
DATE : February 4 1986
DRAWN BY : David Aquino Y.
COMMENT : Peru-Hauling study