

EVALUATION OF TWO HAULAGE SYSTEMS  
AS APPLIED TO IRON CONCENTRATE  
TRANSPORTATION IN EASTERN BOLIVIA

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by

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An Engineering Report submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Engineering.

Signed: Renato Veneros  
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ABSTRACT

This study presents an economic evaluation of two transportation systems as applied to a specific mine haulage operation.

In the first part it evaluates transportation costs by means of a fleet of trucks over a distance of 68 miles. It takes into account the actual features of the existing road and determines the optimal number and type of trucks to be needed for the required annual production. It is shown that this operation can be improved appreciably by paving the road. This part is solved by computer-assisted simulation.

Railroad haulage system analysis is contemplated in the second part . Aspects such as breaching jungle areas, cost estimates of jungle access trails, railroad equipment selection, and costs estimates for this operation are determined. Computer procedures are also used to determine traveling times.

Finally, a comparison between both systems is performed. It is apparent that on the basis of haulage costs only, the railroad system is substantially better.

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INTRODUCTIONGeneral

The Bolivian mining industry is charged with the responsibility of developing and exploiting its mineral resources to sustain its economy which, indeed, is the base of the Bolivia's economy. It is obvious that the demand for mineral commodities in the coming years will increase manifold. Given adequate mineral resources, the task of expanding production by a factor of three or four offers no small challenge. The demand for raw materials in the mineral aspect is complicated by the fact that mining, unlike the other industries, markets a wasting asset. Consumed mineral resources cannot be replenished and most of the high-grade, easily-mined deposits have been exhausted. However, there still are some mineral deposits which can be considered of relatively high grade, but they are not mined out because of other different aspects such inaccessibility, isolation, weather conditions, and so forth. An iron-manganese deposit located in southeast of Bolivia is one such deposit.

Two years ago, Corporacion Minera de Bolivia, the State's Bolivian mining company, started preliminary work at El Mutun deposit. For the experimental stage a pilot

plant with a 700 MTPD capacity was built and an access road from Puerto Suarez to the mine was built. The exploitation phase will begin by working the alluvial deposits in the narrow valleys of this area. The mining of these alluvials will last for several years. The ores will be concentrated in a mill and then they will be transported to Puerto Busch, a harbor on the Paraguay River, from whence they will be shipped down to the Argentina State Steel Company at San Nicolas, Argentina. In this smelter the concentrate will be converted into steel. Feasibility studies have determined that for an economical operation the minimum tonnage to be shipped down to the smelter must be 1,000,000 MTPY.

The haulage of this concentrate from the mill to the river harbor over a distance of 68 miles is the topic of this dissertation.

The use of trucks as a main transportation system for this operation is the original plan contemplated by the company's management. A two-way road was built with this purpose.

### Problem Statement

The haulage cycle considered in this report can be explained as follows: after the ore is treated in the mill it is stored in an ore bin. The trucks are loaded from that bin, leaving the loading area and beginning the long distance travel toward the river port at which the concen-

trate is unloaded into the port facilities. After dumping the units leave the port, making their way back to the mill for reloading.

The optimum selection and assignment of equipment will achieve maximum profit for the company. The analysis described in this report assists management in the selection of the best system of ore transportation. Both a truck and a railroad system are considered.

#### Purpose and Scope

The only certain and absolute way management can determine cost and productivity of any mining system is to install and operate the system. However, when systems involve large capital expenditures this procedure is seldom economically feasible and practical. The probabilistic nature of mining and production would necessitate a lengthy experiment for each alternative to locate the optimum system. Simulation provides a better approach. Simulation methods are used when truck studies are made. Standard simulation is employed as well in the railroad analysis.

Summarizing, this study performs the analysis of sequential operations and costs for a truck haulage system, makes a cost estimation for a railroad operation and, finally, compares both alternatives giving management ways of evaluating such systems without changing the actual operation.

The results obtained are analyzed, and some thoughts are given pertaining to the practical application of each system.

## FACTORS REQUIRING SPECIAL CONSIDERATION

### Location

The "El Mutun" deposit lies in the southeast corner of Bolivia. The pilot plant, already in operation, is located 17 miles due south of Puerto Suarez, a small town in the Bolivian-Brasilian border, which constitutes the nearest town to the deposit serving as a connection point with the rest of the country. Puerto Suarez is 390 miles by rail east from Santa Cruz de la Sierra, and 680 miles from Cochabamba City (see Figure 1.).

### Geography and Climate of the Zone

The area in which the transportation system is located corresponds to the low lands lying in the middle of South America. In general, it is a flat land with slight undulations, isolated depressions, and deep, fertile soil. The surface cover consists of sediments of alluvial and aeolian origin transported by water and wind from the Andes Mountains and the Brasilian Highland. Below the unconsolidated material are horizontal strata resting on a granite base.

The climate corresponds to the tropical regions. The temperature is generally warm, humid, and with heavy rainfall during the Summer. Annual rainfall is estimated bet-

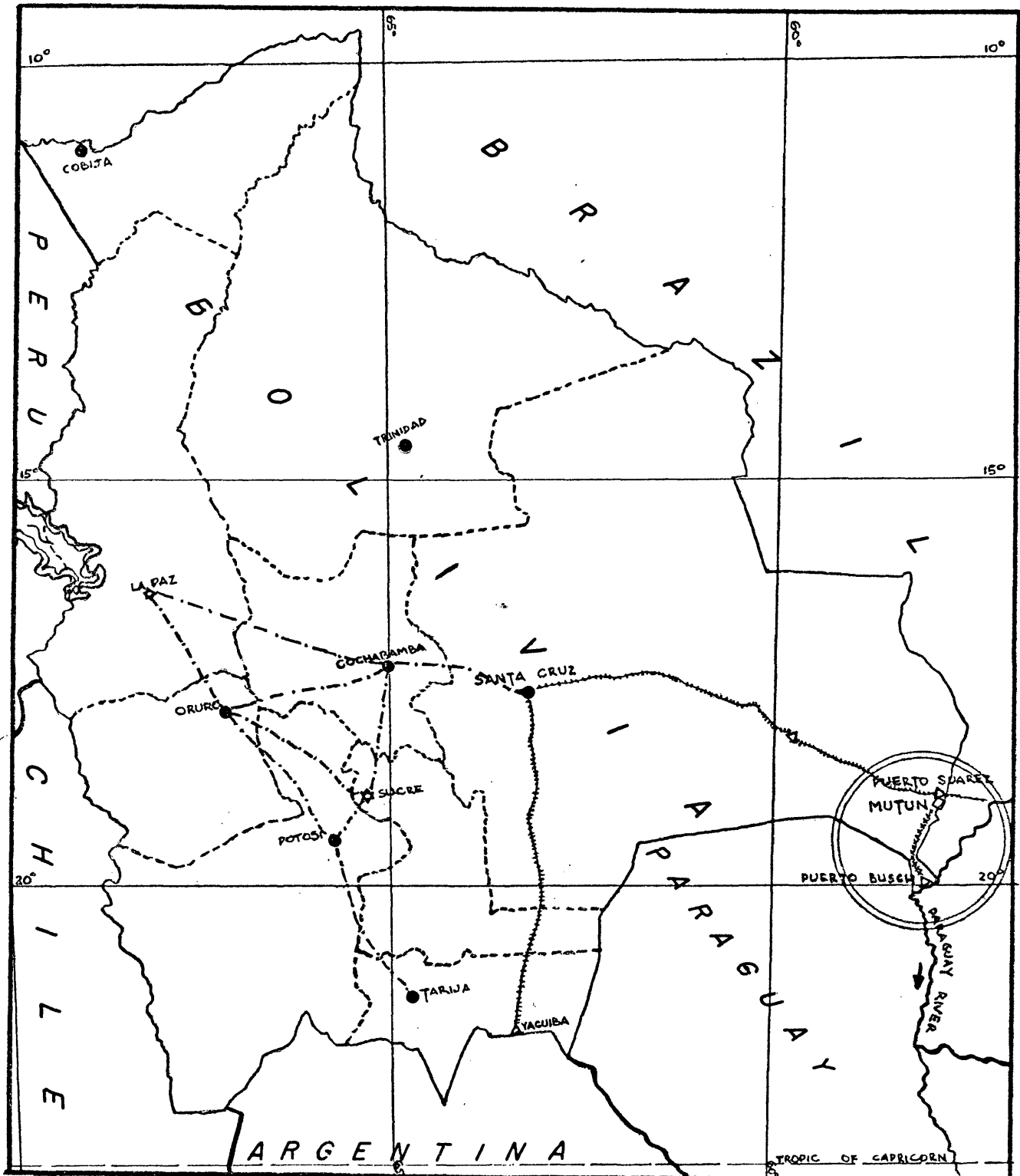


Figure 1. Location of the Area Under Study

ween 35 and 45 in. This part of Bolivia is very thinly populated, most of the inhabitants being farmers.

#### Building Roads in Jungle Areas

The construction of permanent roads in jungle areas, especially in the present case in which the works are being developed in the center of the continent presents two major difficulties: 1) the isolation, and 2) the climate.

The isolation means that any project must be largely self-sufficient, and for longer periods than is normal. Self-sufficiency involves not only the supply of hardware, personnel, and engineering capacity but also such matters as technical reference materials, communication equipment, and the like.

The climate is very demanding on men and machines. The heavy rainfall during the Summer months forms lagoons and turns the land swampy; the drainage is slow. It has been reported that during January and February the highest temperatures of the continent are found in this region.

METHODS OF ANALYSIS AND THEIR LIMITATIONS

The following methods of analysis can provide the necessary means to solve an optimization process:

Conventional Methods -Calculus

The classical methods of Calculus provide elegant solutions to a relatively limited number of problems. Calculus is in fact principally applicable to problems involving force fields such as those of gravity, electromagnetism, stresses, and field pressures. These situations are, unfortunately, of limited relevance to many of the problems in the design and operation of large-scale systems like the one considered in this thesis. Thus, calculus is not applicable in situations where a large number of variables are not continuous functions and do not have continuous derivatives at all points, which is true of the present case.

Dynamic Programming

Dynamic Programming is a technique that can be used in a specific function subject to a few constraints, e. g. two or three. It is mostly used in allocation problems and often useful for making a sequence of interrelated decisions.

Dynamic programming is a general type of approach to problem solving, and the particular equations used must be developed to fit each individual situation.

The large number of constraints taken into account in this study is the main reason for not using this technique.

### Linear Programming

Linear programming is applied to situations dealing with either maximizing or minimizing the value of some linear (objective) function subject to a set of linear constraints. The coefficients relating input and output are known. There are no provisions made for relationships subject to random fluctuations or errors in determinations. All of these limitations make linear programming unsuitable for a study where laws of probabilities and chance play a key role in the process. Thus, this technique is not applicable in this problem.

### Systems Simulation

Systems simulation is a method used to reproduce and manipulate the production properties of a real world system in the reduced form of a model. Simulation does not always give numerical answers but provides a set of sub-optimum solutions from which the required answers can be selected for the existing operating conditions or for the proposed

operations or changes in the system.

Systems simulation is, in most cases, a stochastic optimization tool, though models of deterministic optimization are not uncommon.

The system under study is a stochastic process, which involves a large number of variables; consequently, simulation procedures are well suited for solving and optimizing the problem.

Simulation offers to decision makers a unique opportunity to experiment with proposed operational changes without altering the actual conditions.

The trend toward this method has been accelerated rapidly by the widespread availability of high-speed digital computers, which reduce the time required for computation and can also generate the necessary random numbers required for simulation. Thus, the expansion or compression of time is possible and a problem area can be analyzed more critically.

TRUCK HAULAGE ANALYSISGeneral

The optimization of a fleet of trucks for the concentrate haulage system is accomplished by using simulation. This chapter discusses and analyses the different concepts and techniques used in calculating such items as traveling times, annual costs, and costs per ton for each unity in the system.

Two kinds of simulation are used in this dissertation: probabilistic simulation is employed whenever certain servicing times are taken into account and which recognizes the probabilistic nature of the situation involved; on the other hand, the movement of trucks along the haul roads is calculated by using standard simulation. This last technique enables each vehicle to perform according to its mechanical characteristics and the typical profile of the road. The need of a digital computer is of paramount importance in performing the huge number of calculations. The computer accomplishes the staggering computational and book-keeping work and furnishes necessary means for compressing the time scale by allowing several days' operations to be simulated in a matter of minutes.

### Full Simulation

Because of the fact that this study deals with the development of a new mine there is, sometimes, insufficient data available. Therefore, some assumptions are necessary. The input data for the computer program was obtained from historical data gathered from earlier studies carried out under similar circumstances.

Considering that the data can be described accurately by a standard probability distribution, only characteristic parameters of the distribution indicating a degree of central tendency, such as the mean, and a degree of dispersion, such as the standard deviation, are needed by the computer. Random element times can then be calculated directly with an algebraic equation; this fact allows a reduction in the number of calculations performed and thus the economy as well as the efficiency is improved.

The haulage was explained earlier. The existence of an overhead hopper is contemplated because there are no limitations as far as the type of material to be handled which is not bulky and flows freely. Loading times were obtained from hopper manufacturers and such information is used as input in the program. Table 1. shows loading times for each truck size under study. Data referred to turning, spotting, and dumping times was obtained from a study performed before (Bandeira 1969). Figures for the three types of vehicles considered are given in Table 2.

Table 1. Loading Times Using an Overhead Hopper

| <u>Truck Size (Tons)</u> | <u>Loading Times (min)</u> |
|--------------------------|----------------------------|
| 35                       | 3.5                        |
| 45                       | 3.8                        |
| 50                       | 4.0                        |

---

Table 2. Turning, Spotting, and Dumping Times

| <u>Truck Size (Tons)</u> | <u>Turning, Spotting and Dumping Times (min)</u> | <u>Spotting Time at Storage Bin (min)</u> |
|--------------------------|--|---|
| 35                       | 1.3  | 0.3                                       |
| 45                       | 1.3  | 0.3                                       |
| 50                       | 1.3  | 0.3                                       |

---

A Standard Simulation of Truck Performance

As has previously stated, standard simulation is used here for only one operation in the model -that of determining the theoretical performance of the haul trucks along the road. In this way the actual truck performance can be closely estimated.

Truck performance characteristics are commonly expressed in graphs showing developed tractive effort as a function of truck speed. An example is shown in Figure 2. Rim-pull is equivalent to the tractive effort developed by

the truck's engine and power train, assuming no wheel slip on the roadway. Only a portion -on the order of 75 percent- of the engine's rated power, depending on the speed, is available to create necessary tractive effort, the balance being lost in the power train and accessories. More power is lost at low truck speeds because of greater gear reductions involved. If it were not for this the rim-pull developed would have a hyperbolic relationship with respect to the velocity.

$$\text{Rim-pull} = \frac{K}{\text{Velocity}}$$

In fact, the performance curves of all trucks approximate hyperbolic curves, with small deviations related to gear ratios and torque converter characteristics, within the speed range of the vehicle.

Under load the tractive effort is expended in overcoming the rolling resistance on the road, the grade, and in accelerating the truck and its load. As the truck gains speed the tractive effort available for acceleration diminishes, so that the truck approaches some maximum speed for a given combination of engine power, gross vehicle weight, grade, and road characteristics.

The problem of the designer of truck simulator program is to determine the speed of the truck over each increment of the road and the time consumed in traveling that incre-

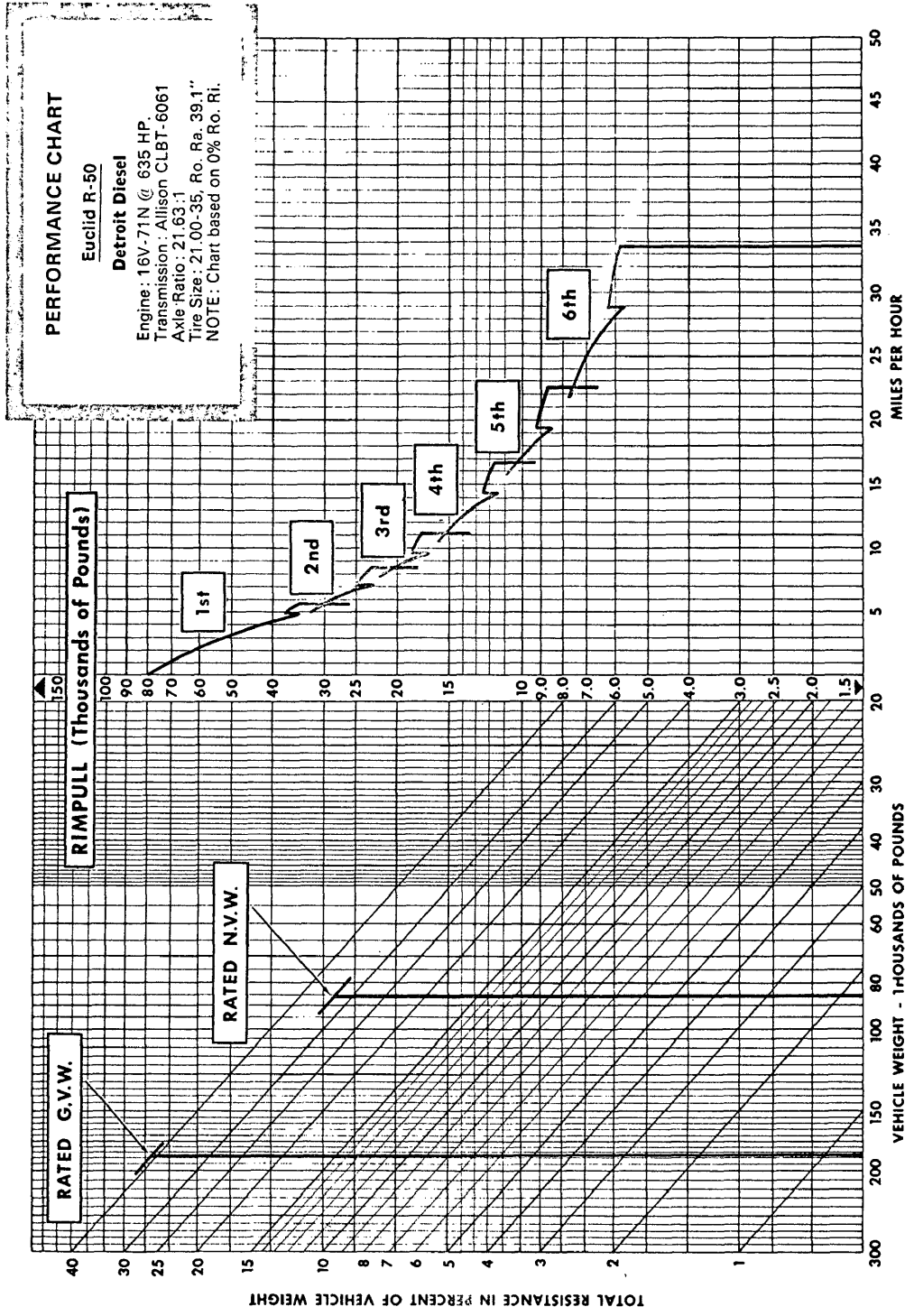


Figure 2. Performance Curve for Euclid R-50 Rear Dump Truck  
 Source: Euclid, Inc.,  
 Form No. 7150-S3  
 Subsidiary of White Motor Corporation  
 Cleveland, Ohio

ment. The summation of these incremental times is the total time required to go from the loading point to the dumping point. A similar calculation determines the time for the return trip.

The problem is complicated by the existence of artificial constraints. For example, speed limits may be imposed in the interest of safety or to prevent accelerated deterioration of the equipment and tires. These may vary erratically, according to the factors affecting the route. These constraints must be taken into consideration, in addition to those pertaining to the road surface, the grade, and related factors.

The acceleration that can be produced by the available rim-pull is obtained from Newton's Second Law of Motion:

$$F = (\text{mass})(\text{acceleration}) \quad \text{or}$$

$$F = ma$$

where  $F$  is the net rim-pull after deduction of the effects of grade and rolling resistance and the mass is that of the truck and its load. It is convenient to express the acceleration as "miles per hour per second" or mphps. It is also convenient to express this as a function of the tractive effort per ton of the vehicle weight.

The following formula is used:

$$a = \frac{\text{Tractive effort/ton of gross vehicle weight}}{\frac{2000 \text{ lbs/ton}}{32.2 \text{ ft/sec}^2} \times \frac{5280 \text{ ft/mile}}{3600 \text{ sec/hr}}}$$

whence

$$a = 0.011 \text{ mphps per pound of tractive effort per ton}$$

A single segment level haul road would be the simplest case to be considered. With a grade resistance of zero the total resistance would be equal to the rolling resistance. The potential velocity is calculated from the relationship existent between velocity and rim-pull in the performance curves (Figure 3.). The truck's acceleration will increase at a rapid rate from standstill. The acceleration rate is reduced as velocity increases until the tractive effort

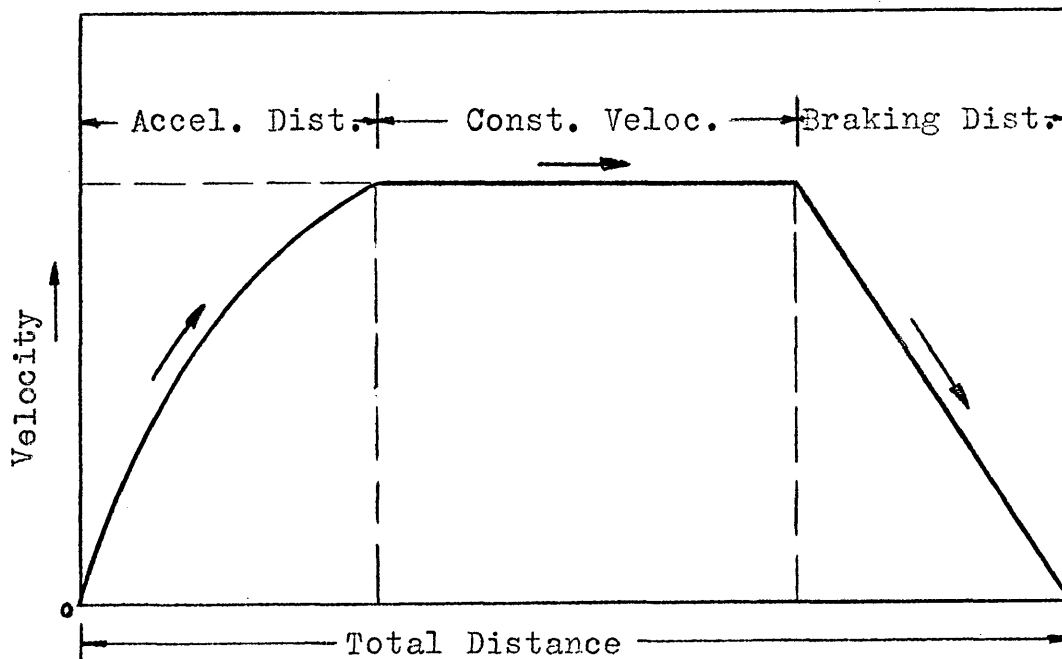


Figure 3. Velocity Profile of a Single Segment Road

equals the combined rolling and grade resistance, at which time a steady state velocity is achieved. This condition will continue until it should be necessary to bring the truck to a stop.

### Simulation Procedures

Simulation demands the use of a high-speed digital computer. Even though moderately complex systems can easily exhaust storage capacity in small computers popular in industry, its ability to "speed-up-time" gives to this technique a strong advantage and usefulness.

The computer program used to determine truck travel times was modified from one developed at the Colorado School of Mines for use in a course in surface mining. Its use permits the evaluation of the performance characteristics of different trucks over different road surfaces and profiles. Three types of trucks, namely 35-, 45-, and 50-ton capacity, over two different surface road types -the one which simulates the existing road with a rolling resistance of 3 percent (60 lbs per ton) and a paved road with a rolling resistance of 1.5 percent (30 lbs per ton)- were tested. One hundred and twelve segments were considered.

This computer program requires the use of two data files: the first one containing descriptive information about truck route and the second one giving vehicle char-

acteristics information. The file with the truck route has features of the road such as length of segment, grade of section, surface code (rolling resistance corresponding to each section), speed limit, and section number. Vehicle characteristics input the following information: net vehicle weight, truck's payload, and performance data on the vehicle: speed at which evaluation is made, tractive effort at that speed, and maximum retarding forces at speed considered.

A listing of this program along with a typical computer output is given in Appendix I.

Ownership and operating costs per unit of the system are determined by means of a computer program written with this purpose. Appendix II. discusses the different aspects taken into consideration in performing such calculation and also shows the computer program listing as well as the results obtained for the three trucks under study.

The stochastic nature of the process is contemplated in the probabilistic simulator. It uses the travel times given by the first simulator, and the unitary costs obtained in the program of costs. The model makes the following assumptions:

1. Trucks are not allowed to pass each other in the same direction
2. No allowance for adjustments due to breakdowns is made

Table 3. Traveling Times Table

| <u>Truck Type</u> | <u>Surf. Code*</u> | <u>Time min.</u> | <u>Adjusted Time Min.</u> |
|-------------------|--------------------|------------------|---------------------------|
| A<br>35-Ton       | 1<br>3             | 297<br>363       | 356<br>436                |
| B<br>45-Ton       | 1<br>3             | 308<br>374       | 370<br>449                |
| C<br>50-Ton       | 1<br>3             | 271<br>348       | 325<br>418                |

\* Code 1 corresponds to a rolling resistance = 1.5%GVW

Code 3 corresponds to a rolling resistance = 3.0%GVW

Table 4. Cost per Ton Table

| <u>Truck Type</u> | <u>Surf. Code</u> | <u>No. of Trucks</u> | <u>Delay Time*</u> | <u>Load. Time*</u> | <u>Hauling Time*</u> | <u>Cost/Ton \$</u> |
|-------------------|-------------------|----------------------|--------------------|--------------------|----------------------|--------------------|
| A<br>35-Ton       | 1<br>3            | 49<br>60             | 311<br>306         | 6218<br>6114       | 828,211<br>1,016,619 | 2.489<br>3.060     |
| B<br>45-Ton       | 1<br>3            | 39<br>47             | 385<br>393         | 7696<br>7852       | 838,369<br>1,043,485 | 2.362<br>2.875     |
| C<br>50-ton       | 1<br>3            | 31<br>40             | 410<br>409         | 8196<br>8172       | 733,875<br>954,077   | 2.097<br>2.728     |

\*Time given in minutes

3. Cycle times are supposed to be distributed according to the normal distribution.

A random number generator available at the Computer's Center Library is used in this program.

The procedure to calculate cost per ton for each type of truck can be described as follows. To start, all kinds of costs previously obtained were converted into a yearly basis. Then by adding them up the total cost per year is found, which divided by the annual production gives the cost per ton.

It is a matter of company policy to define the number of shifts to be worked per year, as well as the duration of each shift. For this problem a working year of 600 shifts of 8 hours each was defined.

The conversion of the several costs per scheduled hour into costs per year was accomplished by multiplying the former by 4800 (total number of working hours per year).

In Appendix III can be found a complete listing of this program as well as a computer output for one of the units analyzed. Results on this section are given in Table 5.

#### Paving Road Estimation

By paving the road in existence the following advantages can be obtained:

1. A reduction in the rolling resistance factor which

leads to a higher vehicle performance, greater tire life, and more truck miles per gallon of fuel consumption.

2. Dust conditions drastically reduced during the dry season, thus safety improved for better visibility,
3. Total mud elimination during the rainy months,
4. In this particular case it would make possible the traffic of vehicles the whole year round.

The road paving cost estimate is performed based on figures furnished by the Colorado Department of Highways. The data used was compiled by the Cost Estimates Unit of the Staff Design Division and can be found in the 1972 Cost Data Publication.

Calculations on this section are given in Appendix IV. Results comparing costs in both types of surfaces are shown in Tables 4., 5., and 6.

Table 5. Difference in Cost per Ton for  
Three Types of Trucks

|            | Surf.<br>Code | Truck Type |       |       |
|------------|---------------|------------|-------|-------|
|            |               | A          | B     | C     |
| Cost/Ton   | 1             | 2.489      | 2.362 | 2.097 |
| \$         | 3             | 3.060      | 2.875 | 2.728 |
| Difference |               | 0.571      | 0.513 | 0.631 |

Table 6. Total Annual Cost Difference  
(Optimum Fleet Obtained)

|               | <u>Unpaved Road</u> | <u>Paved Road</u> | <u>Difference</u> |
|---------------|---------------------|-------------------|-------------------|
| Total Cost \$ | 3,008,984.          | 2,312,991         | 695,993.          |

---

Table 6. shows the annual difference in transportation cost for both alternatives. Savings on the order of \$700,000. per year can be expected, while an annual amortization of \$290,000. for paving the road is estimated. Thus, net savings on the vicinity of \$400,000. per year, which is a 13 percent decrease of the planned annual investment might be the direct benefit of this operation, besides the other advantages earlier mentioned.

RAILROAD HAULAGE SYSTEM ANALYSISGeneral

Because of the rather large distance over which the ore must be hauled it is desirable to consider the possibility of railroad haulage as an alternative. If such a railroad were to be constructed, it has to be the same gauge as the existing Corumba-Santa Cruz Railroad which connects Corumba with Sao Paulo in Brasil and Puerto Suarez with Santa Cruz in Bolivia. It would have the merit of providing an extension of railroad service to the harbor of Puerto Busch on the Paraguay River, with much benefit to this area.

Because of the possibility of such a railroad offering commercial common-carrier service, as well as serving as an ore hauler, its construction would involve numerous problems in addition to those created by the iron ore transportation. Therefore, to establish a comparison on the minimum feasible basis, as if it were to carry only iron, the analysis will be made on the basis of the least favorable condition. If rail haulage is attractive in such a case it will be more attractive when the other factors are included later.

Estimation of railroad costs is difficult because of the tropical jungle through which it must penetrate. One of the best sources of information for estimating cost of jun-

gle penetration is the U. S. Army Transportation Research Command.

### Breaching Jungle Areas

In breaching jungle areas a method investigated by the cited institution has been thoroughly evaluated. A typical operation would be conducted as follows:

A standard tractor, e. g. Caterpillar D8, using its blade cuts a swath of one blade width (about 4 m). It would be necessary to cut three times such a width to have 12 m space. A Caterpillar D8 tractor can easily cut through trees up to 0.5 m wide at the base; it can, in general, avoid larger trees as it cuts its trail because the jungle although often dense, is made up of a preponderance of small diameter trees. Other vehicles such as tracked vehicles would follow along behind the tractor as the trail is cut and carry enough fuel and supplies for the workers. Right after these vehicles the crews building the embankment would follow, building at the same time the rail track. Workers would remain on the job until it was completed. Once the embankment and the rail track is built, a small train would travel back and forth for logistic purposes.

As it was concluded by the U. S. Army, it became clear that primary environmental factors affecting off road mobility in jungle areas are vegetation and drainage of the

area. Another interesting conclusion obtained was the evidence of a definite relationship existent between the ease of vehicular mobility in forest areas and the statistical distribution of size classes of trees.

#### A Formula for Jungle Penetration Time

An equation developed by J. T. Soules of the Rome Plow Co., Cedarton, Georgia, for estimating times for clearing forested areas in temperate zones with standard tractors appeared to be a starting point for developing a numerical value for jungle mobility. This empirical relationship is expressed as follows:

$$T = B + M_1N_1 + M_2N_2 + M_3N_3 + M_4N_4 + DF$$

where

- T : Time per hectare in minutes to clear all trees.
- B : Base time for each tractor per hectare
- N : Number of trees per hectare in each diameter range obtained from field survey
- M : Minutes of cutting time per tree in each diameter range.
- D : Sum of diameter in centimeters for all trees per hectare above 150 cm in diameter
- F : Minutes of cutting time per centimeter of diameter for trees above 150 cm in diameter.

The values of B,  $M_1 - M_4$ , and F can be found on page

91, Engineering/Mining Journal, February 1971. The values of  $N_1 - N_4$ , are characteristics of each particular area under study.

### Jungle Mobility Index

Another and more direct empirical approach was devised that appears to account for more of the significant factors that affects jungle mobility index. These factors become apparent as a result of a botanical, engineering, and time-motion studies that were conducted by the U. S. Army Corps of Engineers. Then, they were correlated with aerial photography already taken. These on-the-ground studies established that the major hindrance to mobility was the vegetation, and that there was a direct relationship between difficulty of mobility and age of forest. The jungle clearing equation shows that the degree of difficulty is a function of a size distribution of trees; however, this distribution is statistically the same for any tropical forest of the same type and age wherever it is located. Since age and type of forest can be determined from aerial photography, it is not necessary to obtain tree counts. For each such statistical distribution of trees, it was found that a given amount of effort was required to penetrate or clear the forest with a given tractor at a given rate. This rate called the "Forest Mobility Rate", is the primary mobility factor and is modi-

fied by secondary factors such as underfoot conditions, rainfall, tractor type, efficiency, and stream crossings.

These primary and secondary factors are related by the empirically derived "Jungle Mobility Index" (JMI) as follows:

$$\text{JMI} = \frac{(\text{F} \times \text{U} \times \text{R}) + \text{S}}{\text{T} \times \text{E}}$$

where:

JMI: Jungle Mobility Index expressed in hour per Km

F : Forest Mobility Rate. These rates can be determined empirically for each type and age of forest. Forest Mobility Rate includes the effects of typical micro-terrain features and soil conditions, unity hr/Km

U : Slope. This is the percent slope upon which the vehicle is working

R : Rainfall. The amount of precipitation in the previous 48 hours is considered. It is given in mm

T : Tractor. This is the factor relating various makes and models of tractors to the Caterpillar D8H equipped with a bulldozer blade, cab guard, winch, and wide-track option. Its value ranges from 0.25 to 1.8

E : Efficiency. This factor considers training and/or experience of tractor operators

S : Streams. Defined as water courses whose water is not visible through the jungle canopy. These do not necessarily contain water but are usually damp. It is computed:  $S = (\text{No. of Streams Xing} \times 0.5) / \text{Distance in Km}$

To obtain the time and ultimately the cost for a given penetration or clearing, the JMI calculated for a certain

forest type is multiplied by the length of the trail to be cut.

### Cost Estimation of Jungle Access Trail

Based upon the two earlier concepts, it is possible to make a cost estimate of a jungle access trail.

Costs of preparing the trails are calculated according to the JMI. It is evaluated as follows:

$$JMI = \frac{(F \times U \times R) + S}{T \times E}$$

where

F : 1.1 hour per Km

U : 1.0 for the total length corresponding to a slope between 0 and 10 percent

R : 1.5 for the total length corresponding to an average rainfall of 1.0 cm per day

T : 1.3 Caterpillar D8 equipped with a Rome KG clearing blade

E : 0.5 it is assumed that operators are experienced with tractors but have never cleared jungle

S :  $(460 \times 0.5)/100 = 2.3$  (Assuming 460 streams in 100 Km)

So, the JMI comes out

$$JMI = 5.5 \text{ hour per Km}$$

The total estimated time to prepare an access trail

over the 68 miles would therefore be 605 hours.

Assuming an 8-hour work day, and an additional 14-day allowance for contingencies, it would take 90 days to complete the trail. The following calculations are performed:

|  |              |
|--|--------------|
| 2 Caterpillar D8 with Rome KG blade<br>@ \$33 per hour for 720 hours         | \$ 48,000.00 |
| 1 Cistern truck to haul fuel @ \$200/day<br>(As per U.S. Corps of Engineers) | 18,000.00    |
| 1 Truck for camp facilities @<br>\$200 per day (Ibid)                        | 18,000.00    |
| General camp facilities (food,<br>electric plants) for 90 days               | 20,000.00    |
|  | <hr/>        |
| Total Owning and operating costs   | \$104,000.00 |
| Overhead and Profit @ 125 percent  | \$130,000.00 |
|  | <hr/>        |
| Total estimated cost for trail opening                                       | \$234,000.00 |
|  | <hr/>        |

The figure obtained seems to be realistic according to information received from earlier operations performed in this area. Cost on embankment construction has been estimated as two-thirds of the road embankment cost which total amount is approximately \$500,000.00 in the length of 68 miles. Thus, the total amount estimated for the railroad embankment is 340,000.00.

Adding up the previous figure obtained, the cost of jungle trail opening plus embankment construction is estimated at \$ 575,000.00 which makes \$8,750.00 per mile.

### Choice of Method of Operation

In using rail haulage one has the choice between short trains operating frequently and longer trains operating less often. If the required tonnage of 1,103,000 tons per year were to be hauled over a period of 300 days, the amount to be moved per day is 3680 tons. On the one-meter gauge used by the connecting lines a 50-ton car would be the approximate maximum that could be handled. Seventy-three of these must be delivered per day.

The maximum tractive effort of a locomotive is limited by its weight, not its horsepower, but the maximum speed that can be reached is determined by the power available. The resistance offered by the locomotive and the ore cars can be estimated by the equations given by Brauns and Orr in the AIME Surface Mining volume. Such equations are known as the Davis Formulas. They are:

$$\text{Locomotive Resistance, lb/ton} = 1.3 + \frac{29}{W} + .03 + \frac{.0024AV^2}{WN}$$

$$\text{Freight car Resistance, lb/ton} = 1.3 + \frac{29}{W} + .045V + \frac{.0005AV^2}{WN}$$

Examination of the computer program used for the trucks will show that it is adaptable to rail haulage as well. By replacing the section concerned with the rolling resistance

of the various kinds of roads with a section based on these equations, and using the proper drawbar characteristics of the locomotive to be used, the round trip of any selected size of train can easily be calculated. The modified program is shown in Appendix V. This modified program was used with two sizes of locomotives and various numbers of cars, with the results shown in Table 7. For convenience the road profile used for trucks is employed for the train, but with the understanding that the actual line would be better engineered.

Table 7. Train Traveling Times Table

| <u>Locomotive Size</u> | <u>Number of car</u> | <u>Loading Time*</u> | <u>Dumping Time*</u> | <u>Traveling Time*</u> | <u>Total Time*</u> |
|------------------------|----------------------|----------------------|----------------------|------------------------|--------------------|
| 120-Ton.               | 25                   | 100                  | 50                   | 236                    | 386                |
|                        | 30                   | 120                  | 60                   | 250                    | 430                |
|                        | 40                   | 160                  | 80                   | 310                    | 550                |
| 80-Ton.                | 25                   | 100                  | 50                   | 250                    | 390                |
|                        | 30                   | 120                  | 60                   | 280                    | 460                |
|                        | 40                   | 160                  | 80                   | 345                    | 585                |

\* Time given in minutes.

Experience shows that in an 8-hour shift there are 450 minutes of working time, the remaining 30 minutes being consumed by travel time to and from the job. Analysis of Table 7. shows that a 120-ton locomotive pulling 30 cars is within

that figure; so, such train is selected for the cost estimation.

A diesel-electric locomotive is considered because of the advantages it presents:

1. High availability
2. Maintenance costs relatively low
3. Production of standard-size units relatively high
4. Low operating costs.

Job analysis and cost related to the selection of rail haulage operation is described in Appendix V. On the basis of this estimation, the expected cost per ton of ore delivered to the port would be approximately \$1.40 or \$0.0206 per ton per mile. This represents a saving over the best truck haulage situation checked of \$0.697 per ton.

## SUMMARY AND CONCLUSIONS

### Summary of Procedure

The steps performed in the development of this study were made in the following sequence:

1. Traveling times for different units on two types of roads were determined. A program developed at Colorado School of Mines, Mining Department, was applied. Results obtained are given in Table 3., and Appendix I shows the listing of this program as well as a computer output for one of the units.
2. Traveling times obtained were increased by a factor of 20 percent up in order to get actual travel times. This correction was done due to the fact that trucks are not operated at their full potential on a day-to-day basis. The advised increment was taken from the paper presented in the AIME preprint no. 68-AR-310.
3. Ownership and operating costs for each unity considered was calculated. Details are shown in Appendix II.
4. Adjusted traveling times were used as data in the probabilistic simulator (Appendix III.). Total loading, traveling, and delay times on the system for each fleet studied is calculated. The total cost per ton for different numbers of units is also given. Re-

- sults obtained are shown in Table 4.
5. A paving cost estimation on the existing road was made. Results can be found in Appendix IV.
  6. The probabilistic simulator was run several times until sufficient results for analysis were available. Difference of cost per ton between the existent road and the paved road was computed. Table 5. shows such differences.
  7. Annual difference in cost between the two kinds of roads were calculated, (Table 6.).
  8. Yearly savings by paving the road were calculated.
  9. A railroad analysis was made. It contemplates aspects such as breaching jungle areas, cost estimation of jungle access trails, railroad equipment selection, estimation of ownership, operating, and repair costs. Traveling times for trains were computed using a modified version of the truck simulator. A complete description of the followed procedure, the results obtained, computer listing, and computer output is shown in Appendix V.
  10. Finally, a comparison between both alternatives was made.

### Conclusions

Based upon the results obtained in this study, the most

suitable system of transportation for the concentrate was found to be a railroad operation.

Truck haulage costs for the optimum fleet of trucks selected -thirty-one 50-ton trucks- was determined at \$2.728 per ton hauled corresponding to \$0.041 per ton per mile. Lower costs were gotten in this system by considering the paving of the road. The figures obtained were \$2.097 per ton or \$0.0308 per ton per mile.

On the other hand, the lowest rail haulage cost found was \$1.40 per ton transported or \$0.0206 per ton per mile.

Yearly transportation savings on the order of 34 percent of the annual investment can be expected by building and operating a railroad system.

RECOMMENDATIONS

The selection of trucks or trains as the primary method of transport cannot rest on the haulage cost alone; many other factors contribute to the total costs of production and delivery at the Argentinian market. This total cost must be kept as low as possible if the commercial success of the mining venture is to be assured.

The following point should be investigated further before a final decision is made:

1. The transporting capabilities of the Paraguay-Parana River. What must be the nature of the barges or vessels that will move the ore from Puerto Busch to the steel mill? This will affect the design of the transfer facilities and their costs.
2. The variability of the ore and the necessity for separating the various qualities and grades. If the ore must be handled in a large number of categories this will affect the problems of loading facilities and unloading and storage facilities. The arrival of many trucks spread out over a 24-hour period will require a different design, and cost, of the port facilities than will the arrival of a few trains at longer intervals.
3. The effect of changes in scale of operation. If it be

assumed that the eventual size of the mining operations may double, for example, this will require enlargement of the facilities on both ends and may result in the physical overloading of the intervening road or railroad. Enlargement costs may differ, affecting the relative superiority of one system over the other.

4. The social effects of each choice. The building of either a large, heavy-duty highway, to carry heavy traffic, or of a new railroad in an hitherto undeveloped area, is sure to create many new social problems and opportunities. Not only should the proper choice result in the lowest total capital and operating costs, it should also create the maximum of benefit to the area traversed.
5. The improvements that might be obtained through changes in size of the transportation equipment. This work so far has been done on the assumption that 50-ton trucks or cars were the largest that could be handled effectively over the road or on the meter-gauge railroad. This assumption needs to be verified over the range of applicable technology and any opportunity for more efficiently sized haulage units to be used investigated.
6. The influence of various local conditions on the performance of the equipment needs more study. For example, high ambient temperature may require lower speed limits to prevent rapid tire deterioration.

APPENDIX I

STANDARD SIMULATION PROGRAM TO  
DETERMINE AVERAGE HAUL TIMES

```

C *****
C
C
C "TRUCK.F4" (TRUCK EVALUATION PROGRAM). ADAPTED FOR MFP-10
C TIME-SAVING SYSTEM. CONVERSATIONAL INPUT. REQUIRES TWO
C DATA-FILES:
C TWO FILES ARE REQUIRED, WITH ANOTHER OPTIONAL. THESE ARE:
C A. FILE CONTAINING DESCRIPTIVE INFORMATION ABOUT TRUCK ROUTE:
C     INITIAL DESCRIPTIVE LINE FOR IDENTIFICATION OF ROUTE
C     SUBSEQUENT LINES TO DESCRIBE EACH SECTION:
C         (A) LENGTH OF SECTION, FEET
C         (B) GRADE OF SECTION, PERCENT
C         (C) SURFACE CODE:
C             1=CONCRETE OR ASPHALT
C             2=WELL-MAINTAINED HARD FRY DIRT, GRAVEL
C             3=DRY DIRT AND GRAVEL, NOT FIRMLY PACKED
C             4=WET MUDDY SURFACE ON FIRM BASE, OR SOFT UN-
C             PLOWED DIRT, POORLY MAINTAINED.
C             5=PACKED SNOW
C             6=LOOSE SNOW, 4 INCHES
C             7=UNPACKED DIRT FILLS
C             8=LOOSE SAND OR GRAVEL
C             9=DEEPLY RUTTED, OR SOFT SPONGY BASE
C         (D) SPEED LIMIT, MPH
C         (E) SECTION NUMBER. COMMONLY A DIGIT BUT -
C             L   IF TO DESIGNATE LOADING. OTHERS THEN ARE C.
C             D   IF TO DESIGNATE DUMPING. OTHER VALUES ZERO.
C
C B. FILE WITH INFORMATION ABOUT EQUIPMENT UNDER STUDY:
C     FIRST FIVE LINES MAY CONTAIN ANY DESIRED INFORMATION,
C     IN ANY FORMAT. WILL BE DUPLICATED IN OUTPUT.
C     SIXTH LINE CONTAINS EMPTY WT AND WT OF LOAD (NOMINAL)
C     SEVENTH AND SUBSEQUENT LINES CONTAIN PERFORMANCE DATA
C     ON EQUIPMENT BEING STUDIED:
C         (A) SPEED (INTEGER) AT WHICH EVALUATION MADE
C         (B) TRACTIVE EFFORT (FIM-PULL) AT THAT SPEED, LBS.
C         (C) MAX RETARDATION THRU TEARS AT THAT SPEED, LBS.
C     DATA SHOULD COVER WHOLE WORKING RANGE OF SPEEDS.
C
C C. OPTIONAL FILE FOR AUTOMATIC INPUT OF CONTROL INFORMATION:
C     LINE 1: OPERATING ELEVATION, FT.
C     LINE 2: ENGINE TYPE. 2=TWO CYCLE, 4=4 CYCLE
C     LINE 3: NORMAL LOADING AND DUMPING TIMES, SECONDS.
C     LINE 4: PER-CENT TO DOWNRATE ENGINE FOR WEAR.
C     LINE 5: PERCENT OF RATED LOAD TO BE CARRIED.
C     LINE 6: ACCEPTABLE ACCELERATION, MPH PER SECOND.
C     LINE 7: PERCENT OF SHIFT TIME TRUCK IS OPERATING.
C
C WRITTEN BY C.O.FRUSH, COLO. SCH. OF MINES. NOV., 1971
C
C *****

```

```

C
  DIMENSION CAPT1(14),CAPT2(14),CAPT3(14),CAPT4(14),CAPT5(14)
  DIMENSION CAPT6(11),KSP(61),FPF(61),FPF(61)
  DIMENSION LEN(250),GRAC(250),ISUP(250),ISPL1(250),SEC(250)
  INTEGER SEC
  CALL ERNSFT(10)
  WRITE(4,1)
  SP=0
1  FORMAT(1X,'NAME OF FILE WITH ROUTE INFORMATION? ',S)
  READ(4,2)NAME1
2  FORMAT(A5)
  CALL IFILE(1,NAME1)
  WRITE(4,3)
3  FORMAT(1X,'NAME OF FILE WITH VEHICLE INFORMATION? ',S)
  READ(4,2)NAME2
  CALL IFILE(2,NAME2)
  ITEST=0
  WRITE(4,4)
4  FORMAT(1X,'HOW IS CONTROL INFORMATION TO BE INPUT?
  1 1=TTY, 2=FROM STORED FILE. ',S)
  READ(4,5)IHOW
5  FORMAT(I)
  IF(IHOW.NE.2)GO TO 15
  IT=3
  WRITE(4,6)
6  FORMAT(1X,'NAME OF FILE WITH RUN-CONTROL DATA? ',S)
  TOTIM=0.
  READ(4,2)NAME3
  CALL IFILE(3,NAME3)
  GO TO 500
  TOTM=0.0
15 IT=4
500 WRITE(4,10)
10  FORMAT(1X,'WHAT IS OPERATING ELEVATION? ',S)
  READ(IT,20)ELEV
  IF(IT.EQ.4)GO TO 25
  WRITE(4,526)ELEV
526 FORMAT(1X,F10.2)
20  FORMAT(F)
25  WRITE(4,30)
30  FORMAT(1X,'ENGINE TYPE? 2-CYCLE=2, 4-CYCLE=4 ',S)
  READ(IT,20)ENG
  IF(IT.EQ.4)GO TO 570
  WRITE(4,526)ENG
570 IF(ENG-2)269,271,269
269 IF(ENG-4)270,274,270
270 WRITE(4,40)
  IF(IHOW.NE.2)GO TO 25
40  FORMAT(1X,'ONLY CODES 2 OR 4 CAN BE ACCEPTED. RE-ENTER.',S)
  GO TO 2190
271 IF(ELEV-6000)272,273,273

```

```

272  PFAC=1.0-(ELEV/1000.)*0.01333
      GO TO 280
273  PFAC=0.92-0.03*(ELEV-6000.)/1000.
      GO TO 280
274  IF(ELEV-1000.) 276,275,275
275  PFAC=1.00-0.03*(ELEV-1000.)/1000.
      GO TO 280
276  PFAC= 1.0
280  WRITE(4,50)
50   FORMAT(1H , 'WHAT ARE NORMAL LOADING AND
      1 DUMPING TIMES, SECONDS? ', $)

      READ(11,55) ILOAD, IDUMP
      IF(11.EQ.4) GO TO 780
      WRITE(4,756) ILOAD, IDUMP
756  FORMAT(1X, 14, 2X, 14)
55   FORMAT(2I)

760  WRITE(4,60)
60   FORMAT(1H , 'BY WHAT % SHALL TRUCK BE DOWN-RATED FOR WEAR? ', $)
      READ(11,80) RATE
      IF(11.EQ.4) GO TO 810
      WRITE(4,526) RATE
810  WRITE(4,65)
65   FORMAT(1H , 'PERCENT OF RATED LOAD TO BE CARRIED? ', $)
      READ(11,20) PCTL
      IF(11.EQ.4) GO TO 840
      WRITE(4,526) PCTL
840  WRITE(4,70)
70   FORMAT(1H , 'WHAT IS ACCEPTABLE ACCELERATION, MPH PER SEC.? ', $)
      READ(11,20) AC
      IF(11.EQ.4) GO TO 870
      WRITE(4,526) AC
870  ACCEL=AC*5280./3600.
      WRITE(4,72)
72   FORMAT(1H , 'WHAT PCT OF SHIFT TIME IS TRUCK OPERATING? ', $)
      READ(11,20) EFF
      IF(11.EQ.4) GO TO 919
      WRITE(4,526) EFF
350  FORMAT(16A5)
919  READ(2,350) CAP1
      READ(2,350) CAP2
      READ(2,350) CAP3
      READ(2,350) CAP4
      READ(2,350) CAP5
400  READ(2,80) WTEFF, FTLD
80   FORMAT(5A, 2F)
      READ(1,350) CAP6
      WRITE(6,350) CAP6
355  FORMAT(1X, 14A5)
      WRITE(6,355) CAP1

```

```

WRITE(C,355)CAP12
WRITE(C,355)CAP13
WRITE(C,355)CAP14
WRITE(C,355)CAP15
360  FORMAT(1E-, 'SEC      LEN  BREAK  TIME      TOTAL SPEED  EXIT
      1    TONS    TON    TOTAL')
362  FORMAT(1A, '      FT      DIS    SEC      TIME LIMIT  MPH
      1          MILES    TON-MIL')
720  WRITE(C,360)
      WRITE(C,362)
      N=0
432  N=N+1
      IF(N-61)434,1172,1172
434  READ(2,90,END=1172,ERR=1250)KSP(N-1),RPF(N-1),RPF(N-1)
      GO TO 432
1172  N=0
1174  N=N+1
      READ(1,95,END=1205,ERR=1275)LEN(M),GRA(M),ISUR(M),
      ISPLT(M),SEC(M)
      GO TO 1174
93  FORMAT(5X,1,2F)
95  FORMAT(5X,1,F,1,1,A3)
1205  M=M-1
      DO 2010 I=1,M
      IF(SEC(I).EQ.'L')GO TO 1400
      IF(SEC(I).EQ.'D')GO TO 1430
      GO TO(880,900,920,940,960,980,1000,1012,1016)ISUR(I)
850  WRITE(C,860)SEC(I)
860  FORMAT(1E-, 'SURFACE CODE ERROR IN SECTION ',A2)
      GO TO 1500
880  SGRA=0.015
      GO TO 1020
900  SGRA=0.02
      GO TO 1020
920  SGRA=0.03
      GO TO 1020
940  SGRA=0.04
      GO TO 1020
960  SGRA=0.025
      GO TO 1020
980  SGRA=0.045
      GO TO 1020
1000  SGRA=0.08
      GO TO 1020
1012  SGRA=0.10
      GO TO 1020
1016  SGRA=0.16
1020  TGR=GRA(I)/100+SGRA+0.02
1030  LEN1=LEN(I)
      JSPL=ISPLT(I)
1040  LEN1=LEN1-2

```

```

IF(LEN1.LE.100)JSPL=ISPLT(I+1)+1
IF(LEN1)1060,1060,1090
1060  DIS=LEN1+2.00001
      IDEST=1
      GO TO 1110
1090  DIS=2.00001
      IDEST=2
1110  IF(SP)1500,1120,1120
1120  JSP=SP*3600/5280 +0.5
      DO 1150 IX=1,61,1
      IF(JSP-(IX-1))1150,1160,1150
1150  CONTINUE
1160  IF(JSP-JSPL)1170,1170,1240
1170  PULL=1000.*RPP(IX-1)*(1.-DRATE/100.)*PFAC
      DRAG=GVW*TGR
      DIFF=PULL-DRAG
      ACC=32.2*DIFF/GVW
      IF(ACC.LE.ACCEL)GO TO 1230
1220  ACC=ACCEL
1230  GO TO 1330
1240  DRAG=GVW*TGR
      ACC=32.2*DRAG/GVW
      IF(ACC.GE.ACCEL)GO TO 1730
      TOTDR=DRAG+REIARD
      ACC=32.2*TOTDR/GVW
      IF(ACC.GE.ACCEL)GO TO 1730
      BDIS=BDIS+DIS
1730  ACC=-ACCEL
1330  QUANT=SP**2+2.*ACC*DIS
      IF(QUANT.LT.0)QUANT=0.0
1770  T=(-SP+SQRT(QUANT))/ACC
      SP=SP+ACC*T

      GO TO 1450
1400  T=ILOAD
      GVW=WTEMP+W TLD*PCTLD/100.
      GO TO 1445
1430  T=IDUMP
      GVW=WTEMP
1445  IDEST=1
1450  TIME=TIME+T
      TOTIM=TOTIM+T
      GO TO (1480,1040)IDEST
1480  AVEL=DIS*3600./(T*5280.)
      TONS=(GVW-WTEMP)/2000.
      TONMI=TONS*LEN(I)/5280
      TOTM=TOTM+TONMI
      WRITE(6,1540)SEC(I),LEN(I),BDIS,TIME,TOTIM,ISPLT(I),AVFL,
      1TONS,TONMI,TOTM
1540  FORMAT(1X,A3,2X,I5,2X,F5.0,2X,F5.0,2X,F6.0,2X,I2,3X,
      1F5.2,2X,F6.2,2X,F6.1,2X,F7.1)

```

```
      EDIS=0.
      TIME=0.
2010  CONTINUE
1230  WRITE(6,1580)
1580  FORMAT(1H-, 'END OF DATA')
      GO TO 1300
1250  WRITE(6,125)
125   FORMAT(1H , 'ERROR')
1275  CONTINUE
1300  TRIPS=8*3600.*(EFF/100.)/TOTIM
      SHTONS=TRIPS*WTLL*PCTLD/200000.
      SHTMI=TRIPS*101M
1920  WRITE(6,1920)TRIPS
1920  FORMAT(1X, 'TRUCK MAKES ',F6.2, ' TRIPS PER SHIFT.')
```

WRITE(6,1940)SHTONS

```
1940  FORMAT(1X, 'IT CARRIES ',F8.1, ' TONS DURING THE SHIFT.')
```

WRITE(6,1960)SHTMI

```
1960  FORMAT(1X, 'THIS EQUALS ',F8.1, ' TON-MILES/SHIFT.')
```

```
1500  WRITE(6,2100)
2100  FORMAT(1H-, 'TRUCK STOPPED.')
```

```
2190  WRITE(6,2200)
2200  FORMAT(1H1, 'END OF JOB')
      END
```

.

0010 DATA ON MOUNTY ROAD. ROLLING RESISTANCE CODE "1".  
 0020 EUCLID 55-TON BEAF DUMP  
 0030 ENGINE - CUMMINS VT-1710-C 0635 HP.  
 0040 TRANSMISSION - ALLISON CLFI-6061  
 0050 AXLE RATIO - 21.63: 1  
 0060 TIRE SIZE - 21.00-35, NO. PA. 39.1"

| SEC | LEN<br>FT | BRAKE<br>DIS | TIME<br>SEC | TOTAL<br>TIME | SPEED<br>LIMIT | EXIT<br>MPH | TON<br>MILES | TOTAL<br>TON-MIL |
|-----|-----------|--------------|-------------|---------------|----------------|-------------|--------------|------------------|
| L   | 0         | 0.           | 240.        | 240.          | 0              | 0.00        | 0.0          | 0.0              |
| 1   | 1640      | 0.           | 62.         | 302.          | 60             | 24.57       | 0.0          | 15.5             |
| 2   | 2625      | 0.           | 56.         | 358.          | 60             | 33.50       | 0.0          | 40.4             |
| 3   | 1312      | 0.           | 31.         | 389.          | 60             | 25.35       | 0.0          | 52.8             |
| 4   | 1640      | 0.           | 46.         | 435.          | 60             | 23.51       | 0.0          | 63.3             |
| 5   | 984       | 0.           | 25.         | 461.          | 60             | 22.53       | 0.0          | 77.7             |
| 6   | 7210      | 0.           | 183.        | 644.          | 60             | 26.50       | 0.0          | 146.7            |
| 7   | 5995      | 0.           | 136.        | 780.          | 60             | 32.27       | 0.0          | 221.9            |
| 8   | 2297      | 0.           | 61.         | 841.          | 60             | 22.50       | 0.0          | 223.7            |
| 9   | 2953      | 0.           | 89.         | 930.          | 60             | 22.69       | 0.0          | 251.6            |
| 10  | 656       | 0.           | 17.         | 947.          | 60             | 30.00       | 0.0          | 257.9            |
| 11  | 2297      | 0.           | 60.         | 1007.         | 60             | 24.10       | 0.0          | 279.6            |
| 12  | 984       | 0.           | 25.         | 1032.         | 60             | 29.05       | 0.0          | 288.9            |
| 13  | 1640      | 0.           | 40.         | 1072.         | 60             | 27.19       | 0.0          | 304.5            |
| 14  | 2625      | 0.           | 63.         | 1135.         | 60             | 29.35       | 0.0          | 329.3            |
| 15  | 1640      | 0.           | 45.         | 1180.         | 60             | 22.50       | 0.0          | 344.8            |
| 16  | 1312      | 0.           | 37.         | 1217.         | 60             | 25.13       | 0.0          | 357.3            |
| 17  | 984       | 0.           | 32.         | 1249.         | 60             | 18.47       | 0.0          | 366.6            |
| 18  | 2953      | 0.           | 84.         | 1332.         | 60             | 25.93       | 0.0          | 394.6            |
| 19  | 3937      | 0.           | 94.         | 1427.         | 60             | 30.35       | 0.0          | 431.8            |
| 20  | 2953      | 0.           | 71.         | 1497.         | 60             | 27.11       | 0.0          | 459.8            |
| 21  | 328       | 0.           | 9.          | 1506.         | 60             | 25.33       | 0.0          | 462.9            |
| 22  | 2625      | 0.           | 69.         | 1574.         | 60             | 26.50       | 0.0          | 487.8            |
| 23  | 984       | 0.           | 21.         | 1596.         | 60             | 33.50       | 0.0          | 497.1            |
| 24  | 656       | 0.           | 16.         | 1611.         | 60             | 24.36       | 0.0          | 503.3            |
| 25  | 2952      | 0.           | 79.         | 1690.         | 60             | 26.46       | 0.0          | 531.3            |
| 26  | 1312      | 0.           | 29.         | 1719.         | 60             | 33.50       | 0.0          | 543.7            |
| 27  | 2297      | 0.           | 59.         | 1779.         | 60             | 22.50       | 0.0          | 565.4            |
| 28  | 1968      | 0.           | 55.         | 1833.         | 60             | 25.66       | 0.0          | 584.1            |
| 29  | 2624      | 0.           | 64.         | 1897.         | 60             | 29.06       | 0.0          | 608.9            |
| 30  | 1640      | 0.           | 43.         | 1940.         | 60             | 24.48       | 0.0          | 624.4            |
| 31  | 3609      | 0.           | 88.         | 2028.         | 60             | 29.42       | 0.0          | 658.6            |
| 32  | 1312      | 0.           | 27.         | 2055.         | 60             | 33.50       | 0.0          | 671.0            |
| 33  | 1969      | 0.           | 58.         | 2114.         | 60             | 17.60       | 0.0          | 689.7            |
| 34  | 984       | 0.           | 27.         | 2140.         | 60             | 31.00       | 0.0          | 699.0            |
| 35  | 982       | 0.           | 27.         | 2167.         | 60             | 21.30       | 0.0          | 708.3            |
| 36  | 328       | 0.           | 9.          | 2176.         | 60             | 26.29       | 0.0          | 711.4            |
| 37  | 656       | 0.           | 19.         | 2195.         | 60             | 20.89       | 0.0          | 717.6            |
| 38  | 1640      | 0.           | 37.         | 2233.         | 60             | 33.50       | 0.0          | 733.2            |
| 39  | 1312      | 0.           | 40.         | 2273.         | 60             | 16.24       | 0.0          | 745.6            |
| 40  | 1969      | 0.           | 53.         | 2325.         | 60             | 30.79       | 0.0          | 764.2            |

|    |       |    |      |       |    |       |     |        |
|----|-------|----|------|-------|----|-------|-----|--------|
| 41 | 1640  | 0. | 43.  | 2369. | 60 | 22.50 | 0.0 | 779.8  |
| 42 | 2953  | 0. | 81.  | 2449. | 60 | 26.14 | 0.0 | 807.7  |
| 43 | 1640  | 0. | 38.  | 2487. | 60 | 32.30 | 0.0 | 823.2  |
| 44 | 1312  | 0. | 32.  | 2519. | 60 | 24.47 | 0.0 | 835.7  |
| 45 | 934   | 0. | 23.  | 2542. | 60 | 33.46 | 0.0 | 845.0  |
| 46 | 328   | 0. | 7.   | 2549. | 60 | 31.36 | 0.0 | 848.1  |
| 47 | 984   | 0. | 20.  | 2570. | 60 | 33.49 | 0.0 | 857.4  |
| 48 | 3609  | 0. | 80.  | 2650. | 60 | 28.16 | 0.0 | 891.6  |
| 49 | 2952  | 0. | 63.  | 2713. | 60 | 33.49 | 0.0 | 919.5  |
| 50 | 1640  | 0. | 54.  | 2767. | 60 | 15.65 | 0.0 | 935.1  |
| 51 | 3281  | 0. | 95.  | 2862. | 60 | 26.00 | 0.0 | 966.1  |
| 52 | 4921  | 0. | 105. | 2967. | 60 | 33.50 | 0.0 | 1012.7 |
| 53 | 6890  | 0. | 163. | 3130. | 60 | 26.50 | 0.0 | 1078.2 |
| 54 | 1969  | 0. | 45.  | 3175. | 60 | 33.31 | 0.0 | 1096.6 |
| 55 | 656   | 0. | 15.  | 3190. | 60 | 25.84 | 0.0 | 1102.9 |
| 56 | 1312  | 0. | 29.  | 3219. | 60 | 33.50 | 0.0 | 1115.3 |
| 57 | 1312  | 0. | 40.  | 3259. | 60 | 16.24 | 0.0 | 1127.7 |
| 58 | 2297  | 0. | 54.  | 3313. | 60 | 33.50 | 0.0 | 1149.5 |
| 59 | 1969  | 0. | 42.  | 3355. | 60 | 30.35 | 0.0 | 1168.1 |
| 60 | 3937  | 0. | 81.  | 3437. | 60 | 33.49 | 0.0 | 1205.4 |
| 61 | 4921  | 0. | 113. | 3549. | 60 | 27.11 | 0.0 | 1252.0 |
| 62 | 2953  | 0. | 87.  | 3636. | 60 | 22.51 | 0.0 | 1279.9 |
| 63 | 3937  | 0. | 106. | 3742. | 60 | 26.50 | 0.0 | 1317.2 |
| 64 | 656   | 0. | 27.  | 3769. | 60 | 11.61 | 0.0 | 1323.4 |
| 65 | 984   | 0. | 27.  | 3796. | 60 | 33.91 | 0.0 | 1332.8 |
| 66 | 3937  | 0. | 80.  | 3877. | 60 | 33.47 | 0.0 | 1370.0 |
| 67 | 8530  | 0. | 205. | 4082. | 60 | 26.50 | 0.0 | 1450.6 |
| 68 | 9842  | 0. | 296. | 4378. | 60 | 22.50 | 0.0 | 1544.0 |
| 69 | 8202  | 0. | 216. | 4594. | 60 | 26.49 | 0.0 | 1621.7 |
| 70 | 4593  | 0. | 98.  | 4692. | 60 | 33.49 | 0.0 | 1665.8 |
| 71 | 2953  | 0. | 79.  | 4771. | 60 | 22.50 | 0.0 | 1693.1 |
| 72 | 1640  | 0. | 60.  | 4831. | 60 | 17.25 | 0.0 | 1720.7 |
| 73 | 2624  | 0. | 66.  | 4897. | 60 | 32.89 | 0.0 | 1733.5 |
| 74 | 1966  | 0. | 50.  | 4947. | 60 | 22.49 | 0.0 | 1752.2 |
| 75 | 4265  | 0. | 95.  | 5042. | 60 | 33.49 | 0.0 | 1792.5 |
| 76 | 8202  | 0. | 197. | 5239. | 60 | 26.50 | 0.0 | 1870.2 |
| 77 | 2625  | 0. | 85.  | 5324. | 60 | 18.66 | 0.0 | 1895.1 |
| 78 | 2953  | 0. | 71.  | 5395. | 60 | 33.48 | 0.0 | 1923.0 |
| 79 | 2625  | 0. | 69.  | 5464. | 60 | 22.50 | 0.0 | 1947.9 |
| 80 | 5577  | 0. | 148. | 5613. | 60 | 26.50 | 0.0 | 2000.7 |
| 81 | 1640  | 0. | 35.  | 5648. | 60 | 33.50 | 0.0 | 2016.2 |
| 82 | 4265  | 0. | 119. | 5767. | 60 | 22.50 | 0.0 | 2056.6 |
| 83 | 5249  | 0. | 140. | 5967. | 60 | 26.50 | 0.0 | 2126.3 |
| 84 | 3937  | 0. | 85.  | 5992. | 60 | 33.49 | 0.0 | 2142.6 |
| 85 | 4593  | 0. | 129. | 6121. | 60 | 22.50 | 0.0 | 2187.1 |
| 86 | 6234  | 0. | 165. | 6286. | 60 | 26.50 | 0.0 | 2246.1 |
| 87 | 4593  | 0. | 95.  | 6381. | 60 | 33.50 | 0.0 | 2289.6 |
| 88 | 2297  | 0. | 64.  | 6445. | 60 | 20.56 | 0.0 | 2311.4 |
| 89 | 3281  | 0. | 77.  | 6522. | 60 | 33.49 | 0.0 | 2342.5 |
| 90 | 10498 | 0. | 256. | 6777. | 60 | 26.50 | 0.0 | 2441.9 |
| 91 | 2625  | 0. | 58.  | 6835. | 60 | 33.49 | 0.0 | 2466.7 |

|     |       |      |      |        |    |       |     |        |
|-----|-------|------|------|--------|----|-------|-----|--------|
| 92  | 2297  | 0.   | 64.  | 6899.  | 60 | 20.56 | 0.0 | 2485.5 |
| 93  | 9186  | 0.   | 243. | 7142.  | 60 | 26.50 | 0.0 | 2575.5 |
| 94  | 2953  | 0.   | 71.  | 7213.  | 60 | 29.37 | 0.0 | 2603.4 |
| 95  | 10170 | 0.   | 259. | 7472.  | 60 | 26.50 | 0.0 | 2699.7 |
| 96  | 1640  | 0.   | 48.  | 7519.  | 60 | 22.50 | 0.0 | 2715.3 |
| 97  | 1968  | 0.   | 48.  | 7567.  | 60 | 31.89 | 0.0 | 2733.9 |
| 98  | 4265  | 0.   | 100. | 7667.  | 60 | 27.03 | 0.0 | 2774.3 |
| 99  | 4921  | 0.   | 114. | 7782.  | 60 | 31.71 | 0.0 | 2820.9 |
| 100 | 5577  | 0.   | 186. | 7967.  | 60 | 18.49 | 0.0 | 2873.7 |
| 101 | 6562  | 0.   | 177. | 8144.  | 60 | 26.50 | 0.0 | 2925.9 |
| 102 | 3281  | 0.   | 79.  | 8223.  | 60 | 29.59 | 0.0 | 2966.9 |
| 103 | 5249  | 0.   | 132. | 8354.  | 60 | 26.50 | 0.0 | 3016.6 |
| 104 | 1969  | 0.   | 48.  | 8402.  | 60 | 28.84 | 0.0 | 3035.3 |
| 105 | 2297  | 0.   | 66.  | 8468.  | 60 | 22.50 | 0.0 | 3057.0 |
| 106 | 15747 | 0.   | 410. | 8878.  | 60 | 26.50 | 0.0 | 3206.1 |
| 107 | 2953  | 0.   | 63.  | 8941.  | 60 | 33.50 | 0.0 | 3234.1 |
| 108 | 557   | 0.   | 11.  | 8952.  | 60 | 33.50 | 0.0 | 3239.4 |
| 109 | 4951  | 0.   | 130. | 9082.  | 60 | 23.56 | 0.0 | 3286.3 |
| 110 | 1969  | 0.   | 45.  | 9127.  | 60 | 33.49 | 0.0 | 3304.9 |
| 111 | 2297  | 0.   | 47.  | 9173.  | 60 | 33.47 | 0.0 | 3326.7 |
| 112 | 3500  | 102. | 78.  | 9251.  | 60 | 25.95 | 0.0 | 3359.8 |
| D   | 0     | 0.   | 120. | 9371.  | 0  | 0.01  | 0.0 | 3359.8 |
| 113 | 3500  | 0.   | 72.  | 9444.  | 60 | 33.49 | 0.0 | 3359.8 |
| 114 | 2297  | 0.   | 47.  | 9490.  | 60 | 33.49 | 0.0 | 3359.8 |
| 115 | 1969  | 0.   | 40.  | 9530.  | 60 | 33.50 | 0.0 | 3359.8 |
| 116 | 4951  | 0.   | 101. | 9631.  | 60 | 33.50 | 0.0 | 3359.8 |
| 117 | 557   | 0.   | 11.  | 9643.  | 60 | 33.50 | 0.0 | 3359.8 |
| 118 | 2953  | 0.   | 60.  | 9703.  | 60 | 33.47 | 0.0 | 3359.8 |
| 119 | 15747 | 0.   | 321. | 10023. | 60 | 33.49 | 0.0 | 3359.8 |
| 120 | 2297  | 0.   | 47.  | 10070. | 60 | 33.50 | 0.0 | 3359.8 |
| 121 | 1969  | 0.   | 40.  | 10110. | 60 | 33.47 | 0.0 | 3359.8 |
| 122 | 5249  | 0.   | 107. | 10217. | 60 | 33.50 | 0.0 | 3359.8 |
| 123 | 3281  | 0.   | 67.  | 10284. | 60 | 33.49 | 0.0 | 3359.8 |
| 124 | 6562  | 0.   | 134. | 10417. | 60 | 33.50 | 0.0 | 3359.8 |
| 125 | 5577  | 0.   | 113. | 10531. | 60 | 33.50 | 0.0 | 3359.8 |
| 126 | 4921  | 0.   | 100. | 10631. | 60 | 33.50 | 0.0 | 3359.8 |
| 127 | 4165  | 0.   | 85.  | 10715. | 60 | 33.48 | 0.0 | 3359.8 |
| 128 | 1968  | 0.   | 40.  | 10756. | 60 | 33.49 | 0.0 | 3359.8 |
| 129 | 1640  | 0.   | 33.  | 10789. | 60 | 33.52 | 0.0 | 3359.8 |
| 130 | 10170 | 0.   | 207. | 10996. | 60 | 33.49 | 0.0 | 3359.8 |
| 131 | 2953  | 0.   | 60.  | 11056. | 60 | 33.48 | 0.0 | 3359.8 |
| 132 | 9168  | 0.   | 187. | 11243. | 60 | 33.51 | 0.0 | 3359.8 |
| 133 | 2297  | 0.   | 47.  | 11289. | 60 | 33.52 | 0.0 | 3359.8 |
| 134 | 2625  | 0.   | 53.  | 11343. | 60 | 33.50 | 0.0 | 3359.8 |
| 135 | 10498 | 0.   | 214. | 11556. | 60 | 33.50 | 0.0 | 3359.8 |
| 136 | 3231  | 0.   | 66.  | 11622. | 60 | 33.50 | 0.0 | 3359.8 |
| 137 | 2297  | 0.   | 47.  | 11669. | 60 | 33.50 | 0.0 | 3359.8 |
| 138 | 4593  | 0.   | 94.  | 11762. | 60 | 33.48 | 0.0 | 3359.8 |
| 139 | 6234  | 0.   | 127. | 11889. | 60 | 33.49 | 0.0 | 3359.8 |
| 140 | 4593  | 0.   | 93.  | 11983. | 60 | 33.52 | 0.0 | 3359.8 |
| 141 | 3937  | 0.   | 80.  | 12063. | 60 | 33.48 | 0.0 | 3359.8 |

|     |      |    |      |        |    |       |     |        |
|-----|------|----|------|--------|----|-------|-----|--------|
| 142 | 5249 | 0. | 167. | 12171. | 60 | 33.51 | 0.0 | 3359.8 |
| 143 | 4265 | 0. | 87.  | 12258. | 60 | 33.49 | 0.0 | 3359.8 |
| 144 | 1640 | 0. | 33.  | 12290. | 60 | 33.48 | 0.0 | 3359.8 |
| 145 | 5577 | 0. | 114. | 12400. | 60 | 33.51 | 0.0 | 3359.8 |
| 146 | 2625 | 0. | 53.  | 12457. | 60 | 33.52 | 0.0 | 3359.8 |
| 147 | 2953 | 0. | 60.  | 12517. | 60 | 33.47 | 0.0 | 3359.8 |
| 148 | 2625 | 0. | 53.  | 12570. | 60 | 33.50 | 0.0 | 3359.8 |
| 149 | 8202 | 0. | 167. | 12737. | 60 | 33.49 | 0.0 | 3359.8 |
| 150 | 4265 | 0. | 87.  | 12824. | 60 | 33.49 | 0.0 | 3359.8 |
| 151 | 1968 | 0. | 40.  | 12864. | 60 | 33.51 | 0.0 | 3359.8 |
| 152 | 2624 | 0. | 53.  | 12918. | 60 | 33.51 | 0.0 | 3359.8 |
| 153 | 1640 | 0. | 33.  | 12951. | 60 | 33.52 | 0.0 | 3359.8 |
| 154 | 2953 | 0. | 60.  | 13011. | 60 | 33.51 | 0.0 | 3359.8 |
| 155 | 4593 | 0. | 94.  | 13107. | 60 | 33.51 | 0.0 | 3359.8 |
| 156 | 2202 | 0. | 167. | 13271. | 60 | 33.50 | 0.0 | 3359.8 |
| 157 | 9842 | 0. | 200. | 13471. | 60 | 33.51 | 0.0 | 3359.8 |
| 158 | 8537 | 0. | 174. | 13645. | 60 | 33.49 | 0.0 | 3359.8 |
| 159 | 3937 | 0. | 80.  | 13725. | 60 | 33.48 | 0.0 | 3359.8 |
| 160 | 984  | 0. | 21.  | 13746. | 60 | 33.29 | 0.0 | 3359.8 |
| 161 | 656  | 0. | 13.  | 13759. | 60 | 36.75 | 0.0 | 3359.8 |
| 162 | 3937 | 0. | 80.  | 13839. | 60 | 33.50 | 0.0 | 3359.8 |
| 163 | 2953 | 0. | 60.  | 13899. | 60 | 33.51 | 0.0 | 3359.8 |
| 164 | 4921 | 0. | 100. | 14000. | 60 | 33.50 | 0.0 | 3359.8 |
| 165 | 3937 | 0. | 80.  | 14080. | 60 | 33.50 | 0.0 | 3359.8 |
| 166 | 1969 | 0. | 40.  | 14128. | 60 | 33.50 | 0.0 | 3359.8 |
| 167 | 2297 | 0. | 47.  | 14167. | 60 | 33.45 | 0.0 | 3359.8 |
| 168 | 1312 | 0. | 27.  | 14193. | 60 | 33.51 | 0.0 | 3359.8 |
| 169 | 1312 | 0. | 27.  | 14220. | 60 | 33.46 | 0.0 | 3359.8 |
| 170 | 656  | 0. | 13.  | 14233. | 60 | 33.51 | 0.0 | 3359.8 |
| 171 | 1969 | 0. | 40.  | 14273. | 60 | 33.50 | 0.0 | 3359.8 |
| 172 | 6890 | 0. | 140. | 14414. | 60 | 33.49 | 0.0 | 3359.8 |
| 173 | 4921 | 0. | 100. | 14514. | 60 | 33.50 | 0.0 | 3359.8 |
| 174 | 3281 | 0. | 67.  | 14581. | 60 | 33.46 | 0.0 | 3359.8 |
| 175 | 1640 | 0. | 33.  | 14614. | 60 | 33.52 | 0.0 | 3359.8 |
| 176 | 2952 | 0. | 60.  | 14674. | 60 | 33.48 | 0.0 | 3359.8 |
| 177 | 3609 | 0. | 73.  | 14748. | 60 | 33.50 | 0.0 | 3359.8 |
| 178 | 984  | 0. | 20.  | 14768. | 60 | 33.49 | 0.0 | 3359.8 |
| 179 | 328  | 0. | 7.   | 14774. | 60 | 33.50 | 0.0 | 3359.8 |
| 180 | 984  | 0. | 20.  | 14794. | 60 | 33.48 | 0.0 | 3359.8 |
| 181 | 1312 | 0. | 27.  | 14821. | 60 | 33.51 | 0.0 | 3359.8 |
| 182 | 1640 | 0. | 33.  | 14855. | 60 | 33.48 | 0.0 | 3359.8 |
| 183 | 2953 | 0. | 60.  | 14915. | 60 | 33.51 | 0.0 | 3359.8 |
| 184 | 1640 | 0. | 33.  | 14948. | 60 | 33.52 | 0.0 | 3359.8 |
| 185 | 1969 | 0. | 40.  | 14988. | 60 | 33.50 | 0.0 | 3359.8 |
| 186 | 1312 | 0. | 27.  | 15015. | 60 | 33.50 | 0.0 | 3359.8 |
| 187 | 1640 | 0. | 33.  | 15048. | 60 | 33.50 | 0.0 | 3359.8 |
| 188 | 656  | 0. | 13.  | 15062. | 60 | 33.50 | 0.0 | 3359.8 |
| 189 | 328  | 0. | 7.   | 15068. | 60 | 33.50 | 0.0 | 3359.8 |
| 190 | 982  | 0. | 20.  | 15086. | 60 | 33.51 | 0.0 | 3359.8 |
| 191 | 1640 | 0. | 33.  | 15122. | 60 | 33.51 | 0.0 | 3359.8 |
| 192 | 1969 | 0. | 40.  | 15162. | 60 | 33.51 | 0.0 | 3359.8 |

|     |      |      |      |        |    |       |     |        |
|-----|------|------|------|--------|----|-------|-----|--------|
| 193 | 1312 | 0.   | 27.  | 15188. | 60 | 33.46 | 0.0 | 3359.8 |
| 194 | 3609 | 0.   | 73.  | 15262. | 60 | 33.49 | 0.0 | 3359.8 |
| 195 | 1640 | 0.   | 33.  | 15295. | 60 | 33.50 | 0.0 | 3359.8 |
| 196 | 2024 | 0.   | 53.  | 15349. | 60 | 33.50 | 0.0 | 3359.8 |
| 197 | 1968 | 0.   | 40.  | 15389. | 60 | 33.49 | 0.0 | 3359.8 |
| 198 | 2297 | 0.   | 47.  | 15435. | 60 | 33.52 | 0.0 | 3359.8 |
| 199 | 1312 | 0.   | 27.  | 15462. | 60 | 33.48 | 0.0 | 3359.8 |
| 200 | 2953 | 0.   | 60.  | 15522. | 60 | 33.50 | 0.0 | 3359.8 |
| 201 | 656  | 0.   | 13.  | 15535. | 60 | 33.50 | 0.0 | 3359.8 |
| 202 | 984  | 0.   | 20.  | 15556. | 60 | 33.50 | 0.0 | 3359.8 |
| 203 | 2625 | 0.   | 53.  | 15609. | 60 | 33.50 | 0.0 | 3359.8 |
| 204 | 328  | 0.   | 7.   | 15616. | 60 | 33.51 | 0.0 | 3359.8 |
| 205 | 2953 | 0.   | 60.  | 15676. | 60 | 33.50 | 0.0 | 3359.8 |
| 206 | 3937 | 0.   | 80.  | 15756. | 60 | 33.51 | 0.0 | 3359.8 |
| 207 | 2953 | 0.   | 60.  | 15816. | 60 | 33.48 | 0.0 | 3359.8 |
| 208 | 984  | 0.   | 20.  | 15836. | 60 | 33.50 | 0.0 | 3359.8 |
| 209 | 1312 | 0.   | 27.  | 15863. | 60 | 33.51 | 0.0 | 3359.8 |
| 210 | 1640 | 0.   | 33.  | 15896. | 60 | 33.51 | 0.0 | 3359.8 |
| 211 | 2625 | 0.   | 53.  | 15949. | 60 | 33.47 | 0.0 | 3359.8 |
| 212 | 1640 | 0.   | 33.  | 15983. | 60 | 33.49 | 0.0 | 3359.8 |
| 213 | 984  | 0.   | 20.  | 16003. | 60 | 33.47 | 0.0 | 3359.8 |
| 214 | 2297 | 0.   | 47.  | 16050. | 60 | 33.49 | 0.0 | 3359.8 |
| 215 | 656  | 0.   | 13.  | 16063. | 60 | 33.46 | 0.0 | 3359.8 |
| 216 | 2953 | 0.   | 60.  | 16123. | 60 | 33.48 | 0.0 | 3359.8 |
| 217 | 2297 | 0.   | 47.  | 16170. | 60 | 33.50 | 0.0 | 3359.8 |
| 218 | 5905 | 0.   | 120. | 16290. | 60 | 33.50 | 0.0 | 3359.8 |
| 219 | 7216 | 0.   | 147. | 16437. | 60 | 33.49 | 0.0 | 3359.8 |
| 220 | 984  | 0.   | 20.  | 16457. | 60 | 33.50 | 0.0 | 3359.8 |
| 221 | 1640 | 0.   | 33.  | 16490. | 60 | 33.49 | 0.0 | 3359.8 |
| 222 | 1312 | 0.   | 27.  | 16517. | 60 | 33.50 | 0.0 | 3359.8 |
| 223 | 2625 | 0.   | 53.  | 16571. | 60 | 33.50 | 0.0 | 3359.8 |
| 224 | 1640 | 102. | 33.  | 16604. | 60 | 31.39 | 0.0 | 3359.8 |

END OF DATA

TRUCK MAKES 1.73 TRIPS PER SHIFT.

IT CARRIES 86.7 TONS DURING THE SHIFT.

THIS EQUALS 5827.6 TON-MILES/SHIFT.

TRUCK STOPPED.

APPENDIX II

OWNERSHIP AND OPERATING COSTS FOR A TRUCK

APPENDIX IIOWNERSHIP AND OPERATING COST FOR A TRUCK

The cost of moving a cubic yard or ton of material is determined by dividing the hourly cost of ownership and operating cost (O & O) by the hourly production.

Ownership Cost

The ownership cost is the sum of the hourly charges for Depreciation, Interest, Taxes, Insurance, and Storage.

Depreciation The hourly depreciation charge is the delivered price of the unit (less the value of tires) divided by the depreciation period in hours. A straight line method with no salvage or resale value is usually employed.

Five items are necessary to make the depreciation calculation. They are:

- Purchase price
- Extras
- Freight
- Tire Costs
- Depreciation period

Purchase price may be the dealer's quote or taken directly from current lists or catalogs.

Extras include options and attachments necessary for

the machine to perform well and necessary for the comfort of the operator.

Freight costs can be estimated more accurately by persons responsible for paying them. In general is roughly calculated @ \$3.50 per 100 lb shipping weight.

Tire costs should be obtained from the local tire distributor. If this is not convenient, it can be estimated from handbooks.

Depreciation period is difficult to determine since useful life can exceed the depreciation period by a considerable amount if a good preventive maintenance program is carried out.

Interest, Taxes, Insurance, Storage In determining the cost of interest on the equipment invested, costs of insurance premiums for general liability, fire, and theft, taxes on the assessed valuation of the equipment, and cost of storage of the equipment, the following formula is used:

$$\frac{\text{Hourly Cost Int. Tax. Insur. Stor.} \times \text{Prevailing Rate}(\%) \times \text{Average Year. Invest.}}{\text{Hours operated per year}}$$

The current prevailing rate is 13 percent, made up of 9 percent for interest, 2 percent for taxes, and 2 percent for insurance and storage.

To determine Average Yearly Investment, simply multiply

the delivered price by 50 percent.

### Operating Costs

The hourly operating costs are those incurred while the vehicle is working and include the following items:

- Tire replacement
- Tire repairs
- General repairs
- Fuel
- Service
- Operator

Tire replacement costs are equal to the original cost of the tire divided by the estimated life of the tire. Cost is obtained by the local tire distributor. The determination of original tire life is extremely difficult as is influenced by many operating conditions such as speed, grade, maintenance, surface, curves, and others. A method of estimating tire life has been devised where a maximum life of 6000 hours is multiplied by factors which account for speed, curves, loads, grades, and the like.

It is customary to apply a certain margin of safety in the form of tire repair cost.

General repairs include parts and labor costs involved in normal maintenance and periodic overhaul of the vehicle. General repairs should be based on actual experience. However, an hourly charge can be established for estimating

purposes by using the hourly depreciation charge of the unit as being indicated by the repair costs. Wide experience shows that the average hourly repair cost can be determined very simply as a percentage of 10,000 hour depreciation charge. Selection of percentage to be applied is a matter of judgement.

Fuel costs are based on local rates and engine fuel consumption rate. Engine consumption rate depends on engine horsepower and vehicle duty cycle.

Service cost is the cost of oil, grease and filters, and the labor included in performing normal service items. The amount charged for this will vary according to the frequency at which this servicing is done and based on the labor rate applied. Most estimators agree that the service cost can be based on the size of the engine in the equipment.

Operator cost varies from one location to another based on real wage rates. Operator cost should include not only the direct wage, but any benefits paid by the company which reverts to the operator.

The sum of the operating cost and ownership cost gives the estimated owning and operating cost.

```

C *****
C
C PROGRAM COSTOS.F4 CALCULATES OWNERSHIP, OPERATING
C AND TOTAL COSTS OF DIFFERENT SIZES OF TRUCKS.
C COSTS ARE GIVEN IN DOLLARS PER YEAR AND IN DOL-
C LARS PER HOUR.
C
C *****
C
C INPUT VARIABLES
C
C PP = PURCHASE PRICE [S]
C EX = OPTIONAL EQUIPMENT COST [S]
C FE = TRANSPORTATION CHARGE, FREIGHT [S]
C ST = CAPACITY OF TRUCK [TONS]
C XY = NUMBER OF YEARS TO BE DEPRECIATED
C TC = TIRES COST [S]
C HP = GROSS HORSE POWER TRUCK [HP]
C F1 = FRONT TIRES FACTOR
C F2 = REAR TIRES FACTOR
C F3 = FUEL CONSUMPTION FACTOR
C F4 = FUEL COST [S/GALLON]
C
C GENERATED VARIABLES AND RESULTS
C
C DP = DELIVERED PRICE [4]
C OV = ORIGINAL VALUE OF TIRES [S]
C TA = TOTAL AMOUNT TO BE DEPRECIATED [S]
C YD = DEPRECIATION PER YEAR [S/YEAR]
C HD = DEPRECIATION PER HOUR [S/HOUR]
C AV = AVERAGE INVESTMENT PER YEAR [S/YEAR]
C OC = OWNERSHIP COST PER YEAR [S/YEAR]
C TH = OWNERSHIP COST PER HOUR [S/HOUR]
C FT = FRONT TIRES LIFE
C RT = REAR TIRES LIFE
C TL = TIRES LIFE
C TCS = TIRES COST PER HOUR [S/HOUR]
C TR = TIRES REPAIR COST PER HOUR [S/HOUR]
C RL = REPAIRS AND LABOR COST PER HOUR [S/HOUR]
C GF = FUEL CONSUMPTION
C FC = COST OF FUEL PER GALLON [S/GALLON]
C OG = COST OF LABOR, OIL, GREASE, ETC [S/HP]
C CO = OPERATING COST PER HOUR [4/HOUR]
C OO = TOTAL OWNERSHIP AND OPERATING COST PER HOUR
C
C *****
C
C DIMENSION PP(10),EX(10),FE(10),TC(10),
C 1 TI(10),FR(10),ST(10),XY(10)

```

```

READ(1,100)(FP(I),EA(I),FR(I),TC(I),
1 TI(I),HP(I),ST(I),AY(I), I=1,3)
READ(1,200)F1,F2,F3,F4
WRITE(6,300)
WRITE(6,301)

C
C   COMPUTING OWNERSHIP COST
C

DO 400 I=1,3
DP=FP(I)+EA(I)+FR(I)
OV=TC(I)*6.
TA=DP-OV
YD=TA/(AY(I))
HD=YD/8760.
AV=DP*.5
OC=AV*TI(I)+YD
TH=AV*TI(I)/8760.

C
C   COMPUTING OPERATING COST
C

FT=F1*6000.
RT=F2*6000.
TL=(FT+RT)/2.
TCS=OV/TL
TR=TCS*.15
RL=((DP-FR(I))*6)/15000.
GF=.06*HP(I)*F3
FC=GF*F4
OG=FC*.333
CO=TCS+TH+RL+FC+OG
OO=TH+CO
WRITE(6,500)(ST(I),OC,TH,CO,OO)
400 CONTINUE

C
C   FORMATS
C
100 FORMAT(8F)
200 FORMAT(4F)
300 FORMAT(//,' TRUCK SIZE',2X,' OWNERSHIP',3X,
1 ' OWNERSHIP',2X,' OPERATING',3X,' TOTAL COST')
301 FORMAT(13X,' COST/YEAR',3X,' COST/HOUR',2X,
1 ' COST/HOUR',4X,' PER HOUR')
500 FORMAT(/1X,F8.2,4X,F10.2,5X,F6.2,6X,
1 F6.2,7X,F6.2)
STOP
END

```

## OWNERSHIP AND OPERATING COSTS FOR TRUCKS

| TRUCK SIZE | OWNERSHIP<br>COST/YEAR | OWNERSHIP<br>COST/HOUR | OPERATING *<br>COST/HOUR | TOTAL COST<br>PER HOUR |
|------------|------------------------|------------------------|--------------------------|------------------------|
| 35.00      | 22670.25               | 0.67                   | 5.03                     | 5.70                   |
| 45.00      | 28672.50               | 0.83                   | 5.97                     | 6.81                   |
| 50.00      | 31705.50               | 0.94                   | 7.28                     | 8.21                   |

\* Operating costs do not include operator's wages. They are considered in the cost per ton calculation.

APPENDIX III

PROBABILISTIC SIMULATION TO DETERMINE  
COST PER TON FOR FLEET OF TRUCKS

```

C *****
C
C HAULAGE SIMULATION AND COST PER TON CALCULATION
C
C INPUT VARIABLES
C
C NUMBTL - NUMBER OF TRUCKLOADS
C AVRGLT - AVERAGE LOADING TIME
C AVRGHT - AVERAGE HAULING TIME
C DELAYS - PERCENT DELAYS IN LOADING STATION
C FACTO1 - FACTOR FOR LUNCH TIME AND STARTUP
C FACTO2 - NUMBER OF SCHEDULED SHIFTS PER YEAR
C FACTO3 - STANDBY FACTOR FOR TRUCKS
C COSTOH - COST PER OPERATING HOUR FOR A TRUCK
C COSTOF - COST PER SCHEDULED HOUR FOR A FOREMAN
C COSTOD - COST PER SCHEDULED HOUR FOR A DRIVER
C COSTOW - COST PER SCHEDULED HOUR FOR A WORKER
C TDAOCO - TRUCK DEPRECIATION AND OWNERSHIP COST
C TONNAG - TONNAGE PER TRUCKLOAD
C TOTTON - TOTAL TONNAGE TO BE HAULED PER YEAR
C
C GENERATED VARIABLES
C
C SIGNAL - STANDARD DEVIATION OF LOADING TIME
C SIGMAH - STANDARD DEVIATION OF HAUL TIME
C AMINLT - MINIMUM LOADING TIME
C AMINHT - MINIMUM HAULING TIME
C FIRST - NUMBER OF TRUCKS FOR FIRST SIMULATION
C TRU(N) - TRUCK NUMBER N
C HAULT - HAUL TIME
C TLOAD - LOADING TIME
C J - NUMBER OF TRUCKLOADS
C THAULT - TOTAL HAUL TIME
C TLOADT - TOTAL LOADING TIME
C R - RANDOM NORMAL NUMBER
C DELMIN - MINIMUM DELAYS
C TRUOPC - TRUCK OPERATING COST
C TRUSHC - TOTAL SCHEDULED COST
C TOTDOC - TOTAL DEPRECIATION AND OWNERSHIP COST
C CPT(I) - COST PER TON FOR (I) TRUCKS
C TIMEHO - HOPPER OPERATING TIME
C TOTTHO - TOTAL HOPPER OPERATING TIME
C TOTIHO - TOTAL HOPPER DELAY TIME
C
C *****
C
C
C

```

```

DIMENSION TRU(110),CPT(110)
READ(1,1000)NUMBTL,AVRGLT,AVRGHT,DELAYS,FACT01,FACT02,
1 COSTOH,COSTOF,COSTOD,COSTOW,TDAOCO,FACT03,FACT04,
2 TONNAG,TOTTON
SIGMAL=.10*AVRGLT
SIGMAH=.12*AVRGHT
AMINLT=.80*AVRGLT
AMINHT=.80*AVRGHT

C
WRITE(6,999)

C
FIRST=AVRGHT/(AVRGLT*4)-1.
K=FIRST
M=K+15
DO 10 I=K,M
DO 20 N=1,I
20 TRU(N)=0.
TIMEHO=0.
HAULT=0.
TLOAD=0.
J=0
THAULT=0.
TLOADT=0.
TOTIHO=0.
150 DO 130 N=1,I
J=J+1
DELTAT=TIMEHO-TRU(N)
IF(DELTAT)50,360,40
40 TRU(N)=TRU(N)+DELTAT
GO TO 360
50 TOTIHO=TOTIHO-DELTAT
TIMEHO=TIMEHO-DELTAT
360 CALL RANDOM(SIGMAL,AVRGLT,R)
IF(R-AMINLT)60,600,600
60 TLOAD=AMINLT
GO TO 70
600 TLOAD=R
70 TRU(N)=TRU(N)+TLOAD
TIMEHO=TIMEHO+TLOAD
TLOADT=TLOADT+TLOAD

C
CALL RANDOM(SIGMAH,AVRGHT,R)
IF(R-AMINHT)80,90,90
80 HAULT=AMINHT
GO TO 500
90 HAULT=R
500 TRU(N)=TRU(N)+HAULT
IF(N-1)100,100,110
100 IF(TRU(N)-TRU(I))120,130,130
110 IF(TRU(N)-TRU(N-1))140,130,130
120 HAULT=HAULT+TRU(I)-TRU(N)

```

```

    TRU(N)=TRU(I)
    GO TO 130
140   HAULT=HAULT+TRU(N-1)-TRU(N)
      TRU(N)=TRU(N-1)
130   THAULT=THAULT+HAULT
111   IF(J-NUMBTL) 150,160,160
160   DELMIN=TLOADT*DELAYS
170   IF(TOTIHO-DELMIN) 180,190,190
180   TOTTHO=(TLOADT+DELMIN)*FACTO1
C
190   TOTTHO=(TLOADT+TOTIHO)*FACTO1
C
C
230   TRUOPC=FACTO2*COSTOH*8.*(THAULT/TOTTHO)
      PI=I
      TRUSHC=FACTO2*8.*(COSTOF+COSTOW+PI*COSTOD)
      TOTDOC=TDAOC0*FACTO3*PI
      AJ=J
      TOTPRO=AJ*TONNAG*FACTO2*8.*60./TOTTHO
240   CPT(I)=(TRUOPC+TRUSHC+TOTDOC)/TOTPRO
C
      WRITE(6,3000) TONNAG
      WRITE(6,2000) I,CPT(I)
      WRITE(6,4000) TOTPRO
10   CONTINUE
C
C   FORMATS
C
999   FORMAT(1X,'TRUCK SIMULATION AND COST PER TON CALCULATION')
1000  FORMAT(I,14F)
2000  FORMAT(7X,18HNUMBER OF TRUCKS =,I8,/,11X,
          1 14HCOST PER TON =,F13.4)
3000  FORMAT(15X,///,25H TRUCK CAPACITY IN TONS =,F11.2)
4000  FORMAT(5X,20H ANNUAL PRODUCTION =,F10.1)
      STOP
      END

```

```

SUBROUTINE RANDOM(SIGMAL,AVRGLT,R)
A=0.
X=0.
DO 15 I=1,12
X=RAN(0.)
A=A+X
R=(A-6.)*SIGMAL+AVRGLT
RETURN
END
15

```

## TRUCK SIMULATION AND COST PER TON CALCULATION

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 26  
 COST PER TON = 2.08696  
 ANNUAL PRODUCTION = 950930.8

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 27  
 COST PER TON = 2.08381  
 ANNUAL PRODUCTION = 988710.9

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 28  
 COST PER TON = 2.08270  
 ANNUAL PRODUCTION = 1024497.4

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 29  
 COST PER TON = 2.10069  
 ANNUAL PRODUCTION = 1048313.6

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 30  
 COST PER TON = 2.09116  
 ANNUAL PRODUCTION = 1092861.0

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 31  
 COST PER TON = 2.09730  
 ANNUAL PRODUCTION = 1124724.2

TRUCK CAPACITY IN TONS = 50  
 NUMBER OF TRUCKS = 32  
 COST PER TON = 2.09781  
 ANNUAL PRODUCTION = 1159388.4

TRUCK CAPACITY IN TONS = 50  
NUMBER OF TRUCKS = 33  
COST PER TON = 2.11387  
ANNUAL PRODUCTION = 1186001.4

TRUCK CAPACITY IN TONS = 50  
NUMBER OF TRUCKS = 34  
COST PER TON = 2.12136  
ANNUAL PRODUCTION = 1213722.8

TRUCK CAPACITY IN TONS = 50  
NUMBER OF TRUCKS = 35  
COST PER TON = 2.12098  
ANNUAL PRODUCTION = 1251166.0

TRUCK CAPACITY IN TONS = 50  
NUMBER OF TRUCKS = 36  
COST PER TON = 2.11092  
ANNUAL PRODUCTION = 1294782.5

TRUCK CAPACITY IN TONS = 50  
NUMBER OF TRUCKS = 37  
COST PER TON = 2.13355  
ANNUAL PRODUCTION = 1309871.2

APPENDIX IV

ROAD PAVING COSTS ESTIMATES

APPENDIX IVROAD PAVING COSTS ESTIMATES

Road paving costs estimates are based on data furnished by the Colorado Department of Highways. Figures correspond to the year of 1972.

Due to much higher labor costs in the U. S. A. this estimate should have lower numbers for Bolivian patterns; however, because of the special condition of this specific project other items are increasingly higher; so, after an analysis of the situation, it was concluded that the average cost taken into account is close enough for the estimate.

Costs include all constituents of the way pavement complete in place, but do not include 10 percent for engineering and contingencies.

Estimates are calculated as follows:

Because of the heavy loads to be sustained, a thickness of 5-in. pavement is advisable to use. Under such conditions:

|   |         |
|---|---------|
| Average cost per square yard per inch of thickness for 5-in. hot bituminous pavement is | \$ 0.50 |
| Cost per square yard for a 5-in. thickness:   | \$ 2.50 |

## Road characteristics:

Length : 68 miles - 119,680 yd  
Width : 39 ft - 13 yd  
Area : 1,555,240 sq-yd

|   |                |
|---|----------------|
| Total cost 68 miles   | \$2,887,000.00 |
| Amortization period   | 10 years       |
| Annual amortization   | \$ 288,700.00  |
| Annual difference in cost transportation between paved and unpaved road (from Table 6.) | \$ 695,993.00  |
| Net annual savings  | \$ 417,293.00  |
| Annual Savings percentage   | 13.85          |

APPENDIX V

7

RAIL HAULAGE ANALYSIS

```

C *****
C
C
C 'CONVERTED FROM TRUCK.P4 ON MARCH 10, 1973. COB)
C "TRSN.P4" (TRAIN EVALUATION PROGRAM) ADAPTED FOR PLP-10
C TIMESHARING SYSTEM. CONVERSATIONAL INPUT. REQUIRES THREE
C DATA-FILES, WITH ANOTHER OPTIONAL. THESE ARE:
C A. NFILE CONTAINING DESCRIPTIVE INFORMATION ABOUT TRACK PORTION:
C     INITIAL DESCRIPTIVE LINE FOR IDENTIFICATION OF ROUTE
C     SUBSEQUENT LINES TO DESCRIBE EACH SECTION:
C         (A) LENGTH OF SECTION, FEET
C         (B) GRADE OF SECTION, PERCENT
C         (C) DEGREE OF TRACK CURVATURE
C         (D) SPEED LIMIT, MPH
C         (E) SECTION NUMBER. COMMONLY A DIGIT BUT -
C             L IF TO DESIGNATE LOADING. OTHERS THEN ARE 0.
C             D IF TO DESIGNATE DUMPING. OTHER VALUES ZERO.
C
C B. NFILE WITH INFORMATION ABOUT EQUIPMENT UNDER STUDY:
C     FIRST FIVE LINES MAY CONTAIN ANY DESIRED INFORMATION
C     IN ANY FORMAT. WILL BE DUPLICATED IN OUTPUT.
C     SIXTH LINE CONTAINS LOCO WT (TONS), NO OF AXLES, AND
C     FRONTAL AREA OF LOCOMOTIVE (SQ.FT)
C     SEVENTH AND SUBSEQUENT LINES CONTAIN PERFORMANCE DATA
C     ON EQUIPMENT BEING STUDIED:
C         (A) SPEED (INTEGER) AT WHICH EVALUATION MADE
C         (B) TRACTIVE EFFORT (DRAWBAR-PULL) AT THAT SPEED, LBS.
C     DATA SHOULD COVER WHOLE WORKING RANGE OF SPEEDS.
C
C C. NFILE WITH INFORMATION ABOUT CARS USED AND LOADS:
C     LINE 1: EMPTY WEIGHT OF CAR, TONS.
C     LINE 2: WEIGHT OF LOAD CARRIED, TONS.
C     LINE 3: NUMBER OF AXLES PER CAR
C     LINE 4: FRONTAL AREA PROJECTED, SQ. FT.
C
C D. OPTIONAL FILE FOR AUTOMATIC INPUT OF CONTROL INFORMATION:
C     LINE 1: DUMPING ELEVATION, FT.
C     LINE 2: ENGINE TYPE. 2=TD0 CYCLE, 4=4 CYCLE
C     LINE 3: NORMAL FWD CAR LOAD AND LOAD AXLES, SECONDS.
C     LINE 4: PERCENT TO FORWARD ENGINE FOR REAR.
C     LINE 5: PERCENT OF CARRIED LOAD TO BE CARRIED.
C     LINE 6: ACCEPTABLE ACCELERATION, G'S PER SECOND.
C     LINE 7: PERCENT OF SHUT-TIME TRAIN IS OPERATING.
C
C WRITTEN BY C.D. GUSH, COLO. SCH. OF MINS., NOV., 1971
C
C *****
C
C
C DIMENSION CAPTIC(10),CAPTR(10),COE13(10),COE2(10),CAP15(10)
C DIMENSION CAP16(10),RSE(C0),TSP(C1)
C DIMENSION LBS(400),GRA(400),LOCOS(400),IS-ELT(400),SFC(400)

```

```

1012000 SEC
1012001 SET(10)
1012002 WRITE(4,1)
1012003 IF=0
1012004 FORMAT(1X,'NAME OF FILE WITH ROUTE INFORMATION? ',S)
1012005 READ(4,2)NAME1
1012006 FORMAT(A5)
1012007 CALL IFILE(1,NAME1)
1012008 WRITE(4,3)
1012009 FORMAT(1X,'NAME OF FILE WITH LOCOMOTIVE INFORMATION? ',S)
1012010 READ(4,2)NAME2
1012011 CALL IFILE(2,NAME2)
1012012 WRITE(4,532)
1012013 FORMAT(1X,'NAME OF FILE WITH CAR INFORMATION? ',S)
1012014 READ(4,2)NAME4
1012015 CALL IFILE(7,NAME4)
1012016 WRITE(4,536)
1012017 FORMAT(1X,'HOW MANY CARS IN THE TRAIN? ',S)
1012018 READ(4,532)NOCAR
1012019 FORMAT(I)
1012020 ITEST=0
1012021 WRITE(4,4)
1012022 FORMAT(1X,'HOW IS CONTROL INFORMATION TO BE INPUT?
1 1=TTY, 2=FROM STORED FILE. ',S)
1012023 READ(4,5)IHOW
1012024 FORMAT(I)
1012025 IF(IHOW.EQ.2)GO TO 15
1012026 IT=3
1012027 WRITE(4,6)
1012028 FORMAT(1X,'NAME OF FILE WITH RUN-CONTROL DATA? ',S)
1012029 TOTIM=0.
1012030 READ(4,2)NAME3
1012031 CALL IFILE(3,NAME3)
1012032 GO TO 565
1012033 TOTR=0.5
1012034 IT=4
1012035 WRITE(4,10)
1012036 FORMAT(1X,'WHAT IS OPERATING ELEVATION? ',S)
1012037 READ(11,20)ELPV
1012038 IF(IT.EQ.4)GO TO 25
1012039 WRITE(4,526)ELPV
1012040 FORMAT(1X,F10.2)
1012041 FORMAT(G1,F)
1012042 WRITE(4,35)
1012043 FORMAT(1X,'ENGINE TYPE? 2-CYCLE=2, 4-CYCLE=4 ',S)
1012044 READ(11,20)ENG
1012045 IF(IT.EQ.4)GO TO 570
1012046 WRITE(4,526)ENG
1012047 IF(ENG-2)269,271,269
1012048 IF(ENG-4)270,274,270
1012049 WRITE(4,40)

```

```

      IF(ILOAD.NE.2)GO TO 25
40  FORMAT(1H , 'ONLY CODES 2 OF 4 CAN BE ACCEPTED. RE-ENTER. ',S)
      GO TO 2199
271  IF(ELEV-6000)272,273,273
272  PFAC=1.0-(ELEV/1000.)*0.01333
      GO TO 284
273  PFAC=0.92-0.03*(ELEV-6000.)/1000.
      GO TO 289
274  IF(ELEV-1000.) 276,275,275
275  PFAC=1.00-0.03*(ELEV-1000.)/1000.
      GO TO 288
276  PFAC= 1.0
280  WRITE(4,50)
50  FORMAT(1H , 'WHAT ARE NORMAL PER-CAR LOADING AND
      1 DUMPING TIMES, SFCOMDS? ',S)

      READ(IT,55)ILOAD,IDUMP
      IF(IT.EQ.4)GO TO 789
      WRITE(4,1022)ILOAD,IDUMP
1022  FORMAT(1X,15,2X,15)
55  FORMAT(6X,2I)

789  WRITE(4,60)
60  FORMAT(1H , 'BY WHAT % SHALL ENGINE BE DOWN-RATED FOR WEAR? ',
      READ(IT,20)LRATE
      IF(IT.EQ.4)GO TO 810
      WRITE(4,526)LRATE
810  WRITE(4,65)
65  FORMAT(1H , 'PERCENT OF RATED LOAD TO BE CARRIED? ',S)
      READ(IT,20)PCTLD
      IF(IT.EQ.4)GO TO 840
      WRITE(4,526)PCTLD
840  WRITE(4,70)
70  FORMAT(1H , 'WHAT IS ACCEPTABLE ACCELERATION, MPH PER SEC.? ',
      READ(IT,20)AC
      IF(IT.EQ.4)GO TO 870
      WRITE(4,526)AC
870  ACCEL=AC*5280./3600.
      WRITE(4,78)
78  FORMAT(1H , 'WHAT PCT OF SHIFT TIME IS TRAIN OPERATING? ',S)
      READ(IT,20)PFF
      IF(IT.EQ.4)GO TO 919
      WRITE(4,526)PFF
350  FORMAT(10A5)
219  READ(2,350)CAP11
      READ(2,350)CAP12
      READ(2,350)CAP13
      READ(2,350)CAP14
      READ(2,350)CAP15
400  READ(2,80)BTLOC,NAALL,PAILO
50  FORMAT(5X,F,1X,F)

```

```

      READ(1,350)CAPT6
      WRITE(6,350)CAPT6
355   FORMAT(1X,10A5)
      WRITE(6,355)CAPT1
      WRITE(6,355)CAPT2
      WRITE(6,355)CAPT3
      WRITE(6,355)CAPT4
      WRITE(6,355)CAPT5
1412  READ(7,1412)TRAF
      FORMAT(6A,F)
      READ(7,1412)WFILE
      READ(7,1415)RAALE
1415  FORMAT(6X,I)
      READ(7,1412)FARCA
360   FORMAT(1H-, 'SEC   LEN   BRAKE   TIME   TOTAL   SPEED
      1  VEL  TONS   TON-   TOTAL')
362   FORMAT(1A, '      FT   DIS   SEC   TIME   LIMIT
      1  MPH      MILES  TON-MI')
720   WRITE(6,360)
      WRITE(6,362)
      N=0
432   N=N+1
      IF(N=51)434,1172,1172
434   READ(2,95,END=1172,ERR=1250)SP(N-1),DPR(N-1)
      GO TO 432
1172  N=0
1174  M=M+1
      READ(1,95,END=1205,ERR=1275)LEN(M),CFAC(M),FCUR(M),
      ISPLT(M),SEC(M)
      GO TO 1174
95    FORMAT(5X,I,F)
95    FORMAT(6X,I,F,F,I,A3)
1205  M=M-1
      DO 2010 I=1,M
      IF(SEC(I).EQ.'L')GO TO 1400
      IF(SEC(I).EQ.'D')GO TO 1430
1020  TGP=CFAC(I)
1030  LEN1=LEN(I)
      JSPL=ISPLT(I)
1040  LEN1=LEN1-2
      IF(LEN1.LE.100)JSPL=ISPLT(I+1)+1
      IF(LEN1)1060,1060,1090
1060  DIS=LEN1+2.00001
      IREST=1
      GO TO 1110
1090  DIS=2.00001
      IREST=2
1110  IF(SP)1500,1120,1120
1120  JSP=SP*3600/5280 +0.5
      DO 1150 I=1,61,1
      IF(JSP-(I-1))1150,1160,1150

```

```

1150 CONTINUE
1160 AXLDL=WTLOC/VAALE
      WTCAR=WTEMP+WTLD*PCTLD/100.
      AXLEC=WTCAR/KAALR
      IF(JSP-JSPL)1170,1170,1240
1170 PULL=1000.*DBP(IX-1)*(1.-DRATE/100.)*PFAC
      DRLOC=WTLOC*(1.3+29./AXLDL+0.03*JSP+0.0024*FARLO
1*JSP**2/WTLOC)
      DRCHS=NOCAR*WTCAR*(1.3+29./AXLEC+0.045*JSP+0.0005
1*FARCA*JSP**2/WTCAR)
      DRCUR=(WTLOC+NOCAR*WTCAR)*0.8*DGCUR(I)
      DRAG=DRLOC+DRCHS+DRCUR+(WTLOC+NOCAR*WTCAR)*TGR
      DIFF=PULL-DRAG
      ACC=32.2*DIFF/GVW
      IF(ACC.LE.ACCEL)GO TO 1230
1220 ACC=ACCEL
1230 GO TO 1330
1240 DRLOC=WTLOC*(1.3+29./AXLDL+0.03*JSP+0.0024*FARLO*JSP
1**2/WTLOC)
      WTCAR=WTEMP
      DRCHS=NOCAR*WTCAR*(1.3+29./AXLEC+0.045*JSP+0.0005
1*FARCA*JSP**2/WTCAR)
      DRCUR=(WTLOC+NOCAR*WTCAR)*0.8*DGCUR(I)
      DRAG=DRLOC+DRCHS+DRCUR+(WTLOC+NOCAR*WTCAR)*TGR
      ACC=32.2*DRAG/GVW
      IF(ACC.GE.ACCEL)GO TO 1730
      EDIS=BDIS+DIS
1730 ACC=-ACCEL
1330 QUANT=SP**2+2.*ACC*DIS
      IF(QUANT.LT.0)QUANT=0.0
1770 T=(-SP+SQRT(QUANT))/ACC
      SP=SP+ACC*T

      GO TO 1450
1400 T=ILOAD*NOCAR
      GVW=WLOC+NOCAR*(WTEMP+WTLD*PCTLD/100.)
      TONS=NOCAR*WTLD*PCTLD/100.
      GO TO 1445
1430 T=IDUMP*NOCAR
      GVW=WLOC+NOCAR*WTEMP
      TONS=0.
1445 IDEST=1
1450 TIME=TIME+T
      TOTIM=TOTIM+T
      GO TO (1480,1040)IDEST
1480 AVEL=DIS*3600./(T*5280.)
      TONMI=TONS*LEN(I)/5280
      TOTM=TOTIM+TONMI
      WRITE(6,1540)SEC(I),LEN(I),BDIS,TIME,TOTIM,ISPLT(I),AVEL,
1 TONMI,TOTM

```

```
1540   FORMAT(1X,A2,2X,15,2X,F6.0,2X,2(F6.0,2X),12,2X
1   F5.2,2X,F6.1,2X,F7.1)
      BDIS=0.
      TIME=0.
2010   CONTINUE
1200   WRITE(6,1500)
1500   FORMAT(1H-, 'END OF DATA')
      GO TO 1300
1250   WRITE(6,125)
125    FORMAT(1H-, 'ERROR')
1275   CONTINUE
1300   TRIPS=8*3600.*(EFF/100.)/TOTIM
      SHTONS=TRIPS*WTLD*PCTLD*NOCAR/100.
      SHTMI=TRIPS*TOTM
      WRITE(6,1920)TRIPS
1920   FORMAT(1X, 'TRAIN MAKES ',F6.2, ' TRIPS PER SHIFT.')
      WRITE(6,1940)SHTONS
1940   FORMAT(1X, 'IT CARRIES ',F8.1, ' TONS DURING THE SHIFT.')
      WRITE(6,1960)SHTMI
1960   FORMAT(1X, 'THIS EQUALS ',F8.1, ' TON-MILES/SHIFT.')
1500   WRITE(6,2100)
2100   FORMAT(1H-, 'TRAIN STOPPED.')
2190   WRITE(6,2200)
2200   FORMAT(1H1, 'END OF JOB')
      END
```

0010 DATA ON MOUNTAIN ROAD. SURFACE CODE NUMBER "3"  
 00010 TRACTIVE EFFORT VERSUS LOCOMOTIVE SPEED  
 00020 FOR A DIESEL ELECTRIC LOCOMOTIVE AS IT APPEARS ON PAGE 123  
 00030 OF THE BOOK "RAILROAD ENGINEERING" BY WILLIAM F. HOY.  
 00040 120-TONS 4 AXLES 40-IN. WHEELS  
 00050 USED AS A DATA ON THE PROGRAM TO DETERMINE TRAVEL TIMES

| SEC | LEN<br>FT | BRAKE<br>DIS | TIME<br>SEC | TOTAL<br>TIME | SPEED<br>LIMIT | EXIT<br>MPH | TON<br>MILES | TOTAL<br>TON-MIL |
|-----|-----------|--------------|-------------|---------------|----------------|-------------|--------------|------------------|
| 0   | 0         | 0.           | 7200.       | 7200.         | 0              | 0.00        | 0.0          | 0.0              |
| 1   | 1640      | 0.           | 43.         | 7243.         | 60             | 32.55       | 465.9        | 465.9            |
| 2   | 2625      | 0.           | 45.         | 7287.         | 60             | 40.50       | 745.7        | 1211.6           |
| 3   | 1312      | 0.           | 30.         | 7317.         | 60             | 29.45       | 372.7        | 1584.4           |
| 4   | 1640      | 0.           | 36.         | 7353.         | 60             | 31.49       | 465.9        | 2050.3           |
| 5   | 984       | 0.           | 19.         | 7372.         | 60             | 35.45       | 279.5        | 2329.8           |
| 6   | 7218      | 0.           | 151.        | 7523.         | 60             | 32.47       | 2050.6       | 4380.4           |
| 7   | 5905      | 0.           | 117.        | 7641.         | 60             | 34.49       | 1677.6       | 6058.0           |
| 8   | 2297      | 0.           | 53.         | 7694.         | 60             | 29.52       | 652.6        | 6710.5           |
| 9   | 2953      | 0.           | 64.         | 7758.         | 60             | 31.46       | 838.9        | 7549.4           |
| 10  | 656       | 0.           | 12.         | 7769.         | 60             | 40.49       | 186.4        | 7735.8           |
| 11  | 2297      | 0.           | 50.         | 7819.         | 60             | 31.47       | 652.6        | 8388.4           |
| 12  | 984       | 0.           | 19.         | 7838.         | 60             | 35.51       | 279.5        | 8667.9           |
| 13  | 1640      | 0.           | 34.         | 7872.         | 60             | 32.53       | 465.9        | 9133.8           |
| 14  | 2625      | 0.           | 52.         | 7925.         | 60             | 34.23       | 745.7        | 9879.5           |
| 15  | 1640      | 0.           | 38.         | 7963.         | 60             | 29.49       | 465.9        | 10345.5          |
| 16  | 1312      | 0.           | 20.         | 7990.         | 60             | 32.49       | 372.7        | 10718.2          |
| 17  | 984       | 0.           | 25.         | 8015.         | 60             | 26.45       | 279.5        | 10997.7          |
| 18  | 2953      | 0.           | 62.         | 8076.         | 60             | 32.49       | 838.9        | 11836.6          |
| 19  | 3937      | 0.           | 78.         | 8156.         | 60             | 34.13       | 1118.5       | 12955.1          |
| 20  | 2953      | 0.           | 62.         | 8218.         | 60             | 32.55       | 838.9        | 13794.0          |
| 21  | 328       | 0.           | 8.          | 8225.         | 60             | 29.54       | 93.2         | 13887.2          |
| 22  | 2625      | 0.           | 55.         | 8281.         | 60             | 32.48       | 745.7        | 14633.0          |
| 23  | 984       | 0.           | 16.         | 8296.         | 60             | 44.52       | 279.5        | 14912.5          |
| 24  | 959       | 0.           | 20.         | 8322.         | 60             | 25.39       | 279.4        | 15191.9          |
| 25  | 2953      | 0.           | 62.         | 8384.         | 60             | 32.52       | 838.9        | 16030.9          |
| 26  | 1312      | 0.           | 24.         | 8409.         | 60             | 37.48       | 372.7        | 16403.6          |
| 27  | 2297      | 0.           | 53.         | 8462.         | 60             | 29.44       | 652.6        | 17056.1          |
| 28  | 1966      | 0.           | 41.         | 8503.         | 60             | 32.51       | 559.1        | 17605.2          |
| 29  | 2624      | 0.           | 52.         | 8555.         | 60             | 34.20       | 745.5        | 18350.7          |
| 30  | 1640      | 0.           | 36.         | 8591.         | 60             | 31.45       | 465.9        | 18816.6          |
| 31  | 3609      | 0.           | 72.         | 8662.         | 60             | 34.32       | 1025.3       | 19841.9          |
| 32  | 1312      | 0.           | 22.         | 8685.         | 60             | 40.52       | 372.7        | 20214.6          |
| 33  | 1969      | 0.           | 51.         | 8735.         | 60             | 20.45       | 559.4        | 20774.0          |
| 34  | 934       | 0.           | 10.         | 8753.         | 60             | 40.53       | 279.5        | 21053.5          |
| 35  | 202       | 0.           | 25.         | 8779.         | 60             | 26.42       | 279.0        | 21332.5          |
| 36  | 306       | 0.           | 7.          | 8785.         | 60             | 30.21       | 93.2         | 21425.7          |
| 37  | 659       | 0.           | 17.         | 8802.         | 60             | 26.37       | 186.4        | 21612.1          |
| 38  | 1640      | 0.           | 27.         | 8829.         | 60             | 43.36       | 465.9        | 22078.0          |
| 39  | 1312      | 0.           | 37.         | 8866.         | 60             | 26.45       | 372.7        | 22450.7          |
| 40  | 1969      | 0.           | 39.         | 8905.         | 60             | 35.49       | 559.4        | 23010.1          |

|    |       |    |      |        |    |       |        |         |
|----|-------|----|------|--------|----|-------|--------|---------|
| 41 | 1640  | 0. | 38.  | 8943.  | 60 | 29.49 | 745.9  | 23479.  |
| 42 | 2953  | 0. | 68.  | 9155.  | 60 | 32.52 | 838.9  | 24317.9 |
| 43 | 1640  | 0. | 32.  | 9636.  | 60 | 35.41 | 465.9  | 24723.6 |
| 44 | 1312  | 0. | 30.  | 9667.  | 60 | 29.53 | 372.7  | 25156.4 |
| 45 | 984   | 0. | 17.  | 9684.  | 60 | 40.51 | 279.5  | 25436.1 |
| 46 | 326   | 0. | 8.   | 9692.  | 60 | 29.49 | 93.2   | 25529.3 |
| 47 | 984   | 0. | 17.  | 9109.  | 60 | 40.48 | 279.5  | 25502.6 |
| 48 | 3619  | 0. | 76.  | 9185.  | 60 | 32.53 | 1125.3 | 26834.1 |
| 49 | 2952  | 0. | 57.  | 9241.  | 60 | 35.51 | 838.6  | 27672.7 |
| 50 | 1640  | 0. | 46.  | 9283.  | 60 | 24.55 | 465.9  | 28138.6 |
| 51 | 3281  | 0. | 69.  | 9357.  | 60 | 32.48 | 932.1  | 29077.7 |
| 52 | 4921  | 0. | 95.  | 9452.  | 60 | 35.46 | 1398.0 | 30468.8 |
| 53 | 6390  | 0. | 144. | 9596.  | 60 | 32.54 | 1957.4 | 32426.1 |
| 54 | 1969  | 0. | 38.  | 9634.  | 60 | 35.47 | 559.4  | 32925.5 |
| 55 | 656   | 0. | 17.  | 9651.  | 60 | 26.43 | 186.4  | 33171.9 |
| 56 | 1312  | 0. | 23.  | 9674.  | 60 | 40.48 | 372.7  | 33540.6 |
| 57 | 1312  | 0. | 37.  | 9711.  | 60 | 24.40 | 372.7  | 33917.3 |
| 58 | 2297  | 0. | 40.  | 9751.  | 60 | 40.50 | 652.6  | 34569.9 |
| 59 | 1969  | 0. | 41.  | 9792.  | 60 | 32.54 | 559.4  | 35129.3 |
| 60 | 3937  | 0. | 76.  | 9868.  | 60 | 35.42 | 1118.5 | 36247.7 |
| 61 | 4921  | 0. | 103. | 9971.  | 60 | 32.55 | 1398.0 | 37645.7 |
| 62 | 2953  | 0. | 68.  | 10040. | 60 | 29.45 | 838.9  | 38484.7 |
| 63 | 3937  | 0. | 83.  | 10122. | 60 | 32.50 | 1118.5 | 39603.1 |
| 64 | 656   | 0. | 20.  | 10142. | 60 | 22.21 | 186.4  | 39789.5 |
| 65 | 984   | 0. | 18.  | 10160. | 60 | 44.50 | 279.5  | 40069.0 |
| 66 | 3937  | 0. | 78.  | 10238. | 60 | 34.32 | 1118.5 | 41127.5 |
| 67 | 8530  | 0. | 179. | 10417. | 60 | 32.48 | 2423.3 | 43610.3 |
| 68 | 9842  | 0. | 228. | 10645. | 60 | 29.50 | 2796.0 | 46406.2 |
| 69 | 8202  | 0. | 172. | 10817. | 60 | 32.50 | 2330.1 | 46736.9 |
| 70 | 4593  | 0. | 88.  | 10905. | 60 | 35.47 | 1304.8 | 50241.2 |
| 71 | 2953  | 0. | 68.  | 10973. | 60 | 29.52 | 838.9  | 50650.7 |
| 72 | 1640  | 0. | 42.  | 11016. | 60 | 26.45 | 465.9  | 51346.0 |
| 73 | 2624  | 0. | 51.  | 11067. | 60 | 35.37 | 745.5  | 52092.0 |
| 74 | 1968  | 0. | 45.  | 11112. | 60 | 29.51 | 559.1  | 52651.1 |
| 75 | 4265  | 0. | 82.  | 11195. | 60 | 35.40 | 1211.6 | 53862.2 |
| 76 | 8202  | 0. | 172. | 11366. | 60 | 32.53 | 2330.1 | 56192.9 |
| 77 | 2625  | 0. | 63.  | 11429. | 60 | 28.46 | 745.7  | 56932.6 |
| 78 | 2953  | 0. | 57.  | 11487. | 60 | 35.49 | 838.9  | 57777.6 |
| 79 | 2625  | 0. | 61.  | 11547. | 60 | 29.44 | 745.7  | 58523.3 |
| 80 | 5577  | 0. | 117. | 11664. | 60 | 32.53 | 1524.4 | 60127.7 |
| 81 | 1640  | 0. | 28.  | 11692. | 60 | 40.49 | 465.9  | 60573.6 |
| 82 | 4265  | 0. | 99.  | 11791. | 60 | 29.49 | 1211.6 | 61725.2 |
| 83 | 5249  | 0. | 110. | 11921. | 60 | 32.54 | 1491.2 | 63276.4 |
| 84 | 3937  | 0. | 76.  | 11977. | 60 | 35.41 | 1118.5 | 64394.9 |
| 85 | 4593  | 0. | 106. | 12083. | 60 | 29.52 | 1304.8 | 65699.7 |
| 86 | 6234  | 0. | 131. | 12214. | 60 | 32.54 | 1771.0 | 67470.7 |
| 87 | 4593  | 0. | 78.  | 12291. | 60 | 40.50 | 1304.8 | 68775.6 |
| 88 | 2297  | 0. | 55.  | 12346. | 60 | 28.37 | 652.6  | 69422.1 |
| 89 | 3281  | 0. | 63.  | 12412. | 60 | 35.49 | 932.1  | 70360.2 |
| 90 | 10496 | 0. | 228. | 12630. | 60 | 32.50 | 2922.4 | 73342.6 |
| 91 | 2625  | 0. | 51.  | 12661. | 60 | 35.49 | 745.7  | 74068.4 |

|     |       |    |       |        |    |       |        |          |
|-----|-------|----|-------|--------|----|-------|--------|----------|
| 92  | 2297  | 0. | 55.   | 12736. | 60 | 28.53 | 652.6  | 74743.9  |
| 93  | 9186  | 0. | 193.  | 12922. | 60 | 32.52 | 2609.7 | 77351.6  |
| 94  | 2953  | 0. | 59.   | 12987. | 60 | 34.41 | 838.9  | 78149.5  |
| 95  | 10170 | 0. | 213.  | 13200. | 60 | 32.53 | 2889.2 | 81078.7  |
| 96  | 1640  | 0. | 38.   | 13238. | 60 | 29.49 | 765.9  | 81544.6  |
| 97  | 1960  | 0. | 38.   | 13276. | 60 | 35.46 | 559.1  | 82113.7  |
| 98  | 4265  | 0. | 89.   | 13366. | 60 | 32.52 | 1211.6 | 82315.2  |
| 99  | 4951  | 0. | 98.   | 13464. | 60 | 34.46 | 1406.5 | 82721.9  |
| 100 | 5577  | 0. | 134.  | 13592. | 60 | 28.34 | 1584.4 | 82816.2  |
| 101 | 6562  | 0. | 138.  | 13734. | 60 | 32.56 | 1864.2 | 83170.5  |
| 102 | 3281  | 0. | 65.   | 13801. | 60 | 34.17 | 932.1  | 83102.6  |
| 103 | 5249  | 0. | 110.  | 13911. | 60 | 32.53 | 1491.2 | 90593.2  |
| 104 | 1069  | 0. | 21.   | 13932. | 60 | 34.25 | 303.7  | 90897.4  |
| 105 | 2297  | 0. | 53.   | 13985. | 60 | 29.50 | 652.6  | 91551.1  |
| 106 | 15747 | 0. | 330.  | 14316. | 60 | 32.55 | 4473.6 | 96123.4  |
| 107 | 2953  | 0. | 54.   | 14370. | 60 | 37.45 | 838.9  | 96160.5  |
| 108 | 557   | 0. | 11.   | 14380. | 60 | 35.49 | 158.2  | 97120.7  |
| 109 | 4951  | 0. | 107.  | 14487. | 60 | 31.51 | 1406.5 | 98427.3  |
| 110 | 1969  | 0. | 36.   | 14523. | 60 | 37.46 | 559.4  | 98920.6  |
| 111 | 2297  | 0. | 46.   | 14569. | 60 | 34.32 | 652.6  | 99039.2  |
| 112 | 3500  | 0. | 74.   | 14643. | 60 | 27.89 | 994.3  | 100633.5 |
| D   | 0     | 0. | 3600. | 18243. | 0  | 0.00  | 0.0    | 100633.5 |
| 113 | 3500  | 0. | 74.   | 18316. | 60 | 32.47 | 0.0    | 100633.5 |
| 114 | 2297  | 0. | 50.   | 18366. | 60 | 31.28 | 0.0    | 100633.5 |
| 115 | 1969  | 0. | 47.   | 18413. | 60 | 28.14 | 0.0    | 100633.5 |
| 116 | 4951  | 0. | 99.   | 18513. | 60 | 34.02 | 0.0    | 100633.5 |
| 117 | 557   | 0. | 13.   | 18526. | 60 | 29.52 | 0.0    | 100633.5 |
| 118 | 2953  | 0. | 71.   | 18597. | 60 | 28.31 | 0.0    | 100633.5 |
| 119 | 15747 | 0. | 331.  | 18927. | 60 | 32.49 | 0.0    | 100633.5 |
| 120 | 2297  | 0. | 44.   | 18972. | 60 | 35.19 | 0.0    | 100633.5 |
| 121 | 1969  | 0. | 43.   | 19014. | 60 | 31.50 | 0.0    | 100633.5 |
| 122 | 5249  | 0. | 110.  | 19125. | 60 | 32.56 | 0.0    | 100633.5 |
| 123 | 3281  | 0. | 71.   | 19196. | 60 | 31.51 | 0.0    | 100633.5 |
| 124 | 6562  | 0. | 138.  | 19334. | 60 | 32.50 | 0.0    | 100633.5 |
| 125 | 5577  | 0. | 102.  | 19435. | 60 | 37.42 | 0.0    | 100633.5 |
| 126 | 4921  | 0. | 107.  | 19542. | 60 | 31.36 | 0.0    | 100633.5 |
| 127 | 4265  | 0. | 90.   | 19632. | 60 | 32.55 | 0.0    | 100633.5 |
| 128 | 1968  | 0. | 46.   | 19677. | 60 | 29.40 | 0.0    | 100633.5 |
| 129 | 1640  | 0. | 32.   | 19709. | 60 | 35.42 | 0.0    | 100633.5 |
| 130 | 10170 | 0. | 213.  | 19923. | 60 | 32.44 | 0.0    | 100633.5 |
| 131 | 2953  | 0. | 64.   | 19987. | 60 | 31.35 | 0.0    | 100633.5 |
| 132 | 9186  | 0. | 193.  | 20180. | 60 | 32.49 | 0.0    | 100633.5 |
| 133 | 2297  | 0. | 42.   | 20222. | 60 | 37.53 | 0.0    | 100633.5 |
| 134 | 2625  | 0. | 61.   | 20282. | 60 | 29.46 | 0.0    | 100633.5 |
| 135 | 10498 | 0. | 220.  | 20503. | 60 | 32.53 | 0.0    | 100633.5 |
| 136 | 3281  | 0. | 76.   | 20579. | 60 | 29.50 | 0.0    | 100633.5 |
| 137 | 2297  | 0. | 42.   | 20621. | 60 | 37.45 | 0.0    | 100633.5 |
| 138 | 4593  | 0. | 119.  | 20740. | 60 | 26.45 | 0.0    | 100633.5 |
| 139 | 6234  | 0. | 131.  | 20871. | 60 | 32.46 | 0.0    | 100633.5 |
| 140 | 4593  | 0. | 89.   | 20960. | 60 | 35.18 | 0.0    | 100633.5 |
| 141 | 3937  | 0. | 91.   | 21051. | 60 | 29.33 | 0.0    | 100633.5 |

|     |      |    |      |        |    |       |     |          |
|-----|------|----|------|--------|----|-------|-----|----------|
| 142 | 5249 | 0. | 110. | 21161. | 60 | 32.52 | 0.0 | 100633.5 |
| 143 | 4265 | 0. | 82.  | 21243. | 60 | 35.44 | 0.0 | 100633.5 |
| 144 | 1640 | 0. | 42.  | 21286. | 60 | 26.55 | 0.0 | 100633.5 |
| 145 | 5577 | 0. | 117. | 21403. | 60 | 32.53 | 0.0 | 100633.5 |
| 146 | 2625 | 0. | 51.  | 21454. | 60 | 35.48 | 0.0 | 100633.5 |
| 147 | 2953 | 0. | 68.  | 21522. | 60 | 29.39 | 0.0 | 100633.5 |
| 148 | 2625 | 0. | 48.  | 21570. | 60 | 37.49 | 0.0 | 100633.5 |
| 149 | 8202 | 0. | 172. | 21743. | 60 | 32.51 | 0.0 | 100633.5 |
| 150 | 4265 | 0. | 99.  | 21841. | 60 | 29.49 | 0.0 | 100633.5 |
| 151 | 1968 | 0. | 38.  | 21880. | 60 | 35.30 | 0.0 | 100633.5 |
| 152 | 2624 | 0. | 61.  | 21940. | 60 | 29.45 | 0.0 | 100633.5 |
| 153 | 1640 | 0. | 28.  | 21969. | 60 | 40.48 | 0.0 | 100633.5 |
| 154 | 2953 | 0. | 57.  | 22026. | 60 | 35.34 | 0.0 | 100633.5 |
| 155 | 4593 | 0. | 106. | 22132. | 60 | 29.35 | 0.0 | 100633.5 |
| 156 | 8202 | 0. | 172. | 22304. | 60 | 32.49 | 0.0 | 100633.5 |
| 157 | 9842 | 0. | 190. | 22494. | 60 | 35.45 | 0.0 | 100633.5 |
| 158 | 8530 | 0. | 179. | 22673. | 60 | 32.51 | 0.0 | 100633.5 |
| 159 | 3937 | 0. | 85.  | 22759. | 60 | 31.38 | 0.0 | 100633.5 |
| 160 | 984  | 0. | 28.  | 22787. | 60 | 23.92 | 0.0 | 100633.5 |
| 161 | 656  | 0. | 13.  | 22800. | 60 | 42.12 | 0.0 | 100633.5 |
| 162 | 3937 | 0. | 83.  | 22882. | 60 | 32.52 | 0.0 | 100633.5 |
| 163 | 2953 | 0. | 57.  | 22939. | 60 | 35.29 | 0.0 | 100633.5 |
| 164 | 4921 | 0. | 103. | 23042. | 60 | 32.51 | 0.0 | 100633.5 |
| 165 | 3937 | 0. | 91.  | 23134. | 60 | 29.52 | 0.0 | 100633.5 |
| 166 | 1969 | 0. | 41.  | 23175. | 60 | 32.51 | 0.0 | 100633.5 |
| 167 | 2297 | 0. | 59.  | 23235. | 60 | 26.13 | 0.0 | 100633.5 |
| 168 | 1312 | 0. | 22.  | 23257. | 60 | 44.46 | 0.0 | 100633.5 |
| 169 | 1312 | 0. | 34.  | 23296. | 60 | 26.52 | 0.0 | 100633.5 |
| 170 | 656  | 0. | 12.  | 23303. | 60 | 40.38 | 0.0 | 100633.5 |
| 171 | 1969 | 0. | 46.  | 23348. | 60 | 29.50 | 0.0 | 100633.5 |
| 172 | 6090 | 0. | 145. | 23493. | 60 | 32.52 | 0.0 | 100633.5 |
| 173 | 4921 | 0. | 114. | 23607. | 60 | 29.33 | 0.0 | 100633.5 |
| 174 | 3281 | 0. | 69.  | 23676. | 60 | 32.53 | 0.0 | 100633.5 |
| 175 | 1640 | 0. | 27.  | 23704. | 60 | 41.48 | 0.0 | 100633.5 |
| 176 | 2952 | 0. | 68.  | 23772. | 60 | 29.42 | 0.0 | 100633.5 |
| 177 | 3609 | 0. | 76.  | 23848. | 60 | 32.52 | 0.0 | 100633.5 |
| 178 | 984  | 0. | 25.  | 23873. | 60 | 26.33 | 0.0 | 100633.5 |
| 179 | 328  | 0. | 7.   | 23880. | 60 | 35.43 | 0.0 | 100633.5 |
| 180 | 984  | 0. | 25.  | 23906. | 60 | 26.33 | 0.0 | 100633.5 |
| 181 | 1312 | 0. | 26.  | 23931. | 60 | 35.32 | 0.0 | 100633.5 |
| 182 | 1640 | 0. | 36.  | 23969. | 60 | 29.41 | 0.0 | 100633.5 |
| 183 | 2953 | 0. | 62.  | 24031. | 60 | 32.45 | 0.0 | 100633.5 |
| 184 | 1640 | 0. | 32.  | 24063. | 60 | 35.50 | 0.0 | 100633.5 |
| 185 | 1969 | 0. | 46.  | 24109. | 60 | 29.37 | 0.0 | 100633.5 |
| 186 | 1312 | 0. | 21.  | 24130. | 60 | 44.46 | 0.0 | 100633.5 |
| 187 | 1640 | 0. | 44.  | 24174. | 60 | 25.46 | 0.0 | 100633.5 |
| 188 | 656  | 0. | 12.  | 24187. | 60 | 40.48 | 0.0 | 100633.5 |
| 189 | 328  | 0. | 8.   | 24195. | 60 | 26.23 | 0.0 | 100633.5 |
| 190 | 984  | 0. | 18.  | 24213. | 60 | 40.52 | 0.0 | 100633.5 |
| 191 | 984  | 0. | 25.  | 24239. | 60 | 26.15 | 0.0 | 100633.5 |
| 192 | 1969 | 0. | 34.  | 24273. | 60 | 40.40 | 0.0 | 100633.5 |

|     |      |    |      |        |    |       |     |          |
|-----|------|----|------|--------|----|-------|-----|----------|
| 193 | 1312 | 0. | 34.  | 24307. | 60 | 21.35 | 0.0 | 100633.5 |
| 194 | 3019 | 1. | 79.  | 24385. | 60 | 31.47 | 1.0 | 100633.5 |
| 195 | 1640 | 0. | 33.  | 24418. | 60 | 34.27 | 0.0 | 100633.5 |
| 196 | 2624 | 0. | 57.  | 24475. | 60 | 21.36 | 0.0 | 100633.5 |
| 197 | 1968 | 0. | 41.  | 24517. | 60 | 32.54 | 0.0 | 100633.5 |
| 198 | 2297 | 0. | 44.  | 24561. | 60 | 35.31 | 0.0 | 100633.5 |
| 199 | 1312 | 0. | 32.  | 24592. | 60 | 28.39 | 0.0 | 100633.5 |
| 200 | 2953 | 0. | 62.  | 24655. | 60 | 32.50 | 0.0 | 100633.5 |
| 201 | 656  | 0. | 11.  | 24666. | 60 | 43.36 | 0.0 | 100633.5 |
| 202 | 984  | 0. | 26.  | 24694. | 60 | 24.20 | 0.0 | 100633.5 |
| 203 | 2625 | 0. | 56.  | 24749. | 60 | 32.44 | 0.0 | 100633.5 |
| 204 | 328  | 0. | 6.   | 24756. | 60 | 35.35 | 0.0 | 100633.5 |
| 205 | 2953 | 0. | 62.  | 24816. | 60 | 32.45 | 0.0 | 100633.5 |
| 206 | 3937 | 0. | 85.  | 24903. | 60 | 31.51 | 0.0 | 100633.5 |
| 207 | 2953 | 0. | 62.  | 24965. | 60 | 32.43 | 0.0 | 100633.5 |
| 208 | 984  | 0. | 17.  | 24982. | 60 | 40.43 | 0.0 | 100633.5 |
| 209 | 1312 | 0. | 28.  | 25010. | 60 | 32.43 | 0.0 | 100633.5 |
| 210 | 1640 | 0. | 32.  | 25041. | 60 | 35.51 | 0.0 | 100633.5 |
| 211 | 2625 | 0. | 57.  | 25098. | 60 | 31.30 | 0.0 | 100633.5 |
| 212 | 1640 | 0. | 34.  | 25133. | 60 | 32.44 | 0.0 | 100633.5 |
| 213 | 984  | 0. | 23.  | 25155. | 60 | 29.35 | 0.0 | 100633.5 |
| 214 | 2297 | 0. | 46.  | 25202. | 60 | 34.10 | 0.0 | 100633.5 |
| 215 | 656  | 0. | 17.  | 25219. | 60 | 26.41 | 0.0 | 100633.5 |
| 216 | 2953 | 0. | 59.  | 25278. | 60 | 33.70 | 0.0 | 100633.5 |
| 217 | 2297 | 0. | 44.  | 25322. | 60 | 35.50 | 0.0 | 100633.5 |
| 218 | 5905 | 0. | 128. | 25450. | 60 | 31.52 | 0.0 | 100633.5 |
| 219 | 7218 | 0. | 152. | 25602. | 60 | 32.49 | 0.0 | 100633.5 |
| 220 | 984  | 0. | 23.  | 25625. | 60 | 29.46 | 0.0 | 100633.5 |
| 221 | 1640 | 0. | 33.  | 25658. | 60 | 34.03 | 0.0 | 100633.5 |
| 222 | 1312 | 0. | 25.  | 25683. | 60 | 35.49 | 0.0 | 100633.5 |
| 223 | 2625 | 0. | 60.  | 25751. | 60 | 26.37 | 0.0 | 100633.5 |
| 224 | 1640 | 0. | 35.  | 25786. | 60 | 27.89 | 0.0 | 100633.5 |

END OF DATA

TRAIN MAKES 1.12 TRIPS PER SHIFT.

IT CARRIES 1675.3 TONS DURING THE SHIFT.

THIS EQUALS 112396.6 TON-MILES/SHIFT.

TRAIN STOPPED.

APPENDIX VRail Haulage Cost Analysis

Equipment Selection Rail haulage equipment is selected based on the following characteristics:

|                       |                |
|-----------------------|----------------|
| Mining rate per year  | 1,103,000 tons |
| Mining rate per day   | 3,680 tons     |
| Working days per year | 300            |
| Shifts per day        | 2              |
| Rolling stock         |                |

A diesel-electric locomotive is selected. From travel time study a 120-ton unit is the most convenient for this study.

Cars: 50-ton capacity  
 weight empty: 25 tons  
 Antifriction bearings  
 Side dump construction

Time data: from computer information it can be seen that a 30-car train can safely make a round trip per shift. So, a locomotive will be capable to make 2 trips per day

One train will haul 1500 tons per shift.

Transportation of 3680 tons will require

$$3680/1500 = 2.46 \text{ train shifts per day}$$

Taking a 90 percent locomotive availability the number of locomotives needed is two.

Assuming an availability of 86 percent for dump cars

the quantity required to permit operation of two 30-car trains will be:

$$(30 \times 2) / 0.86 = 69.8$$

Purchase of 70 cars is recommended.

If the annual production were to increase, the 2 locomotives will still be capable of hauling higher tonnages.

Ownership Costs Estimate of investment required:

|   |                       |
|---|-----------------------|
| 2 locomotives @ \$240,000 each  | \$ 480,000.00         |
| 70 cars @ \$18,000 each   | 1,260,000.00          |
| Track grade construction plus jungle clearing: 68 miles @ \$8,750 per mile                | 595,000.00            |
| Line track: 68 miles of 133-lb rail 8-in. x 10-in. x 8ft treated ties @ \$85,000 per mile | 5,780,000.00          |
| Railway signals   | 100,000.00            |
| Communication for trains  | 15,000.00             |
| Track maintenance machines  | 140,000.00            |
| Locomotive repair shop  | 150,000.00            |
| Dump car repair shop  | <u>50,000.00</u>      |
| Total investment  | <u>\$8,570,000.00</u> |

1. Depreciation

a) Total ownership cost \$7,775,000.00\*

\*Total investment minus grade construction and shop costs.

b) A period of 15 year applying to all rail haulage equipment is used.

Assume that mining operations  
4800 hour per year.

c) Hourly depreciation cost

$$\begin{aligned} \text{Hourly depreciation cost} &= \frac{\text{Total ownership cost}}{\text{Total hrs in dpr. period}} \\ &= \frac{7,775,000}{15 \times 4800} = \$107.99/\text{hour} \end{aligned}$$

d) Depreciation cost per ton of annual production  
scheduled:

$$\frac{\$7,775,000}{1,103,000 \text{ tons} \times 15 \text{ yr}} = \$0.47/\text{ton}$$

## 2. Interest, Taxes, and Insurance

The following values are commonly used:

|           |     |
|-----------|-----|
| Interest  | 6%  |
| Taxes     | 2%  |
| Insurance | 2%  |
| <hr/>     |     |
| Total     | 10% |

$$\text{Average annual investment} = \left( \frac{n-1}{2n} \times 100 \right) \% \text{ of total invest.}$$

for  $n=15$  years

$$\text{Average annual investment} = 53.3\%$$

Therefore, allowance for interest, taxes and insurance  
is 10 percent of annual investment.

$$\text{Cost/hour} = \frac{0.10 \times 0.553 \times 7,775,000}{4800 \text{ hour/yr}} = \$87.27/\text{hour}$$

Operating Costs Fuel oil consumption is the most reliable indicator of the gross work performed by a diesel-electric locomotive. Fuel-oil expense is roughly 20 percent of the cost of locomotive operation and maintenance. Other expense elements also vary in accordance with work performed, but not in direct proportion. The following rail haulage operating cost relationships, derived from experience seems to be realistic for this estimate:

|                            |      |                        |
|----------------------------|------|------------------------|
| Fuel oil cost              | 20%  | of loco opr & rep cost |
| Locomotive operating cost  | 75%  | " " " " " "            |
| Locomotive repair cost     | 25%  | " " " " " "            |
| Track maintenance cost     | 120% | " " " " " "            |
| Car maintenance cost       | 50%  | " " " " " "            |
| Train traffic control cost | 10%  | " " " " " "            |

#### 1. Locomotive operating and repair cost

##### a) Fuel-oil cost

Formula for gross work done, expressed in thousands of foot tons

$$M \text{ foot tons} = \frac{N}{1000S} \left[ (T + W)(L + 26.4H) + 150,000 \right]$$

where:

N is number of trips in period. Say one operating day period of 16 hours

$$\text{Trips per day} = \frac{3680\text{tpd}}{30 \text{ cars} \times 50\text{-tons}} = 2.45$$

S is number of locomotive shifts worked per day: 3

T is net tons hauled per trip: 1500

W is weight of locomotive plus empty cars in tons:

Locomotive: 120

Empty cars: 750

W: 870 tons

L is lift in ft. It is assumed 50 ft lift in this work

H is haul length in miles: 68 miles

26.4 is a constant derived using a train resistance of 10 lb/ton

$$(5280 \times 10)/2000 : 26.4$$

150,000 is a length of empty haul on level track in ft

Therefore:

$$M = \frac{2.45}{1000 \times 3} \left[ (1500 + 870)(50 + 26.4 \times 68) + 150,000 \right]$$

M foot tons 3,694 per locomotive shift per day

Each gallon of fuel oil will produce about 11,500 foot tons of gross work, therefore, total daily fuel consumption is:

$$\frac{3,694,000 \times 3}{11,500} = 964 \text{ gal}$$

Assuming fuel oil cost as \$0.16/gal, its cost per hour of operation over a period of a year would be:

$$\frac{964 \times 0.16 \times 300 \text{ days}}{4800 \text{ hours/year}} = \$9.64/\text{hour}$$

The operating and repair costs are then computed:

b) Locomotive operating and repair cost

$$9.64 \times \frac{1.00}{0.20} = \$48.2/\text{hour}$$

|                   |   |             |   |            |
|-------------------|---|-------------|---|------------|
| Loco operating    | : | 48.2 x 0.75 | = | \$36.15/hr |
| Loco repairs      | : | 48.2 x 0.25 | = | \$12.05/hr |
| Track maintenance | : | 48.2 x 1.20 | = | \$57.84/hr |
| Car maintenance   | : | 48.2 x 0.50 | = | \$18.08/hr |
| Traffic control   | : | 48.2 x 0.10 | = | \$ 4.82/hr |

### Recapitulation

|  | <u>Per Hour</u> | <u>Per ton</u> |
|--|-----------------|----------------|
| Depreciation                                   | \$107.99        | 0.47           |
| Interest, Taxes, Insurance                     | <u>87.27</u>    | <u>0.38</u>    |
| Total Ownership Cost                           | <u>\$195.26</u> | <u>\$0.85</u>  |
| Loco operating                                 | 36.15           | 0.16           |
| Loco repairs                                   | 12.05           | 0.04           |
| Track maintenance                              | 57.84           | 0.25           |
| Car maintenance                                | 18.08           | 0.08           |
| Traffic control                                | <u>4.82</u>     | <u>0.02</u>    |
| Total Opr. & Rep. Costs                        | \$128.94        | \$0.55         |
| Total Ownership, Repair<br>and Operating Costs | <u>\$324.20</u> | <u>\$1.40</u>  |

BIBLIOGRAPHY

## BIBLIOGRAPHY

- Achttien, D. B., and Stine, R. H., 1964, Computer simulation of a haulage system; Mining Congress Journal, v 50, no. 10, p. 41-46.
- American Institute of Mining, Metallurgical, and Petroleum Engineers, 1968, Surface Mining; New York A.I.M.E., Inc., p. 531-552, and p. 553-585.
- American Institute of Mining, Metallurgical, and Petroleum Engineers, 1969, A decade of digital computers in the mining industry; New York, A.I.M.E., Inc., p. 373-384.
- Bandeira, Celio A., 1969, Truck fleet selection by means of simulation; unpublished Master's Thesis, Colorado School of Mines, 98p.
- Carlson, Fred A., 1952, Geography of Latin America; New York, Prentice-Hall, Inc., 478 p.
- Churchmann, C. W., Ackoff, R. L., and Arnoff, E. L., 1957, Introduction to operations research; New York, John Wiley and Sons, Inc., 645 p.
- Crow, E. L., Davis, F. A., and Maxfield, M. W., 1960, Statistics Manual; New York, Dover Publications, Inc., 288 p.
- Engineering and Mining Journal, \_\_\_\_\_, Portfolio of successful mining and processing techniques; New York, a McGraw-Hill Publication, pp. 72-74.
- General Motors Corporation, Terex Division, 1970, Production and estimating of material movement with earthmoving equipment; Hudson, Ohio, Manual prepared by the Terex Division of General Motors Corporation, 78 p.
- Gibbs, L. W., Gross, J. R., and Pfleider, E. P., 1967, System Analysis for truck and shovel selection; Transactions of the Society of Mining Engineers of A.I.M.E., v 238, pp. 354-359.
- Kaufman, A., 1963, Methods and models of operations research; Englewood Cliffs, N. J., Prentice-Hall, Inc., 536 p.

- Lang, A. Scheffer, and Soberman, Richard, M., 1966, Urban rail transit; its economy and technology; Cambridge, Massachusetts, The M.I.T. Press.
- LeSchack, Leonard A., and Long, Jack B., 1971, Transportation studies show best way to breach jungle mining areas; Engineering and Mining Journal, v 172, no. 2, pp. 89-93.
- Meyer, John R., 1970, Techniques of transport planning; Washington D. C., The Brookings Institution, Transport Research Program, v 2.
- Morgan, W. C., and Peterson, L. L., 1968, Comparison of estimating techniques for determining shovel-truck productivity; A.I.M.E., preprint no. 68-AR-310.
- Nelson, Floyd J., 1964, Simulation of a mine haulage locomotive; Colorado School of Mines Quart., v 59, no. 4, pp. 831-847.
- Saaty Thomas L., 1959, Mathematical methods of operations research; New York, McGraw-Hill Book Company, Inc.
- Sanford, Richard Lee, 1965, Stochastic simulation of a belt conveyor system; unpublished Master's Thesis, The Pennsylvania State University, 82 p.