TRUCK FLEET SELECTION BY
MEANS OF SIMULATION

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COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

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 in Mining Engineering.

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Date: August 15, 1969

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Thesis Advisor

Golden, Colorado
Date: Aug 15, 1969
FOREWORD

Magnesita S.A., a Mining and Metallurgical Company in Brazil, has undertaken the development of an open-pit mining operation in northeastern Brazil at Brumado, in the southwest of the state of Bahia. The mine will begin production in 1970. Since the studies for the new mine will involve the build-up of a haulage system, Magnesita S.A. is interested in this specific problem.

It is proposed to use one shovel and several trucks in this operation, and the object of this study was to determine the optimal number and size of the trucks. The minimum haulage cost per ton of ore was taken as the criterion of optimality.
The purpose of this study is to define a shovel-truck system, where the shovel is already in the possession of the company. Thus the problem consists in deciding the optimal number and type of trucks, under given conditions, such as annual tonnage, depreciation policies, availability, and so forth.

The problem was solved by computer-assisted simulation. This led to the selection of the correct operating fleet. An interesting aspect of this study is the use of probability theory to determine the number of trucks that must be purchased in order to satisfy the operating requirements.

Truck costs and haul times were calculated by computer, and subsequently used in the simulation.
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ACKNOWLEDGMENTS

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Dr. D. G. Mickle, who served on the committee until leaving Colorado School of Mines, whose assistance was helpful,

Dr. A. R. Brown, Director of the Computing Center, whose advice as a member of the committee was valuable,

Professor C. O. Frush, of the Mining Department, who replaced Dr. Mickle in the final stages of Engineering Report completion and whose discussions were helpful in clarifying some points.

The author also wishes to thank Magnesita S.A. for the financial support which made this work possible.
CONCLUSIONS

After several approaches to the problem were considered, it was found that simulation of the system was the most satisfactory.

It was found that eight 50-ton trucks would best match the 3\(\frac{1}{2}\)-cu-yd shovel.

From the selected fleet an annual production of 1,609,267 tons at a haulage cost of $0.64 per ton may be expected.

To expect 8 trucks to operate at least 95 percent of the time at a design availability of 80 percent, it was found that a total of 13 trucks should be acquired.
RECOMMENDATIONS

If one is to be sure about the validity of the results from this report, the following points concerned with its application must be observed:

1. In building the model, certain assumptions were made. Before the results of this study are used in practice, the real conditions should be checked against the assumed conditions.

2. In particular, a maintenance program must be set up to provide 80 percent design availability for the trucks, as assumed in this report.

It was given that two shifts would be worked per day. Operation on a three-shift basis would lead to a lower cost per ton.

The results to be found in practice are not expected to match those found in this study exactly. The results depend entirely upon the data used; nevertheless the method is valid whatever data are used.

At this point something must be said about the versatility of the method used. For this particular problem the minimum cost per ton criterion was chosen to select the best fleet to match the given shovel. The same method could be
used if, instead of the minimum cost per ton, the maximum production rate was chosen as the criterion. The only change would be in the control statement that stops the simulation and cost-per-ton program. In other words, the program would not be stopped when the minimum cost per ton was reached, but when the maximum production rate was reached.

The same method can also be used to adjust fleet size due to modified haul distance.

This work may be described as "tactical" in scope in the sense that it is a suboptimization of a large system. It is recommended that a broader or "strategic" study be carried out, incorporating models such as this one in the optimization of criteria such as return on investment or present value.
INTRODUCTION

It is the purpose of this report on shovel-truck matching to determine the best parameters for a truck fleet, i.e., the best truck size and the optimal number of trucks to be used with a $3\frac{1}{4}$-cu-yd shovel in a given situation. The best parameters must be determined to find the system that provides the minimum haulage cost per ton. The available data for the problem are shown in Appendix I.

The present study was developed in the following sequence:

1. Determination of ownership and operating costs for a truck, shovel, and tractor.
2. Determination, for each truck under consideration, of average loading time and average haul time.
3. Determination, for each truck size, of minimum number of trucks to be used in starting simulations.
4. Determination of a convenient number of truckloads to be simulated in the study of each considered combination providing the required accuracy for the results.
5. Determination of production rates by starting at a minimum number of trucks, and increasing this number until the minimum haulage cost is found.
This procedure is repeated for each truck size.

6. Analysis of results and selection of the best fleet.

7. Determination of number of trucks to be acquired, using probability calculations and individual truck availability.

8. Conclusions and recommendations.

In solving this problem trucks of 22-, 35-, and 50-ton capacities were considered, since these are the available sizes at the Brazilian market.
A system consisting of a loading shovel and trucks can be described as follows. A shovel loads a truck in a certain amount of time, called "loading time." After the truck is loaded, it hauls the material to a dumping point and returns to the shovel. The time spent to do so is called "haul time." Depending on the relation between loading and haul time, and on the truck sufficiency at the shovel, a given number of trucks will operate efficiently with one shovel. To understand correctly the system presented here, one must realize two important points:

1. Loading time, as well as haul time, is not constant, but varies according to probability distributions.

2. Due to the stochastic nature of the loading and haul time, delays will happen to the shovel and trucks.

Extending the analysis of the system, it is realized that loading a truck is an operation composed of many elements such as swinging over the box of the truck, dumping the bucket load, swinging back into the bank, and filling the bucket. Also the haul cycle is composed of hauling a load, turning, spotting at the dumping place, returning to the shovel, and spotting at the shovel. So a complex system is being dealt with and some simplifications must be made to
overcome part of this complexity when one uses any model to represent it.

It is assumed that the elements which compose the loading operation will be considered as only one component. The elements of haul time were treated in the same way.

To predict the production rate of the system there are several mathematical models, but most of them make unrealistic assumptions, as may be seen in the following cases.

Model 1 - Conventional Approach

The three assumptions made by this model are the following:

1. Both shovel and trucks operate in cycles in some constant time which includes a constant allowance for delays,
2. Both shovel and trucks carry a constant load size each cycle,
3. The time required to load a truck is equal to the number of dippers required to load a truck multiplied by the expected shovel time per dipper.

Model 2 - Modified Conventional Approach

The second model, which makes assumptions 1 and 2 stated above, takes a different approach to truck load time. After the shovel services a truck, it must then complete the rest of its cycle, i.e. return, dig, and swing before it can start
servicing the next truck. If one assumes that the next truck is waiting and could be spotted under the shovel during the time required by the shovel to return, dig, and swing, the shovel could immediately start another cycle. However, the first truck is free to leave after the last bucket of its load was dumped. Thus, the truck has a shorter load time than predicted by Model 1, and there will be a slight increase in production rate for a given number of trucks.

The previous two models have made the assumptions that cycle times are constant, and this is not true. This assumption leads to a more efficient system than exists in the field where cycle times vary as already stated.

**Model 3 - Queuing Model**

In this model the assumption is made that the time between arrivals of consecutive trucks (interarrival time) and the load time of a truck are exponentially distributed. The exponential distribution provides the highest probability for very short intervals of time with continually decreasing probabilities for longer intervals. This distribution is a good one for interarrival times in that it reflects the phenomenon of bunching, which occurs in the field. On the other hand, the distribution of expected load time, including shovel delays, cannot have an
exponential form because the highest probability density does not occur for the shortest load time. The exponential distribution is used for load time because it greatly simplifies the development of the queuing model. Results from this model have shown that it underestimates the production rate of a system because the model wrongly assumes, as does Model 1, that a truck cannot leave the shovel until the total loading cycle is completed, while in reality the truck can leave after it has been serviced. Another point is that the queuing model cannot reflect the phenomenon of truck interaction and resulting inefficiency caused by putting considerably more than the balanced number of trucks in the system.

Model 4 - Modified Queuing Model

This model differs from the previous one in the same way that Model 2 differs from Model 1. But the other defects stated for Model 3 still are present in this model.

In order to overcome the difficulties discussed above, a simulation process will be used in determining the production of this two-link material handling system. The model simulated utilizes probability theory to compute the probable cycle component times and delay times associated with the equipment operations.
DESCRIPTION OF THE APPLIED METHOD

As already stated the answer to this problem is based on the analysis of the calculated cost per ton for the various combinations under study. So the problem involves the calculation of ownership and operating cost of the equipment used in the system, and the calculation of production rate for each combination. As the determination of production rates for such a system involves the consideration of loading and haul times as data, calculations were performed to provide them. Once the best combination was selected, considerations of fleet availability were made through probability calculations to correct the required number of trucks providing the final answer.

A flow diagram of the entire study is presented in Appendix II.

Ownership and Operating Costs for Equipment

The company policy on purchase of equipment necessitated a detailed study of implicit costs. The costs discussed here are divided into two categories, ownership and operating costs.

Ownership Costs: The ownership of equipment involves many cost items related to the initial investment. These
include depreciation, interest, taxes, insurance, and incidentals. Determining the initial investment, therefore, is a basic requirement.

The initial investments for the various pieces of equipment were calculated by adding to the F.O.B. price the cost for shipping, unloading, and erecting. To get shipping costs for the shovel and trucks, a 1000-mile shipment by railroad was assumed. For the tractor the total delivered price at site was available.

In calculating the annual depreciation the following were used according to the data provided:

1. no salvage value,
2. a 15-year depreciation period for the shovel,
3. a 5-year depreciation period for trucks and tractor,
4. straight line depreciation method.

Interest, taxes, insurance, and incidentals were taken into account by considering the following percentages on average investment (these are local figures):

- taxes ................. 2 percent
- insurance and incidentals ........ 2 percent
- interest...................... 9 percent

Finally to be realistic in finding ownership costs, standby factors for the equipment must be brought into account. Standby factors of 1.5 for trucks and 1 for the shovel and tractor were assumed upon agreement with Dr. A. T. Janssen, after analyzing these factors for several operating
mines.

**Operating Costs:** This category is directly related to actual operating hours. The items involved here are supplies, fuel, lubricating oils, tires, cutting edge replacement, etc. In this particular case the operator's wages were considered apart to fit the model used.

Appendix III shows a breakdown of shovel and tractor costs. As the cost calculations for the trucks involve consecutive repetitions of the same operations, a computer program was written to perform the operations (see Appendix IV).

Table I shows the results from the cost calculations for all equipment involved in the problem.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Ownership Cost per Year (in $)</th>
<th>Operating Cost per Hour (in $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shovel (3(\frac{3}{4})-cu-yd)</td>
<td>19,015.30</td>
<td>10.26</td>
</tr>
<tr>
<td>Rubber-Tired Diesel Tractor</td>
<td>13,809.60</td>
<td>9.25</td>
</tr>
<tr>
<td>22-Ton Truck</td>
<td>11,456.35</td>
<td>4.35</td>
</tr>
<tr>
<td>35-Ton Truck</td>
<td>19,292.16</td>
<td>8.87</td>
</tr>
<tr>
<td>50-Ton Truck</td>
<td>26,555.41</td>
<td>11.68</td>
</tr>
</tbody>
</table>

In this study the wages were considered as a scheduled cost. Because of difficulties presented in determining the number of hours that a tractor will actually operate at a
shovel, its operation was also considered as a scheduled cost. Based on the operating cost for the tractor, a cost of $12 for its scheduled hour was assumed.

**Average Loading Time**

When loading time for the combinations under study was calculated, the following steps were performed:

1. weight per cu yd of loose material = weight in bank x swell factor,
2. tonnage per pass = bucket capacity in cu yd x fill factor x loose weight per cu yd in tons,
3. no. of passes per load = tonnage rating of haulage unit + tons per pass,
4. load time in minutes = no. of passes x excavator cycle time in minutes.

The calculated loading times for the combinations under study are shown in Table II. A fill factor of 80 percent for the bucket and a density of 1.52 ton per broken cubic yard were assumed.

<table>
<thead>
<tr>
<th>Truck Size (in tons)</th>
<th>Load Time (in min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 ton</td>
<td>3.0</td>
</tr>
<tr>
<td>35 ton</td>
<td>4.5</td>
</tr>
<tr>
<td>50 ton</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Average Haul Time

Since the development of a new mine is being dealt with, it is not possible to obtain the average haul time by performing field experiments at the site. So by some other means the average haul time must be found for the truck study. To accomplish that a computer program was used.

This haulage computer program simulates the travel of the vehicle over the described haul roads by incremental velocities, calculating travel times, and travel distances from the known torque vs. speed characteristics of the vehicle. For each given increment of velocity, the program analyzes and makes decisions based on the following points:

1. available tractive effort vs. total resistance,
2. actual acceleration vs. maximum acceleration or deceleration,
3. final speed vs. speed limit,
4. traveled distance vs. section length.

This is, in a sense, a numerical integration of the vehicle's performance, and of course varies for each and every application.

Because the trucks are not operated at their full potential on a day-to-day basis, the actual travel times will be somewhat greater than the calculated values. Twenty-percent increments were added to the calculated values to correct them. This figure was taken from the
After these travel times have been calculated, they are combined with other easily estimated times such as turning and spotting times at the dumping place, dumping time, and spotting time at the shovel. This combination results in a total haul time that is considered as one component of the system.

At this point it must be said that this particular computer program does not provide means to correct the effect of altitude on truck performance, as the road in question is below an altitude of 2000 feet.

A detailed flow diagram is shown in Appendix V, together with a copy of the computer program and its output.

In order to use the computer program to calculate the average haul times, velocity increments of 2 mph were used. The other data concerned with trucks, company policy, and road conditions are shown in Appendix I.

Table III shows the results of the calculated haul times for the trucks under consideration.
Table III. Calculated Average Haul Times.

<table>
<thead>
<tr>
<th>Truck Size (in tons)</th>
<th>Turning, Spinning &amp; Dumping Time (in min)</th>
<th>Spotting Time at Machine (in min)</th>
<th>Traveling Haul Time (in min)</th>
<th>Calculated Average Haul Time (in min)</th>
<th>Corrected Average Haul Time (in min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>1.3</td>
<td>0.3</td>
<td>43.13</td>
<td>51.76</td>
<td>53.36</td>
</tr>
<tr>
<td>35</td>
<td>1.3</td>
<td>0.3</td>
<td>42.32</td>
<td>50.78</td>
<td>52.38</td>
</tr>
<tr>
<td>50</td>
<td>1.3</td>
<td>0.3</td>
<td>41.50</td>
<td>49.80</td>
<td>51.40</td>
</tr>
</tbody>
</table>

Production Rate by Means of Simulation

As already discussed in previous sections, the best process to provide production rate for the shovel-truck combinations was found to be simulation. The model used here was built and translated into a computer program by Dr. A. T. Janssen. In order to use the computer facilities at Colorado School of Mines, the program was translated into Fortran II.

The utilization of the selected model involves the following assumptions:

1. trucks are not allowed to pass each other in the same direction,

2. shovel cannot keep loading continuously (from time to time the shovel must move to reach the material that is being loaded. Considering that the drive by system will be used, a time repositioning factor was assumed to be 5 percent of loading time. This
factor will be taken into account only if the actual delay time for the shovel is less than 5 percent of the loading time),

3. no allowance for adjustment due to breakdowns is made,

4. cycle times are supposed to be distributed according to the normal distribution,

5. to be realistic a minimum value for loading time and haul time must be observed (here these minimum values were assumed to be 70 percent of the average values which causes the distribution to be truncated),

6. in obtaining the gross shovel operating time, a factor of 1.07 was applied on total shovel time.

At this point some method was required to determine the convenient number of truckloads to be simulated for each combination. Here we adopted the statistical concept entitled "Standard Error of the Mean." In the application of this concept, the following two equations are basic:

$$a \overline{x} \geq z S\overline{x} \quad (1)$$

$$S\overline{x} = \frac{S}{\sqrt{N}} \quad (2)$$
where: $a =$ desired accuracy

$x = \text{mean}$

$z =$ integer equal 1, 2, or 3 if the chosen confidence level is 68, 95, or 99 percent

$S\bar{x} =$ standard error of the mean

$s = \text{standard deviation}$

$N =$ number of samples (truckloads).

By substituting the expression for $S\bar{x}$ in equation 2, we get 3.

\[
a \cdot \bar{x} \geq \frac{z \cdot s}{\sqrt{N}} \quad (3)
\]

or

\[
N \geq \left(\frac{z \cdot s}{a \cdot \bar{x}}\right)^2 \quad (4)
\]

From equation 4 we derived the figures presented in Table IV.

**Table IV. Number of Truckloads to be Simulated at Given Confidence Level and Inaccuracy.**

<table>
<thead>
<tr>
<th>Inaccuracy (in percentage)</th>
<th>68 Percent Confidence Level</th>
<th>95 Percent Confidence Level</th>
<th>99 Percent Confidence Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>9</td>
<td>36</td>
<td>81</td>
</tr>
<tr>
<td>1</td>
<td>225</td>
<td>900</td>
<td>2025</td>
</tr>
</tbody>
</table>
Based upon the fact that we are dealing with an industrial problem, and that computer time costs money, we made our decision about the number of truckloads to be simulated. A confidence level of 95 percent and 1 percent accuracy was selected, i.e., 900 truckloads were simulated for each combination under study.

Another point to be observed is that the application of simulation involves generation of random normal deviates. To be sure about the randomness and normality of generated deviates, tests were applied over selected samples. In applying the run test for randomness over the selected sample, a result in between 6 and 16 should be found to prove that the sample is consistent with the null hypothesis of randomness at the 5 percent level of significance (Crow and others, 1960, p. 23). A result of 11 was found. Now, in testing, with 5 percent level of significance, the hypothesis that the selected random sample came from a population having a normal distribution, the calculated chi-square value should be smaller than 15.51. A result of 9.97 for the calculated chi-square value was found.

Again a flow diagram with its correspondent computer program is presented in Appendix VI, showing the sequence of operations for the simulation and cost per ton models.

By applying the described simulation process, the results also shown in Table V were obtained.
Cost Per Ton

The previous sections have been devoted to the development of necessary information to be used, as data, in the operations to determine the cost per ton of given shovel-truck combination.

The general procedure to calculate the cost per ton for each combination can be described as follows. To start, all kinds of costs presented in the previous section were converted into a yearly basis. Then by adding them up we got the total cost per year, which divided by production per year gave 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).

The conversion of those costs directly related to actual operating hours involve data from the simulation. At this point a distinction was made by considering separately shovel and trucks.

For the shovel, the division of the gross operating time of the shovel into the total loading time resulted in an operating factor. The multiplication of this factor by
the scheduled hours per year gave us the number of operating hours per year. Finally the annual operating cost was obtained by multiplying the yearly operating hours with the cost per operating hour.

For trucks, the total time was obtained by multiplying the gross operating time of the shovel by the number of trucks. The operating factor was determined by dividing the gross truck operating time into haul time. The operating hours per year was derived by multiplying the operating factor by the total scheduled hours. Similarly cost per year was the result of the multiplication of the yearly operating hours by cost per operating hour.

The calculations for annual production were performed as follows. To start, the number of simulated truckloads was multiplied by the truck capacity in tons per load. The resultant tonnage was divided by the gross operating time of the shovel in hours. This last obtained figure was multiplied by the scheduled hours per year, giving total production per year for a given shovel-truck combination.

Ultimately the cost per ton was derived by dividing the annual production into total annual cost.

A detailed flow diagram and example of the operations to calculate cost per ton are shown respectively in Figure 4 and Appendix VI. Also the whole computer program is listed in Appendix V.
The resultant annual production and cost per ton for the considered combinations are shown in Table V.

**Analysis of the Results**

Keeping in mind the objectives of the problem, we can easily select from Table V the best result. So the combination composed of 8 trucks of 50 tons each was selected among the other results. At first glance, it could appear obvious that the bigger the truck the cheaper the cost per ton. In order to understand the necessity of analyzing several sizes, a graph is shown in Figure 1, which is self explanatory.

![Cost/Ton vs Truck Size](image)

where:  
A = operating cost  
B = capital cost  
C = summation of A and B

**Figure 1.** Graph showing the way cost per ton components vary.
### Table V. Production and Corresponding Cost per Ton for Each Studied Shovel-Truck System.

<table>
<thead>
<tr>
<th>Number of Trucks</th>
<th>22-Ton Production (ton)</th>
<th>35-Ton Production (ton)</th>
<th>50-Ton Production (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost/Ton ($)</td>
<td>Cost/Ton ($)</td>
<td>Cost/Ton ($)</td>
</tr>
<tr>
<td>6</td>
<td>1,285,510</td>
<td>0.6662</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1,463,938</td>
<td>0.6574</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1,659,038</td>
<td>0.6455</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1,798,387</td>
<td>0.6513</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1,457,004</td>
<td>0.7415</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1,587,589</td>
<td>0.7355</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1,715,652</td>
<td>0.7303</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1,804,005</td>
<td>0.7391</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1,280,388</td>
<td>0.8027</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1,363,404</td>
<td>0.7978</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1,441,965</td>
<td>0.7948</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1,510,360</td>
<td>0.7973</td>
<td></td>
</tr>
</tbody>
</table>

Another point is that attention must be paid to the fact that for long haul distance such as in this problem, one truck plays a small part of the total results. This fact becomes critical especially close to the balanced point of the system. The resultant cost per ton varies a little when the number of trucks changes, so for good detection of the cost per ton variations, one must consider at least four decimal places.

Once the truck and fleet sizes have been selected, the next step is considerations of fleet availability.
FLEET AVAILABILITY

When discussing ownership costs, we saw the necessity of considering a standby factor. At this point, knowing the required fleet size, a complete study of the fleet availability using probability calculations was performed as follows. According to the probability theory, the following expression can be set up:

\[ P(n) = P(nr)^n \times P(nnr)^{n'-n} \times \binom{n'}{n} \]

where:
- \( P(n) \) = probability of \( n \) units being available
- \( P(nr) \) = probability of a single unit being available
- \( P(nnr) \) = probability of a single unit not being available
- \( \binom{n'}{n} \) = combination of \( n' \) units taken \( n \) at a time.

This is the discrete probability that, under the conditions in which each of the units has the same design probability of running a certain percentage of the scheduled time, exactly the required fleet will be available. To put this information in a more useful form the cumulative probabilities were tabulated, and this tabulation gives the probability of at least a certain number \( (n) \) of units being available. In order to provide means for selection of the additional number of trucks, Table VI shows the cumulative probabilities for different fleet sizes.
Table VI. Probability of Having at Least (n) Trucks at Various Design availabilities.

<table>
<thead>
<tr>
<th>Fleet Size</th>
<th>Number at Least</th>
<th>Accumulative Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>0.87913 0.95003 0.98720</td>
</tr>
<tr>
<td>8</td>
<td>0.67780 0.82020 0.92981</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.37581 0.54430 0.73610</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.10737 0.19688 0.34868</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.94959 0.98411 0.99725</td>
</tr>
<tr>
<td>7</td>
<td>0.61740 0.77881 0.91044</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.32212 0.49219 0.69736</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.94959 0.98411 0.99725</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.10737 0.19688 0.34868</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.98059 0.99536 0.99946</td>
</tr>
<tr>
<td>7</td>
<td>0.8244 0.97608 0.99567</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.37581 0.54430 0.73610</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.27488 0.44346 0.65900</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.06872 0.14224 0.28243</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.99300 0.99873 0.99999</td>
</tr>
<tr>
<td>7</td>
<td>0.96996 0.99247 0.99908</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.90087 0.96583 0.99354</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.74732 0.88200 0.96584</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.50165 0.69196 0.86612</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.23365 0.39828 0.62134</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.05497 0.12090 0.25418</td>
<td></td>
</tr>
</tbody>
</table>

Referring to the mathematical expression presented early in this section, one can see that any change in the probability of a single unit being available, i.e., an improvement in the design availability, will have a significant effect over the probability of a given number of units being available. Table VI also shows how a change in design availability can alter the overall picture.
From Table VI we selected the probabilities of having at least 8 units at 80-%, 85-%, and 90-percent design availability. These selected figures are shown in Table VII.

Table VII. Probability of Having at Least 8 Trucks at Specific Design Availabilities.

<table>
<thead>
<tr>
<th>Number of Units in Fleet</th>
<th>At 80 Percent*</th>
<th>At 85 Percent</th>
<th>At 90 Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.67780</td>
<td>0.82020</td>
<td>0.92981</td>
</tr>
<tr>
<td>11</td>
<td>0.83886</td>
<td>0.93055</td>
<td>0.98146</td>
</tr>
<tr>
<td>12</td>
<td>0.92744</td>
<td>0.97608</td>
<td>0.99567</td>
</tr>
<tr>
<td>13</td>
<td>0.96996</td>
<td>0.99247</td>
<td>0.99908</td>
</tr>
</tbody>
</table>

*Expected availability of the individual truck.

Finally, several fleet sizes were selected and tabulated in Table VIII in such a way to be in accordance with both specific design availabilities and specific time availabilities for seven operating units.
Table VIII. Fleet Size Needed for 8-Unit Operation.

<table>
<thead>
<tr>
<th>Unit Design Availability (percentage)</th>
<th>Fleet Size Needed to Have 8-Units Operating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90 Percent of time</td>
</tr>
<tr>
<td>0.80</td>
<td>12</td>
</tr>
<tr>
<td>0.85</td>
<td>11</td>
</tr>
<tr>
<td>0.90</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

If one assumes that a 0.80 design availability involves a reasonable maintenance program and that 0.95 time availability for 8 running units is quite good for industrial purposes, then an addition of 5 trucks is recommended for the required fleet. So a total of thirteen 50-ton trucks must be acquired.
SUMMARY

The study developed in this report was aimed at optimizing a shovel-truck transportation system. The work is divided in two parts: 1) determination of the optimum size and number of trucks that have to be available all the time to operate with a previous existing shovel, and 2) determination of the number of trucks to be bought by the company to satisfy the optimum number, as determined in the first part of the work.

In the first part, a development of a computer simulation of the transportation system was made after the simulation found to be the most suitable approach technique for the problem. The simulation optimized the size and number of trucks for the lowest possible haulage cost.

In the second part, which was developed with a special emphasis and which involves probability calculations, the minimum number of standby trucks was determined so that the minimum number of trucks in operation was satisfied within 95 percent probability.
APPENDIX I

LIST OF AVAILABLE DATA
## DATA FOR THE PROBLEM

### Road Profile

<table>
<thead>
<tr>
<th>Section Number</th>
<th>Section Length (ft)</th>
<th>Grade (%)</th>
<th>Section Number</th>
<th>Section Length (ft)</th>
<th>Grade (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>984.2</td>
<td>0.0</td>
<td>16</td>
<td>1902.8</td>
<td>-3.0</td>
</tr>
<tr>
<td>2</td>
<td>2034.1</td>
<td>-1.0</td>
<td>17</td>
<td>2427.7</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>984.2</td>
<td>-3.5</td>
<td>18</td>
<td>3412.0</td>
<td>-4.0</td>
</tr>
<tr>
<td>4</td>
<td>1574.7</td>
<td>-1.0</td>
<td>19</td>
<td>3543.2</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>1968.4</td>
<td>-4.0</td>
<td>20</td>
<td>1934.1</td>
<td>-6.0</td>
</tr>
<tr>
<td>6</td>
<td>656.1</td>
<td>-5.0</td>
<td>21</td>
<td>984.2</td>
<td>4.5</td>
</tr>
<tr>
<td>7</td>
<td>1181.0</td>
<td>-3.0</td>
<td>22</td>
<td>853.0</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>2230.9</td>
<td>-6.5</td>
<td>23</td>
<td>2624.6</td>
<td>4.5</td>
</tr>
<tr>
<td>9</td>
<td>524.9</td>
<td>-2.0</td>
<td>24</td>
<td>1934.1</td>
<td>-4.4</td>
</tr>
<tr>
<td>10</td>
<td>1837.2</td>
<td>-6.5</td>
<td>25</td>
<td>1377.9</td>
<td>1.8</td>
</tr>
<tr>
<td>11</td>
<td>2230.9</td>
<td>-3.0</td>
<td>26</td>
<td>393.7</td>
<td>-0.9</td>
</tr>
<tr>
<td>12</td>
<td>1574.7</td>
<td>-1.5</td>
<td>27</td>
<td>2165.3</td>
<td>0.7</td>
</tr>
<tr>
<td>13</td>
<td>1968.4</td>
<td>-6.0</td>
<td>28</td>
<td>524.9</td>
<td>-2.0</td>
</tr>
<tr>
<td>14</td>
<td>1837.2</td>
<td>-6.5</td>
<td>29</td>
<td>1312.3</td>
<td>0.0</td>
</tr>
<tr>
<td>15</td>
<td>1312.3</td>
<td>-0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Return over same road. Curves not severe enough to affect speeds. 40-ft road width ample for two-way traffic. Main haul road in pit smooth, hard, well-packed gravel, 2% rolling resistance (A.I.M.E., 1968). No stops, cross traffic or other. No dust control problem.

### Shovel Data

- **Shovel size**: 3½ cu yd
- **Model**: Bucyrus-Erie 61-B
- **Price, f.o.b. factory**: $135,500.00
Truck Data

Altitude                      less than 2000 ft
Speed limit                   30 mph

Miscellaneous Data

Time elements -
300 operating days per year
two 8-hour shifts per day
4,800 operating hours per year

Material -
nature: magnesite ore, well blasted
weight: in bank - 2.5 net tons per cu yd
        loose - 1.52 net tons per cu yd
swell factor: 65%

Material discharge -
no restrictions

Weather conditions -
ambient air temperatures range: 60°F to 100°F
average rainfall (seasonable)

Financial elements -
straight-line depreciation method used for equipment depreciation
15-year depreciation period for the shovel
5-year depreciation period for trucks and tractor (no salvage value considered)
APPENDIX II

FLOW DIAGRAM FOR THE ENTIRE STUDY
DEFINITION OF FLOW DIAGRAM SYMBOLS

- Program terminal
- Onpage connector
- Offpage connector
- Decision operation
- Do-loop or subroutine
- Data processing or calculation
- Input or output operation

Note: numbers in parentheses refer to the record numbers concerned.
Figure 2. Flow diagram for the entire study.
INITIATE MINIMUM NUMBER OF TRUCKS

AVERAGE HAUL TIME CALCULATIONS

OWNERSHIP AND OPERATING COST CALC. FOR TRUCKS

HAUL SIMULATION

1

3

2
CALCULATION OF THE COST PER TON FOR THE COMBINATION CONSIDERED

IS COST FOR THE COMBINATION MINIMUM?

YES

KEEP RESULTS OF COMBINATIONS WITH MINIMUM COST FOR COMPARISON

No

INCREASE NUMBER OF TRUCKS

CHANGE SIZE OF TRUCKS

ARE ALL SIZES OF TRUCKS CONSIDERED?

No

YES
5

ANALYZE MINIMUM COST COMBINATIONS

SELECT COMBINATION THAT BEST FITS THE PROBLEM AT MINIMUM COST

CONSIDER FLEET AVAILABILITY TO RECOMMEND FINAL NUMBER OF TRUCKS

WRITE A FINAL REPORT

END
APPENDIX III

COST CALCULATION FOR THE SHOVEL AND TRACTOR
SHOVEL STUDY

Shovel Specifications and Other Data

Size = 3\% cu yd
Model = Bucyrus-Erie 61-B
Price, f.o.b. factory = $135,500.00
Weight (net domestic, approx.) = 166,650 lb
Freight = Railroad shipment @ $2.00 per cwt.
Assuming 1000 miles transportation distance.

OWNERSHIP COST

Initial Investment
Price, f.o.b. factory (stand. equipment)...$135,500.00
Optional parts............................$ 0.00
$135,500.00 $135,500.00
Shipping charges (railroad shipment -
1000 miles distance)
Weight to be shipped (net weight).........166,650 lb
Blocking Adds 3\%...............................4,999 lb
Total shipping weight....................171,649 lb
Shipping charge @ $2.00 per cwt............$ 3,432.98
Added permit and flagman charges...........350.00
Total shipping cost.........................$ 3,782.98 $ 3,782.98
Cost of unloading and erecting @ .70%
of f.o.b. price...............................$ 948.50 $ 948.50
Initial Investment (delivered to site............$140,231.48
Depreciation

Depreciation to be taken with the straight-line method

Total Cost........................................$140,231.48
Salvage Value........................................0.00
Depreciable Value $140,231.48

Useful life = 15 years

Annual straight-line depreciation @ $66.70 per $1000 of depreciation value........$ 9,353.35 $ 9,353.35
Annual Depreciation $ 9,353.35

Interest, Taxes, Insurance, and Storage

Taxes................................. 2%
Insurance and incidentals..... 2%
Interest............................. 9%

13% on average yearly investment

The average yearly investment = 140,231.48 x .53
= 74,322.68

74,322.68 x .13 = $9,661.95 $ 9,661.95

Yearly cost of int., tax., ins., and stor.............. $ 9,661.95

Ownership Cost Per Year

Annual depreciation.................................$ 9,353.35
Yearly cost of int., tax., etc..................... 9,661.95

Total........................................$ 19,015.30

Total Ownership Cost Per Year $ 19,015.30
**OPERATING COST PER HOUR**

**Repair Maintenance and Supplies**

Depreciable value is $126,208.33

Considering a useful life of 15 years and 95% (repair, maintenance, and supplies), over the depreciable value, we have estimated the hourly cost for these items at 5.5¢ per hour per $1000 of depreciable value, or a total of $7.71.

$ 7.71

**Fuel and Lubricating Oil**

To estimate fuel consumption, we can use either the appropriate formula or the chart in (operating cost guide-power crane and shovel association). The suggested load factor for shovel (heavy duty) is 70%. If we assume 30, we get for 212-hp diesel engine, consumption appr. of 10 gallons per hour. At 16¢ per gallon, the hourly fuel cost for the shovel was estimated at $1.60.

$1.60

Lubricating oil consumption can be estimated at 1/100 of fuel consumption or in this case 10/100 gph at a price of 80¢ per gallon, an approximate hourly cost of $0.80.

$0.80

For the electric light plant with which the machine is equipped, and starting system, the estimated cost of power and lubricating oil is $0.15.

$0.15

**Total Power, Fuel, and Oil Consumption**

$2.55

<table>
<thead>
<tr>
<th>Total Operating Cost Per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair, Maintenance and Supplies</td>
</tr>
<tr>
<td>Fuel and Lubricating Oil</td>
</tr>
<tr>
<td><strong>Total Operating Cost Per Hour</strong></td>
</tr>
</tbody>
</table>

Scheduled Costs

Cost per scheduled hour for a shovel operator = $ 6.00
" " " " " " oiler = $ 4.75

Remark: (The above includes social security, etc.)

Loading-Time Calculation

Fill factor = 80%
Loose cubic yard weight = 1.52
Bucket size = 3.25 cu yd

Capacity per pass:

\[ 3.25 \times 0.8 \times 1.52 = 3.95 \text{ ton} \]

22-Ton Truck

\[ \frac{22}{3.95} = 5.57 \approx 6 \text{ passes} \]

6 \times 0.50 = 3.0 min

35-Ton Truck

\[ \frac{35}{3.95} = 8.85 \approx 9 \text{ passes} \]

9 \times 0.5 = 4.5 min

50-Ton Truck

\[ \frac{50}{3.95} = 12.66 \approx 13 \text{ passes} \]

13 \times 0.5 = 6.5 min
TRACTOR STUDY

Machine: Rubber-tired, four-wheel drive, diesel tractor

Delivered price to site (including attachments, transportation at 1,000 miles, and erection)..... $ 56,860.00

Tire replacement cost: 4 @ 50% of list price........ 4,870.00

Bare machine cost (delivered price less tire cost)...... $ 51,990.00

Depreciation period: 5 years or 10,000 hours

Depreciation method: straight line

Duty conditions: average

Annual Ownership Cost

Depreciation: $51,990 ÷ 5.............. $ 10,398.00

Ins., taxes, int.: $0.03 x delivered price ÷ 1000 x 2000.................. 3,411.00

Annual Ownership Cost.......................... $ 13,809.00

Hourly Operating Cost

Diesel fuel: 9.0 gph x $0.19 per gal.................. $ 1.71
Lube oil, crankcase: 0.10 gph x $0.96 per gal..... .09
Transmission oil: 0.02 gph x $1.44 per gal........ .03
Hydraulic oil: 0.09 gph x $1.33 per gal........... .12
All filters: $96.35 replacement cost per 1000 hr... .10
Axle lubricant: 0.029 gph x $1.36 per gal........ .04
Grease: 0.22 lb per hr x $0.16 per lb.............. .04
Repair parts and labor: 60 percent of bare machine........................................ 3.17
Cutting edge cost: 153.63 per estimated life of 2,000 hr............................. .08
Tire replacement cost: tire life of 2,700 hr...... 1.62
Operator's wage...................................... 5.00

Total Estimated Hourly Operating Cost.................. $ 12.00
APPENDIX IV

COMPUTER PROGRAM TO CALCULATE TRUCK COSTS
OWNERSHIP AND OPERATING COST FOR TRUCKS
PROGRAMMED BY C. A. BANDEIRA
LANGUAGE = FORTRAN    COMPUTER = CDC 8090

* * * * * * * * * * * * * * * INDEX * * * * * * * * * * * * * * * *

INPUT VARIABLES
EXTR(I)  - OPTIONAL EQUIPMENT COST IN DOLLARS (ROCK PROTECTI-
           ON KIT, AIR STARTING, ETC.) AND ERECTION COST

FAC1    - FACTOR IN DETERMINING FRONT TIRE LIFE IN HOURS
           (DEPENDS UPON MAINTENANCE, MAXIMUM SPEEDS, CURVES,
           SURFACE, LOADS, WHEEL POSITION, GRADES AND MISCEL-
           LIAE CONDITIONS)

FAC2    - FACTOR IN DETERMINING REAR TIRE LIFE IN HOURS
           (DEPENDS UPON THE SAME FACTORS THAT FAC1, EXCEPT FOR
           WHEEL POSITION)

FAC3    - FACTOR IN DETERMINING FUEL CONSUMPTION (DEPENDS ON
           TYPE OF DUTY (LIGHT, AVERAGE OR SEVERE)

FAC4    - FUEL COST IN DOLLARS PER GALLON

FREIG(I) - TRANSPORTATION CHARGE IN DOLLARS (FREIGHT RATE*TO-
           TAL WEIGHT TO BE TRANSPORTED)

FROTC(I) - TIRE COST IN DOLLARS

GHP     - GROSS HORSE POWER

PPFOB   - PURCHASE PRICE F.O.B.

SZI(I)   - TRUCK SIZE IN TONS

TIIS    - FACTOR (IN PERCENT) = INTEREST+TAXES+STORAGE+INSUR.

XN(I)   - NUMBER OF YEARS TO BE DEPRECIATED

GENERATED VARIABLES

ATL     - TIRE LIFE-AVERAGE FRONT AND REAR

AYI     - AVERAGE YEARLY INVESTMENT AS PERCENTAGE OF PURCHASE
           PRICE PLUS FREIGHT

DELP    - DELIVERED PRICE

DOWCPY  - DEPRECIATION AND OWNERSHIP COST IN DOLLARS/YEAR
C       DPY    -DEPRECIATION PER YEAR (STRAIGHT LINE DEPRECIATION) 036
C       FTL    -FRONT TIRE LIFE 037
C       FUEL C  -FUEL COST 038
C       GPH    -CONSUMPTION IN GALLONS PER HOUR 039
C       OGGL   -OIL, GREASE AND GREASING LABOR 040
C       RCPh   -REPAIRS INCLUDING PARTS AND LABOR 041
C       RTL    -REAR TIRE LIFE 042
C       TATBD  -TOTAL AMOUNT TO BE DEPRECIATED 043
C       TCPH   -TIRE COST PER HOUR 044
C       TOCPH  -OPERATING COST IN DOLLARS PER HOUR (DOES NOT IN-
               CLUD OPERATOR) 045
C       TOWN C  -OWNERSHIP COST PER YEAR 046
C       TRCPH  -TIRE REPAIRS COST PER HOUR 047
C       TVOT   -ORIGINAL VALUE OF TIRES 048
C
C

* * * * * * * * * * * * * * * * * * * * * * * * * * * * START * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

DIMENSION PPF0B(10), EXTR(10), FREIG(10), FROTC(10), TIIS(10), GHP(10),
1SIZ(10), XN(10)
READ 10, (PPFOB(I), EXTR(I), FREIG(I), FROTC(I), TIIS(I), GHP(I), SIZ(I)
1, XN(I), I=1,3)
READ 20, FAC1, FAC2, FAC3, FAC4
PRINT 30

C
C

* * * * * * * * * * DEPRECIATION AND OWNERSHIP COST * * * * * * * * * *

DO 40 I=1,3
DELP=PPFOB(I)*EXTR(I)*FREIG(I)
TVOT=FROTC(I)*6.
TATBD=DELP-TVOT
DPY=TATBD/XN(I)
AYI=(XN(I)+1.)/(2.*XN(I))
TOWNC=DELP*AYI*TIIS(I)
DOWCPY=DPY*TOWNC

C
C

051
052
053
054
055
056
057
058
059
060
061
062
063
064
065
066
067
068
069
* * * * * * * * OPERATING COST * * * * * * * * *

FTL=FAC1*6000.
RTL=FAC2*6000.
ATL=(FTL+RTL)/2.
TCPH=TVOT/ATL
TRCPH=.15*TCPH
RCPH=((DELP+FREEG(I))*0.6)/15000.
GPH=0.06*GHP(I)*FAC3
FUELCE=GPH*FAC4
OGL=FUELCE*.333
TOCPH=TCPH+TRCPH*RCPH+FUELCE*OGL
PRINT 50,SIZ(I),DOWCPY,TOCPH
40 CONTINUE
I=XEXITF(0)

* * * * * * * * FORMATS * * * * * * * * * * * * *

10 FORMAT (BF10.2)
20 FORMAT (4F10.2)
30 FORMAT (1H1,'/','10X,10HTRUCK SIZE','10X,10HTRUCK DEPRECIATION AND OWN
1ERSHIP COST','10X,10HCOST PER OPERATING HOUR)
50 FORMAT (//,'10X,F10.2','22X,F10.2','32X,F10.2)
END
<table>
<thead>
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<th>Truck Size (in Tons)</th>
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APPENDIX V

FLOW DIAGRAM AND CORRESPONDENT COMPUTER PROGRAM TO CALCULATE AVERAGE HAUL TIME
Figure 3. Flow diagram for the haul time program.
1

IS ENTERING VELOCITY LESS THAN SPEED LIMIT? (67)

No

Yes

INCREASE VELOCITY BY USING INCREMENTS OF 2 mph (76)

READ TRACTIVE EFFORT BASED ON AVERAGE VELOCITY FOR THE INCREMENT (77-78)

DERIVE TRACTIVE EFFORT PER TON (79)

DERIVE TOTAL RESISTANCE PER TON (80)

2
DERIVE NET TRACTIVE EFFORT PER TON (81)

IF NET TRACTIVE EFFORT (82)

IF (VELOCITY - SPEED LIMIT) (83)

DERIVE ACCELERATION FOR THE INCREMENT (84)

TAKE ACCELERATION EQUAL MAXIMUM ACCELERATION (86)

IF (DERIVED ACCEL. = MAX. ACCELERATION) (85)

3

10
DERIVE INCREMENTAL SECONDS AND FEET
(87-89)

DERIVE CUMULATIVE RUNNING TIME AND FEET
(90-91)

IF (VELOCITY - SPEED LIMIT)
(92)

DERIVE DIFFERENCE BETWEEN LENGTH OF THE SECTION AND TOTAL RUNNING FEET
(93)

ARE WE CALCULATING LAST SECTION?
(94)

12
IF (RUNNING TOTAL FEET - LENGTH OF THE SECTION) (95)

ASSUME VELOCITY EQUAL FINAL VELOCITY FOR THE ANTERIOR INCREMENT (96)

ALSO TO ASSUME TOTAL RUNNING TIME AND FEET EQUAL THOSE FOR THE ANTERIOR INCREMENT (97-98)

DERIVE DIFFERENCE BETWEEN LENGTH OF SECTION AND TOTAL RUNNING FEET (149)

ARE WE CALCULATING LAST SECTION? (150)

Yes

No

MAKE VELOCITY EQUAL AVERAGE VELOCITY OF LAST INCREMENT (100)
5

DERIVE REMAINING RUNNING TIME FOR THE SECTION (151)

DERIVE CUMULATIVE RUNNING TIME (152)

PRINT FINAL VELOCITY, CUMULATIVE RUNNING TIME AND OTHER INFORMATION (153)

DERIVE CUMULATIVE HAUL TIME FOR THE CALCULATED SECTIONS (154)

6
DERIVE NET TRACTIVE EFFORT PER TON (72)

IF NET TRACTIVE EFFORT (73)

INCREASE VELOCITY BY ONE (74)

MAKE ENTERING VELOCITY EQUAL SPEED LIMIT (68-69)

DERIVE TRACTIVE EFFORT PER TON AT SPEED LIMIT (70)

DERIVE TOTAL RESISTANCE PER TON (71)
GIVE A NEGATIVE INCREMENT DIMINISHING THE AVERAGE VELOCITY BY 2 mph (102)

DERIVE TRACTIVE EFFORT AT THE AVERAGE VELOCITY FOR THE ABOVE INCREMENT (103)

DERIVE NET TRACTIVE EFFORT (104)

IF NET TRACTIVE EFFORT (105)

DERIVE DECELERATION CORRESPONDENT TO INCREMENT (109)

MAKE FINAL VELOCITY EQUAL AVERAGE VELOCITY FOR THE LAST INCREMENT PLUS ONE (124)

MAKE FINAL VELOCITY EQUAL AVERAGE VELOCITY FOR THE LAST INCREMENT (100)
IF (DECELERATION = MAX. DECELERATION) (110)

DERIVE INCREMENTAL RUNNING TIME AND FEET (112-115)

DERIVE CUMULATIVE RUNNING TIME AND FEET (116-117)

MAKE FINAL VELOCITY EQUAL FINAL VELOCITY FOR LAST INCREMENT (119)

MAKE FINAL VELOCITY EQUAL FINAL VELOCITY FOR ANTERIOR INCREMENT (121-122)

TAKE DECELERATION EQUAL MAXIMUM DECELERATION (111)

IF (RUNNING TOTAL FEET-SECTION LENGTH) (118)

MAKE FINAL VELOCITY EQUAL FINAL VELOCITY FOR ANTERIOR INCREMENT (121-122)
DERIVE TIME AND SPACE TO DECELERATE UP TO ZERO mph
(142-143)

DERIVE DIFFERENCE BETWEEN REMAINING SPACE AND SPACE REQUIRED TO DECELERATE
(144)

DERIVE INCREMENTAL RUNNING TIME FOR THE SPACE DERIVED ABOVE AT CONST. VELOCITY
(145)

DERIVE TOTAL RUNNING TIME
(146)

TAKE FINAL VELOCITY EQUAL ZERO
(147)
DERIVE TIME AND SPACE TO DECELERATE UP TO ZERO mph (127-128)

HAVE WE ENOUGH SPACE TO DECELERATE? (129)

DERIVE TOTAL RUNNING TIME BY ADDING TIME REQUIRED TO DECELERATE (130)

ASSUME VELOCITY EQUAL FINAL VELOCITY FOR THE ANTERIOR INCREMENT (132)

ALSO TO ASSUME TOTAL RUNNING TIME AND FEET EQUAL THOSE FOR THE ANTERIOR INCREMENT (90-91)
DERIVE INCREMENTAL AND TOTAL RUNNING TIME CONSIDERING SPACE DERIVED ABOVE AT CONST VELOCITY (138-139)

DERIVE TIME AND SPACE TO DECELERATE UP TO ZERO mph (133-134)

DERIVE DIFFERENCE BETWEEN SECTION LENGTH AND CUMULATIVE FEET CONSIDERING SPACE TO DECELERATE (135-137)

TAKE FINAL VELOCITY EQUAL ZERO (140)
PRINT CUMULATIVE HAUL TIME FOR THE CALCULATED SECTIONS (155)

HAVE WE CALCULATED TRUCK RETURN? (156-157)

No

MAKE TRUCK GROSS WEIGHT EQUAL WEIGHT OF EMPTY VEHICLE (162)

INVERT POSITION OF SECTION'S LENGTH FOR RETURN CONSIDERATIONS (163-171)

INVERT ALSO GRADES AND ITS SIGNS FOR RETURN CONSIDERATIONS (163-191)

Yes

END
**********
HAUL TIME CALCULATION
**********
PROGRAMMED BY C. A. BANDEIRA
LANGUAGE = FORTRAN
COMPUTER = CDC 8090

**********
INDEX **********

INPUT VARIABLES
ACL = MAXIMUM ACCELERATION IN MPH/SEC
DECL = MAXIMUM DECELERATION IN MPH/SEC
G(I) = GRADE IN PERCENT FOR EACH SECTION
GRPT(I) = GRADE RESISTANCE IN POUNDS PER TON
GWITOM = PAYLOAD IN TON
GWITON = GROSS WEIGHT IN TONS FOR LOADED HAUL
N = TOTAL NUMBER OF SECTIONS
RRPT = ROLLING RESISTANCE IN POUNDS PER TON
TE(K) = TRACTIVE EFFORT IN POUNDS AT PARTICULAR VELOCITY
VELIM = HAUL SPEED LIMIT IN MPH
XLIMLE(I) = HAUL LENGTH IN FEET FOR EACH SECTION

GENERATED VARIABLES
ACMPHS = ACCELERATION IN MPH/SEC
CMPH = TRUCK SPEED
J = AUXILIARY VARIABLE IN THE PROCESS OF THE INVERSION OF ARRAYS
K = INTERGER REPLACING REAL (XK)
S = SPACE REQUIRED TO DECELERATE UP TO 0 MPH
S1 = DIFFERENCE BETWEEN REMAINING SPACE OF THE SECTION AND S
S2 = DIFFERENCE BETWEEN TOTAL LENGTH OF THE SECTION AND CUMULATIVE FEET FOR THIS SECTION PLUS S
SUMTR = CUMULATIVE HAUL TIME FOR THE TOTAL HAUL LENGTH
T = TIME REQUIRED TO DECELERATE UP TO 0 MPH
TEPT = TRACTIVE EFFORT PER TON
TOFT = TOTAL RUNNING SPACE IN FEET
C TOSEC - TOTAL RUNNING TIME IN SECONDS 037
C TRPT - TOTAL RESISTANCE IN POUNDS PER TON 038
C XINCFT - INCREMENTAL FEET 039
C XINCMH - INCREMENTAL MPH 040
C XINCS - INCREMENTAL SECONDS 041
C XK - AVERAGE VELOCITY FOR EACH NEW INCREMENT IN VELOCITY 042
C XLENDI - REMAINING SPACE 043
C XNTEPT - NET TRACTIVE EFFORT 044
C YG(J) - AUXILIARY ARRAY IN THE PROCESS OF INVERSION OF 045
Arrays 046
C YK - REAL REPLACING INTERGER 047
C YLIMLE(J) - AUXILIARY ARRAY IN THE PROCESS OF INVERSION OF 048
Arrays 049
C Z - CONTROL VARIABLE TO COUNT HOW MANY TIMES THE PRO- 050
GRAM IS EXECUTED 051
C 052
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * 053
DIMENSION TE(40), GRPT(30), XLIMLE(30), G(30), YLIMLE(30), YG(30) 054
READ 1, N, RRPT, ACL, DECL, VELIM, GWITON, GWITON 055
READ 80, (TE(K), K=1, 40) 056
READ 85, (GRPT(I), XLIMLE(I), G(I), I=1, 29) 057
PRINT 130 058
Z=0. 059
180 PRINT 27 060
SUMTR=0. 061
CMPH=0. 062
DO 100 I=1, N 063
TOSEC=0. 064
TOFT=0. 065
IF(CMPH-VELIM),5,15,15 066
15 XK=VELIM 067
K=XK 068
TEPT=TE(K)/GWITON 069
TRPT=RRPT+GRPT(I) 070
XNTEPT=TEPT-TRPT 071
IF(XNTEPT)6*10*10
6 K=K+1
GO TO 11
5 CMPH=CMPH+2.
XK=CMPH-1.
K=XK
TEPT=TE(K)/GWITON
TRPT=RRPT+GRPT(I)
XNTEPT=TEPT-TRPT
IF(XNTEPT)11*8*2
2 IF(CMPH-VELIM)9*9*8
9 ACMPS=XNTEPT/100.
IF(ACMPS-ACL)3*3*4
4 ACMPS=ACL
3 XINCMM=2.
XINCSE=XINCMM/ACMPS
XINCFT=XK*XINCSE*1.467
TOSEC=TOSEC+XINCSE
TOFT=TOFT+XINCFT
IF(CMPH-VELIM)7*10*10
7 XLENDI=XLIMLE(I)-TOFT
IF(I-N)19*20*20
19 IF(XLENDI)14*13*5
14 CMPH=CMPH+2.
60 TOFT=TOFT-XINCFT
TOSEC=TOSEC-XINCSE
GO TO 10
8 CMPH=CMPH-1.
GO TO 10
11 K=K-2
TEPT=TE(K)/GWITON
XNTEPT=TEPT/TRPT
IF(XNTEPT)35*70*12
70 YK=K
CMPH=YK
GO TO 10
35 ACMPH$ = XNTEPT/100.
   IF (ACMPH$ + DECL) > 40, 45, 45
40 ACMPH$ = -DECL
45 XINCHE = -2.
   XINCSE = XINCME/ACMPH$.
   XK = K
   XINCFT = XK*XINCSE*1.467
   TOSECP = TOSEC+XINCSE
   TOFT = TOFT+XINCFT
   IF (XLIMIT(I)-TOFT) > 55, 24, 11
24 CMHP = XK-1.
   GO TO 13
55 XK = K
   CMHP = XK+1.
   GO TO 60
12 YK = K
   CMHP = YK+1.
   GO TO 10
20 T = CMHP/DECL
   S = (DECL/2*T**2) * 1.467
   IF (S > XLENDI) > 5, 17, 18
17 TOSEC = TOSEC*+T
   GO TO 30
18 CMHP = CMHP-2.
   T = CMHP/DECL
   S = (DECL/2*T**2) * 1.467
   TOFT = TOFT-XINCFT
   TOSEC = TOSEC-XINCSE
   S2 = XLIMIT(I)- (TOFT+T)
   XINCSE = (S2/5280.) / CMHP * 3600.
   TOSEC = TOSEC+XINCSE+T
30 CMHP = 0.
   GO TO 13
22 T = CMHP/DECL
   S = (DECL/2*T**2) * 1.467
   S1 = XLENDI - S
XINCSE=((S1/5280.)/CMPH)*3600.
TOSEC=TOSEC+XINCSE+T
CMPH=0.
GO TO 13
10 XLENRI=XLIMLE(I)-TOFT
   IF(I-N)23,22,22
23 XINCSE=((XLENRI/5280.)/CMPH)*3600.
   TOSEC=TOSEC+XINCSE
13 PRINT 26,I,XLIMLE(I),G(I),TRPT,CMPH,TOSEC
100 SUMTR=SUMTR+TOSEC
   PRINT 120*SUMTR
   Z=Z+1.
   IF(Z-1.)140,140,160
140 PRINT 150
C
C    * * * * * * * GENERATION OF DATA FOR EMPTY RETURN * * * * * * *
C
GWTON=GWTOM-GWTOM
DO 200 I=1,N
   J=N-I+1
   YG(J)=G(I)
200 YLIMLE(J)=XLIMLE(I)
DO 300 I=1,N
   J=I
   XLIMLE(I)=YLIMLE(J)
   G(I)=YG(J)
300 GRPT(I)=G(I)*20.
GO TO 180
160 I=XEXITF(0)
C
C    * * * * * * * * * * * FORMATS * * * * * * * * * * * * * * *
C
1 FORMAT (I5,6(F10.1))
80 FORMAT (10F8.1)
130 FORMAT (1H1,\,,50X,6HLOADED)
85 FORMAT (3F10.2)

FOR I5,6(F10.1)
FOR 80F8.1
FOR 130H1,\,,50X,6HLOADED
FOR 85F10.2
**OUTPUT**  

## 22-TON TRUCK

### LOADED TRUCK

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**TOTAL HAUL TIME = 1153.7 SECONDS**
APPENDIX VI

FLOW DIAGRAM AND CORRESPONDENT COMPUTER PROGRAM
TO SIMULATE OPERATIONS AND CALCULATE COST PER TON
Figure 4. Flow diagram for the simulation and cost per ton program.
DERIVE DIFFERENCE (XX) BETWEEN SHOVEL AND TRUCK TIME (90)

IF XX (91)

CALL SUBROUTINE TO GENERATE A RANDOM LOAD TIME (BL), GREATER OR EQUAL MIN. LOADING TIME (96-100)

INCREMENT TRUCK (N) TIME, TOTAL SHOVEL TIME, AND TOTAL LOADING TIME BY THE RANDOM LOADING TIME (101-103)

CALL SUBROUTINE TO GENERATE A RANDOM HAUL TIME (H), GREATER OR EQUAL MIN. HAUL TIME (104-108)

2

COMPUTE DIFFERENCE TO TRUCK N TIME (92)

0

COMPUTE DIFFERENCE TO SHOVEL TIME AND TOTAL SHOVEL DELAY TIME (SD) (94-95)

9

9

CALL SUBROUTINE TO GENERATE A RANDOM LOADING TIME (96-100)
INCREMENT TRUCK \( (N) \) TIME BY THE RANDOM HAUL TIME (109)

IF 
\[ N - 1 \]

(110)

- 0

IF 
\[ TR(N) - TR(N-1) \]

(112)

+ 0

DERIVE INCREMENTAL HAUL TIME BY ADDING TO THE RANDOM HAUL TIME THE DIFFERENCE \( TR(N) - TR(I) \) (113)

MAKE HAUL TIME FOR TRUCK \( N \) EQUAL HAUL TIME FOR TRUCK \( I \) (114)

MAKE HAUL TIME FOR TRUCK \( N-1 \) (117)

DERIVE INCREMENTAL HAUL TIME BY ADDING TO THE RANDOM HAUL TIME THE DIFFERENCE \( TR(N-1) - TR(N) \) (116)
DERIVE TOTAL HAUL TIME BY ADDING INCREMENTAL HAUL TIMES (118)

ARE THE ITERATIONS ENOUGH? (119)

Yes

DERIVE MINIMUM DELAY (AMD) DUE TO REPOSITIONING OF SHOVEL (120)

IF SD-AMD (121) - 0

CALCULATE TOTAL SHOVEL TIME BY CONSIDERING TOTAL DELAY EQUAL MINIMUM DELAY (122)

4

3

CONTINUE (88)

6
CALCULATE SHOVEL OPERATING COST (128)

CALCULATE TRUCK OPERATING COST (129)

CALCULATE TOTAL SCHEDULED COST (130-131)

CALCULATE TOTAL DEPRECIATION AND OWNERSHIP COST (132)

CALCULATE COST PER TON CPI(I) FOR THE CONSIDERED COMBINATION (135)
CALCULATE COST PER TON CPI(I) FOR THE CONSIDERED COMBINATION (135)

PRINT OUTPUT COST PER TON FOR THE STUDIED COMBINATION (136-137)

IF I-K (138)

IF CPT(I)-CPT(I-1) (139)

CONTINUE (140)

END
SUBROUTINE USED FOR GENERATION OF NORMAL RANDOM VARIATES

MAIN

CALL GAUSS (SL,AL,V) (96,104)

SUBROUTINE GAUSS (SL,AL,V) (154)

A = 0
X = 0 (155-156)

DO I = 1,12 (157)

A = A + X (159)

V = (A-6)*SL + AL (160)

RETURN (161)

MAIN

GENERATE (R) THROUGH "RANF" (158)
HAUL SIMULATION AND COST PER TON CALCULATION
PROGRAMMED BY A. T. JANSSEN
ADAPTED TO FORTRAN II BY C. A. BANDEIRA
LANGUAGE = FORTRAN
COMPUTER = CDC 6400

INPUT VARIABLES

AH  - AVERAGE HAUL TIME IN MINUTES
AL  - AVERAGE LOADING TIME IN MINUTES
DM  - PERCENTAGE DELAYS OF SHOVEL TIME
F2  - FACTOR FOR LUNCH TIME AND STARTUP
F3  - NUMBER OF SCHEDULED SHIFTS PER YEAR
F4  - COST PER OPERATING HOUR FOR A SHOVEL
F5  - COST PER OPERATING HOUR FOR A TRUCK
F6  - COST PER SCHEDULED HOUR FOR A TRACTOR
F7  - COST PER SCHEDULED HOUR FOR A FOREMAN
F8  - COST PER SCHEDULED HOUR FOR A SHOVEL OPERATOR
F9  - COST PER SCHEDULED HOUR FOR A SHOVEL OILER
F10 - COST PER SCHEDULED HOUR FOR A TRUCK DRIVER
F11 - SHOVEL DEPRECIATION AND OWNERSHIP COST
F12 - TRUCK DEPRECIATION AND OWNERSHIP COST
F13 - TRACTOR DEPRECIATION AND OWNERSHIP COST
F14 - STANDBY FACTOR FOR SHOVEL
F15 - STANDBY FACTOR FOR TRUCKS
F16 - STANDBY FACTOR FOR TRACTOR
F17 - TONS PER TRUCKLOAD
MC  - NUMBER OF TRUCKLOADS TO BE SIMULATED
SC  - SHOVEL CAPACITY IN CUBIC YARDS

GENERATED VARIABLES

AMD - MINIMUM DELAY
AMH - MINIMUM HAUL TIME
AML - MINIMUM LOADING TIME
| AN | BL | CPT(I) | H | J | K | L | M | N | P | Q | R | S | SD | SH | SL | SLG | TCG | TL | T1C | TR | TS | TSC | V | XX |
|----|----|-------|---|---|---|---|---|---|---|---|---|---|---|----|----|----|-----|-----|----|-----|----|---|-----|---|----|
|    |    |       |   |   |   |   |   |   |   |   |   |   |   |    |    |     |      |      |    |      |    |   |     |   |    |

**AN** - Number of Trucks for First Simulation

**BL** - Cost Per Ton for I Trucks

**CPT(I)** - Cost Per Ton for J Trucks

**H** - Cost of Haul Time

**J** - Cost of Haul Time

**K** - Cost of Loading Time

**L** - Cost of Loading Time

**M** - Cost of Shovel Time

**N** - Cost of Shovel Time

**P** - Cost of Shovel Time

**Q** - Cost of Shovel Time

**R** - Cost of Shovel Time

**S** - Total Shovel Delay Time

**SD** - Standard Deviation of Haul Time

**SH** - Standard Deviation of Loading Time

**SL** - Total Loading Time

**SLG** - Total Loading Time

**TCG** - Total Shovel Time

**TL** - Total Shovel Time

**TLC** - Total Shovel Time

**TR** - Total Shovel Time

**TS** - Total Shovel Time

**TSC** - Total Shovel Time

**V** - Total Shovel Time

**XX** - Total Shovel Time

---

**AN** - Number of Trucks for First Simulation

**BL** - Cost Per Ton for I Trucks

**CPT(I)** - Cost Per Ton for J Trucks

**H** - Cost of Haul Time

**J** - Cost of Haul Time

**K** - Cost of Loading Time

**L** - Cost of Loading Time

**M** - Cost of Shovel Time

**N** - Cost of Shovel Time

**P** - Cost of Shovel Time

**Q** - Cost of Shovel Time

**R** - Cost of Shovel Time

**S** - Total Shovel Delay Time

**SD** - Standard Deviation of Haul Time

**SH** - Standard Deviation of Loading Time

**SL** - Total Loading Time

**SLG** - Total Loading Time

**TCG** - Total Shovel Time

**TL** - Total Shovel Time

**TLC** - Total Shovel Time

**TR** - Total Shovel Time

**TS** - Total Shovel Time

**TSC** - Total Shovel Time

**V** - Total Shovel Time

**XX** - Total Shovel Time

---

**DIMENSION** (T0, CPT(50))

**READ** (100, MC, AL, AI, DM, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15, F16, F17, FSC, 115, F15, F17, SC)

**START** (T0, CPT(50))

**SIMULATION** (T0, CPT(50))
50 TR(N)=TR(N)+H
   IF (N-1) 10*10+11
10 IF (TR(N)-TR(I)) 12,13,13
11 IF (TR(N)-TR(N-1)) 14,13,13
12 H=H*TR(I)-TR(N)
   TR(N)=TR(I)
   GO TO 13
13 TH=TH+H
   IF (J=MC) 15,16,16
14 AMD=DM*TL
15 IF (SD-AMD) 18,19,19
16 TS=(TL+AMD)*F2
   GO TO 20
19 TS=(TL+SD)*F2
   * * * * * * * * * * COST PER TON CALCULATION * * * * * * * * * *
20 SUC=F3*F4*H.*(TL/TS)
21 TOC=F3*F5*8.*(TH/TS)
22 RI=1
23 TSC=F3*8.*(F6+F7+F8+F9*RI*F10)
24 TDC=F11+F14+12+F15+RI+F13*F16
25 RJ=J
26 TP=RJ+F17*F3*8.*60./TS
27 CPT(I)=(SOC+TOC+TSC+TDC)/TP
   PRINT 300+SC,F17
   PRINT 200+I,CPT(I),TP
   IF (I-K) 1,1,28
28 IF (CPT(I)-CPT(I-1)) 1,1,29
1 CONTINUE
   * * * * * * * * * * * FORMATS * * * * * * * * * * * * * * * * * *
100 FORMAT (I4/10F8.2))
300 FORMAT (1H","/"/""",35X,30HSHOVEL CAPACITY IN CU. YARDS =F8.2,"/
110X,24HTRUCK CAPACITY IN TONS =F8.2,"/
200 FORMAT (10X,18HNUMBER OF TRUCKS =I3,"/",10X,14HCOST PER TON =F6.4,"/
1X,10X,27THANNUAL PRODUCTION IN TONS =F12.1)
29 STOP
END

** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

**SUBROUTINE**

**SUBROUTINE GAUSS (SL,AL,V)**

A=0.
X=0.
DO 150 I=1,12
   X=RANF(0.)
   A=A+X
150 V=(A-6.)*SL+AL
   RETURN
END

\[ x = \text{uniform random number} \]
\[ v = \text{normal} \]

<table>
<thead>
<tr>
<th>TRUCK SIZE</th>
<th>NUMBER OF TRUCKS</th>
<th>PRODUCTION IN TONS PER YEAR</th>
<th>COST PER TON IN DOLLAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>22-TON</td>
<td>14</td>
<td>1280388</td>
<td>0.8027</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1363404</td>
<td>0.7978</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>1441965</td>
<td>0.7948</td>
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<tr>
<td></td>
<td>17</td>
<td>1510360</td>
<td>0.7973</td>
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<tr>
<td></td>
<td>10</td>
<td>1457004</td>
<td>0.7415</td>
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<tr>
<td></td>
<td>11</td>
<td>1587589</td>
<td>0.7355</td>
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<tr>
<td>35-TON</td>
<td>12</td>
<td>1715652</td>
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<td>0.7391</td>
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<td></td>
<td>6</td>
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<td>0.6662</td>
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<td>1463938</td>
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<tr>
<td></td>
<td>9</td>
<td>1798387</td>
<td>0.6513</td>
</tr>
</tbody>
</table>
APPENDIX VII

EXAMPLE OF COST PER TON CALCULATION
AN EXAMPLE OF A COST PER TON CALCULATION OF A SYSTEM
CONSISTING OF A SHOVEL AND TRUCKS

A. Operating Cost

Shovel:

1. Loading time (from simulation) 1,900.0 min
2. Minimum delay factor: 5% .05
3. Minimum delay time: (1) x (2) 95.0 min
4. Actual delay time (from simulation) 100.0 min
5. Sum of (1) and largest of (3) and (4) 2,000.0 min
6. Correction for lunch and startup 1.07min
7. Gross shovel operating time: (6) x (5) 2,140.0 min
8. Operating factor: (1) ÷ (7) 0.89
9. Scheduled hours per year: 600 x 8 4,800 hours
10. Operating hours per year: (9) x (8) 4,272.00 hr
11. Cost per operating hour (from shovel study) $ 7.46
12. Operating cost per year (11) x (10) $31,869.12

Trucks:

13. Haul time (from simulation) 9,800.0 min
14. Gross shovel operating time (7) 2,140.0 min
15. Number of trucks 7
16. Gross truck operating time: (14) x (15) 14,980.0 min
17. Operating factor: (13) ÷ (16) .655
18. Scheduled truck hours: 7 x 8 x 600 33,600.0 hr
19. Operating hours per year: (17) x (18) 22,008.0 hr
20. Cost per operating hour (from truck study) $ 11.68
21. Operating cost per: (19) x (20) $257,053.44

Total operating cost per year: (12) x (21) $288,922.56

B. Annual Depreciation and Ownership Cost

1. Shovel.....18,468.40 x 1.0....... $ 18,468.40
2. Trucks.....26,555.41 x 1.5 x 7... 378,831.80
3. Tractor....13,809.60 x 1.0...... 13,809.60

Total per year $311,109.80
C. Scheduled Cost

1. Shovel operator per hour................................... $  6.00
2. Shovel oiler..................................................  4.75
3. Truck drivers: 7 x $5.00.................................  35.00
4. Foreman.......................................................  8.00
5. Tractor..........................................................  12.00

Total.............................................................. $65.75

Number of scheduled hours per year.........................  4800

Total per year: 4800 x 65.75....$315,600.00

D. Total Cost Per Year: (A) + (B) + (C)...........$915,632.36

E. Production Per Year:

1. Truck loads simulated (from simulation)..........  300
2. Tons per truck load......................................  50
3. Tons simulated: (1) x (2).............................. 15,000 ton
4. Shovel hours simulated: (A-7) ÷ 60..................  35.67 hr
5. Tons per scheduled hour: 3 ÷ 4.....................  420.5 ton
6. Scheduled hours per year............................... 4,800
   Production per year: (5) x (6)..................... 2,018,900.0

F. Cost Per Ton: D ÷ E........................................ $ .4534
SELECTED BIBLIOGRAPHY


Douglas, James, 1964, Prediction of shovel-truck production, a reconciliation of computer and conventional estimates: Stanford University, Dept. of Civil Eng., Tech. Rept. no. 37.


Matheson, W. N., 1959, Selecting an open-pit haulage method: Mining Eng., v. 11, no. 4, p. 409-412.


Teicholz, Paul, 1963, An analysis of two-link material handling systems with one carrier in one of the links: Stanford University, Dept. of Civil Eng., Tech. Rept. no. 29.