# Loading and transport system at SMC—optimization

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### Synopsis

Engineering refers to the application of mathematics and other sciences to logically develop solutions to problems. However, in opencast mining, due to the randomness of operations, the use of mathematics is often neglected. Instead, practices that have proven successful elsewhere tend to apply. At the other end of the scale, mathematical models have been developed to identify and quantify all the operational parameters involved in the loading and haulage of ore. These are then used to optimize the operation. Optimization, in this context, refers to the reduction of cost through effective utilization of the available time and resources.

Considering these mathematical models, the loading and transport system at SMC (Catoca Mining Society) will be assessed with a view to its optimization. The discussion will be introduced by considering the mine background and other general information, which will highlight the main operational variables.

## Introduction

### *Mine background and general information*

The SMC (Sociedade Mineira do Catoca) was created in 1994 and in 1997 geological exploration up to a depth of 620 metres concurrent with the mining commenced.

The dimensions of the diamond pipe are 900×915 metres and an area of 639 000 $m^2$. Geologically its mineralized body, as shown in Figure 1, is subdivided into three different parts:

- The central part of the pipe up to 200 m consists of volcanogenic–sedimentary rocks
- The inner ring consists of porfiric kimberlites and
- The central part below 260 m consists of kimberlitic breccias.

Each rock type has a different characteristic and property therefore; the excavability will not be the same.

The pipe is being mined by opencast methods at an annual production rate of $1530\times10^3 \times m^3$ rock and $940\times10^3 \times$ct diamond production > 1 mm.

The rock has a density of 1.9 t/$m^3$ and is excavated and transported using the excavator-truck combination. The ore is extracted from the north side of the mine from elevations +940 and +930 as well as in the southeast side of the same elevations. The haulage distances are 1.79 Km and 2.7 Km from the processing plant to the north and southeast sides respectively. For illustration purposes, Figure 2 shows an aerial photograph of the pit.

A total of 47 000 hours per year is used for maintenance. There are three shifts, 8 hours each, and six mechanics per shift. Surveys show that 7 $m^3$ capacity excavators are used to load 30 ton trucks.

The mine is situated in Lunda–Norte province, north east of Luanda—the capital of Angola.

Lunda–Norte province has very little infrastructure that could aid in the mining operations; as such the mine created most of the infrastructure needed. Some of the infrastructure referred to above includes: power, which is supplied by diesel generators; water, which is supplied via mine created infrastructure; a small–scale airport, which serves as a landing site for planes carrying diesel and other goods; a small–scale farm, which supplies agricultural foodstuffs; hostels; and medical services. In conclusion, one may say that the mine aims for self–sufficiency.

### *Project background*

The loading and hauling system at SMC needs to be evaluated since the operations are expanding and new equipment (trucks and shovels) has been introduced. With the increase in the number of units for both excavation and transport, the mine aims to operate at maximum efficiency. However, this

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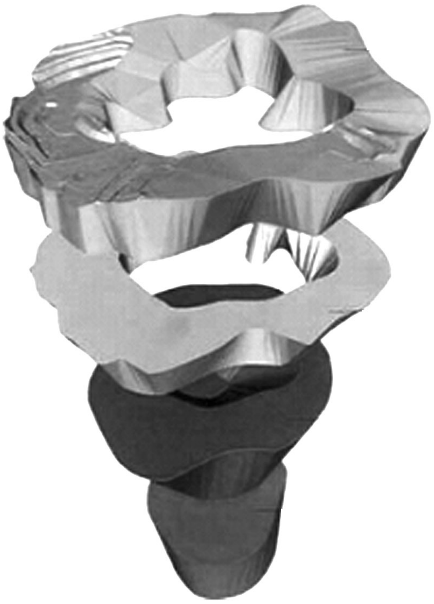

Figure 1—Geology of the pipe (after Dr. Ganga Junior, 2000)


Figure 2—Aerial photograph of the pit (after Dr. Vladimir Zintchenko, 2000)

has not been the case. There is still the problem of either a shortage of units or overload of the plant as dictated by the operational conditions. By operational conditions, one refers to weather, breakdowns, and maintenance—all of which are liable to disrupt the loading and haulage operation.

The problem being experienced at the mine is that the production rates are neither constant nor do they follow the designed or planned outputs.

One notices that on a micro scale this problem is directly related to the distribution/redistribution of truck units. The correct fleet sizing will greatly influence the production output, since the transport distances, as predetermined by economics, and consistency with the mine plan are constant.

The relationship between fleet size, timing of various operations, distances, etc., and production rates should be thoroughly analysed in order to determine the cause of the problem and subsequently the solution-optimization of the loading and transport system.

### Problem statement

The assessment of the loading and haulage system at SMC has been made with a view to its optimization.

### Objectives

The primary objectives include examining the relationship between the various parameters affecting loading and haulage while taking into account the variability of the input parameters. Once each parameter and its contribution to the haulage cycle and output has been identified, one will suggest the means of optimization.

The objectives of the project are:

- To determine the parameters affecting the loading/haulage cycle
- Optimizing
  - The number of trucks serving the loading point
  - The number of haulage cycles of a truck per hour
  - The hourly output.

### Scope of study

The cycle times of the loading and haulage units have been investigated in order to match them appropriately, thus promoting constant production rates.

The investigation was conducted on site, since no GPS (Global Positioning System) facilities are available at the mine.

As a company policy, much of the information concerning the operations and past performances has been restricted; as such one had to gather on site the necessary information for completion of the project.

### Methodology

To design the optimum loading and haulage cycle one must primarily know how loading and haulage affect one another. Using given or assumed truck and bucket capacities, together with truck-changing time, an optimum output can be determined. The number of truck units can also be determined in the same manner, and it will be 'optimum' when no pauses occur during loading and haulage operations. Data (input parameters) were collected on site to enable one to design the optimum loading and transport system.

The data collected on site include:

- Excavator working cycle
- Truck-changing time
- Loading time
- Tipping time
- Travelling time for both empty and laden trucks
- Equipment used and specifications
- Distances from and to drawpoints
- Production rates
- Geological information (density of the rock).

## Observations, measurements and data collection

### Equipment used

Most of the trucks used on the mine are made by caterpillar. Other brands include Liebherr and Bell.

### Trucks

Three types of Caterpillar trucks are currently being used for haulage of rock material, all of which are articulated. The trucks used include:

- D 300
- D 400 E Series 2 , and
- 740

The trucks have a total capacity of 30 tons and average speeds ranging from 50 to 60 km/h when loaded and empty respectively.

Furthermore, the gradient of the roads range from flat to 10 per cent. Thus according to machine specifications the optimum travelling cycle times at these conditions are as shown in Figure 3 below:

The above parameters give an indication of the effects of the varying resistance (grade plus rolling) on the cycle as a function of distance. Grade has the highest percentage contribution to the total resistance. Therefore, decreasing the grade while maintaining the same travelling distance considerably decreases the travelling times for both empty and laden travel.

### *Excavators*

The two brands of excavators being used are the Liebherr and the Caterpillar. The Caterpillar excavators include:

- 5080 (bucket capacity—5.3 $m^3$, and
- 375 L (bucket capacity—4.5 $m^3$),

The Liebherr includes:

- Liebherr 984 Litronic (bucket capacity—7 $m^3$)

Furthermore, the optimum time taken for the Caterpillar excavator to complete its cycle is shown in Figure 4. The Liebherr excavator has a similar working cycle.

### *Determination of the various parameters*

In an opencast mine, the mining cycle is influenced by the excavator working cycle, truck-changing time, loading time, tipping time, travelling time for empty and laden trucks, travelling distance, amongst other factors. These parameters have direct and indirect relationships, which can be expressed mathematically by the use of formulae, as shown below.

### *Excavator bucket and truck capacity*

The bucket capacity can be determined from the output, the time needed for the bucket to perform a working cycle, the necessary manoeuvering time for truck changing, the conversion factors T and F, and the truck capacity. The relationship between the various parameters has been derived by Paul Flachsenberg[1] and is:

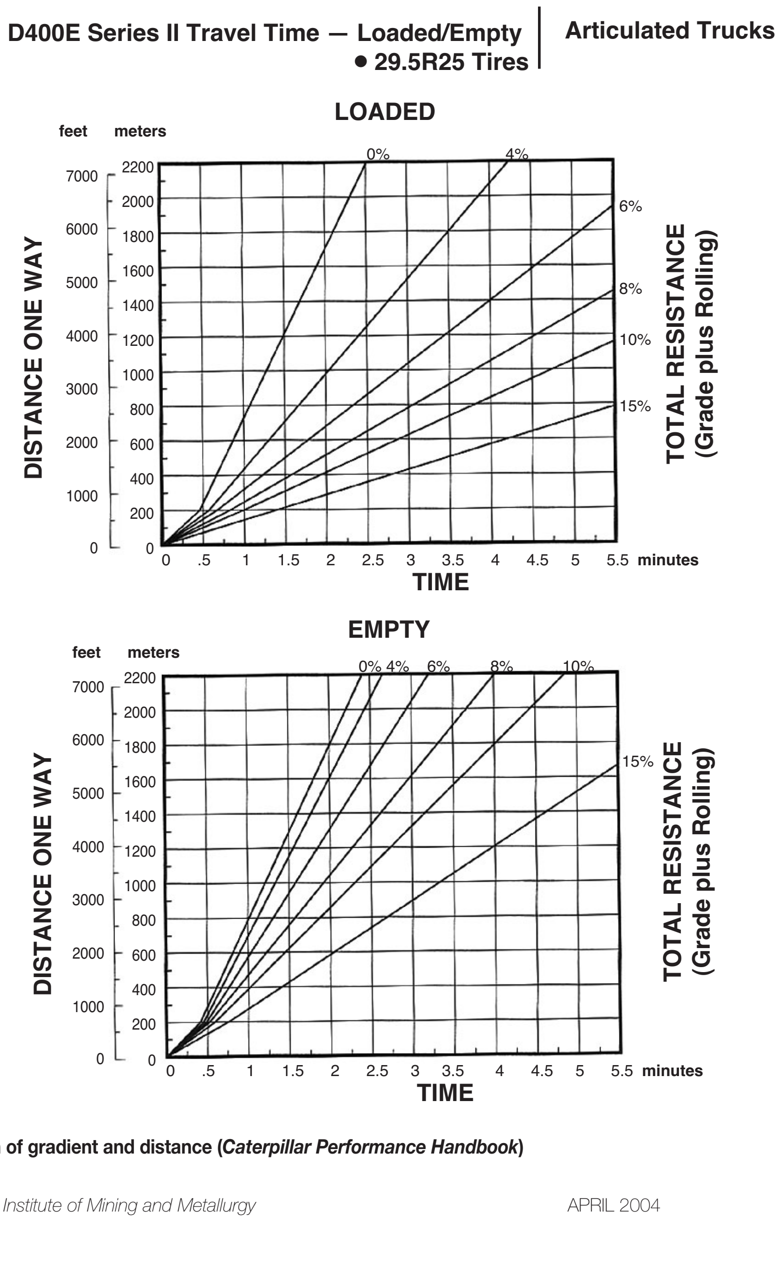


Figure 3—Speed as a function of gradient and distance (*Caterpillar Performance Handbook*)

| MODEL | | 5080 | | |
|---|---|---|---|---|
| Bucket size | ($m^3$) | 5.2 | 11.1 | 17.0 |
| | ($yd^3$) | 6.8 | 14.5 | 22.2 |
| Soil type | | ← | Shot Rock | |
| Swing angle | | ← | 90° | |
| Load area | | ← | No Obstructions | |
| Operator ability | | ← | Average | |
| Load bucket | (min) | 0.16 | 0.18 | 0.20 |
| Swing loaded | (min) | 0.09 | 0.13 | 0.14 |
| Dump bucket | (min) | 0.03 | 0.04 | 0.05 |
| Swing empty | (min) | 0.09 | 0.10 | 0.10 |
| Total cycle time | (min) | 0.37 | 0.45 | 0.49 |

**Figure 4—Excavator working cycle—CAT 5080 (*Caterpillar Performance Handbook*)**

$$L_V = \frac{W \times S}{\left(\frac{T \times W}{Q} - t_{Ra}\right) \times F} \quad [1]$$

Where:

$L_V$ = bucket capacity ($m^3$)
$W$ = truck capacity (tons)
$S$ = time required by the excavator for performing a working cycle (min)
$T$ = conversion factor: 60 (min/h)
$Q$ = output (tons/h)
$F$ = 1.9 $t/m^3$ ×85% = 1.615 $t/m^3$ (the density multiplied by the efficiency) The 85% efficiency factor is an assumed figure to allow for spillage and bucket filling.
$t_{Ra}$ = time for backing up the truck to the shovel (min)

The bucket load (contents) in tons—$L_f$—is determined from the formula:

$$L_f = \frac{W \times S}{\left(\frac{T \times W}{Q} - t_{Ra}\right)} \quad [2a]$$

$$L_V = L_f / F \quad [2b]$$

Furthermore, the number of trucks is determined using the following formula:

$$N = \frac{tn}{t_{La} + t_{Ra}} \quad [3]$$

Where:

$N$ = number of trucks serving the loading point, assuming continuous haulage removal of material by haulage.
$t_{La}$ = time for loading a truck (min)
$tn$ = time required for performing a haulage cycle (min)

### *Hourly production output*

The production output per hour can be determined from the given number of trucks serving a specific loading point in relation to the number of trucks from a given production output.

An important point to remember is that all parameters are interrelated. An unknown variable is determined by assuming the other known and/or constant.

The following equations are used:

$$Q = W \times N \times (T / tn) \quad [4]$$

In addition, $tn = t_w + t_{La} + t_{Ra} + t_{Br}$ [5]

and $t_w = 2a / v$ [6]

and $t_{La} = \left(W / L_f\right) \times S$ [7]

Where:

$t_W$ = time for travelling to and returning from the crusher
$t_{Br}$ = time spent at crusher
$a$ = distance from loading point to crusher
$v$ = average speed of vehicle travelling laden and empty (km/h)
$T/tn$ = number of haulage cycles of a truck per hour

### *Operation cycle at SMC*

The loading and haulage cycle at SMC (Table I) shows that for a distance of 2.8 km, the trucks have a theoretical average of 3.83 cycles per hour and an output of 17438 t/h.

The bar graph in Figure 5 shows the contribution of each parameter to the haulage cycle, with tramming and loading contributing the highest. These two parameters are therefore crucial in the optimization of the haulage cycle, since output (t/h) is inversely proportional to the time required to perform a haulage cycle. Therefore, a means of reducing the time taken for both tramming and loading should be devised in order to reduce the total time taken to complete the haulage cycle and hence increase the hourly output.

Reducing the excavator working cycle and subsequently the time taken to back up the truck to the shovel, increases the number of haulage cycles of a truck per hour and the number of trucks serving the loading point. Hence the output is increased, assuming continuos removal and haulage of material. The relationship between $S$ and $Q$ is as shown in Figure 6 (as the excavator working cycle increases the hourly output decreases).

Taking all the conditions and relationships mentioned above into account, one was set to determine:

- How to maximize the output, while
- Decreasing the number of trucks serving the loading point.

Firstly, one set out to decrease the excavator working cycle. Machine specifications show that the excavator working cycle can be reduced to 0.5 minutes provided that the rock is well shot, the swing angle kept below 90°, no obstructions occur in the loading area, and experienced operators are at work. The immediate result is a decrease in the loading period, which subsequently decreases the haulage cycle time and increases the hourly output. However, the number of trucks serving the loading point is also increased. Table II illustrates these results.

In order to decrease the number of trucks serving the loading point, the speed has to be increased. The speed is indirectly proportional to the time taken to travel to and return from the crusher for a constant haulage distance.

The total resistance (grade and rolling) determines the speed. As mentioned above, the haul roads at SMC have an average resistance of 10 per cent. For a total resistance of 10 per cent (two per cent rolling and eight per cent grade) the speed of the trucks can be increased from an average of

*Table I*

**Haulage cycle at SMC**

| W (tons) | N | tn | T/tn | $T_w$ | $t_{La}$ | $t_{Ra}$ | $L_f$ | S | Q | $L_v$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 7.09 | 15.0749 | 3.980126 | 12.95 | 1.7249 | 0.4 | 11.305 | 0.65 | 847.0985 | 7 |
| 30 | 8.31 | 17.16643 | 3.495195 | 15.1 | 1.636426 | 0.43 | 11.305 | 0.61666 | 871.069 | 7 |
| 30 | 6.27 | 15.66371 | 3.830511 | 13.1667 | 2.167006 | 0.33 | 11.305 | 0.8166 | 720.8634 | 7 |
| 30 | 7.19 | 12.71962 | 4.717122 | 10.95 | 1.236621 | 0.533 | 11.305 | 0.466 | 1017.167 | 7 |
| 30 | 5.75 | 16.32224 | 3.675966 | 13.4833 | 2.255639 | 0.5833 | 11.305 | 0.85 | 634.0397 | 7 |
| 30 | 5.93 | 16.73802 | 3.584653 | 13.9167 | 2.388324 | 0.433 | 11.305 | 0.9 | 637.9984 | 7 |
| 30 | 6.23 | 19.01969 | 3.154625 | 15.966 | 2.653693 | 0.4 | 11.305 | 1 | 589.4502 | 7 |
| 30 | 5.00 | 15.87295 | 3.780015 | 12.7 | 2.122954 | 1.05 | 11.305 | 0.8 | 567.2946 | 7 |
| 30 | 8.34 | 15.45199 | 3.882995 | 13.6 | 1.50199 | 0.35 | 11.305 | 0.566 | 971.9274 | 7 |
| 30 | 8.53 | 19.12389 | 3.137438 | 16.883 | 1.857585 | 0.3833 | 11.305 | 0.7 | 803.254 | 7 |
| 30 | 7.44 | 15.76953 | 3.804806 | 13.65 | 1.459531 | 0.66 | 11.305 | 0.55 | 849.2444 | 7 |
| 30 | 4.65 | 13.48013 | 4.450997 | 10.583 | 2.210526 | 0.6866 | 11.305 | 0.833 | 621.3053 | 7 |
| 30 | 16.36 | 14.76972 | 4.062365 | 13.8667 | 0.486422 | 0.4166 | 11.305 | 0.1833 | 1993.307 | 7 |
| 30 | 7.34 | 15.4742 | 3.877422 | 13.366 | 1.7249 | 0.3833 | 11.305 | 0.65 | 853.8087 | 7 |
| 30 | 7.10 | 15.53759 | 3.861604 | 13.35 | 1.857585 | 0.33 | 11.305 | 0.7 | 822.8251 | 7 |
| 30 | 4.54 | 14.02132 | 4.279197 | 10.933 | 2.388324 | 0.7 | 11.305 | 0.9 | 582.8404 | 7 |
| 30 | 6.65 | 16.24253 | 3.694006 | 13.8 | 1.459531 | 0.983 | 11.305 | 0.55 | 736.9404 | 7 |
| 30 | 5.63 | 18.09699 | 3.315468 | 14.883 | 2.830694 | 0.3833 | 11.305 | 1.0667 | 560.0508 | 7 |
| 30 | 10.41 | 16.13315 | 3.719052 | 14.5833 | 1.149845 | 0.4 | 11.305 | 0.4333 | 1161.406 | 7 |
| 30 | 6.08 | 12.68499 | 4.73 | 10.6 | 1.50199 | 0.583 | 11.305 | 0.566 | 863.3134 | 7 |
| 30 | 7.24 | 17.78627 | 3.373389 | 15.33 | 1.99027 | 0.466 | 11.305 | 0.75 | 732.8185 | 7 |
| Average | 7.242855 | 15.86428 | 3.828902 | 13.50765 | 1.838322 | 0.518305 | 11.305 | 0.692741 | 17438.02 | 7 |

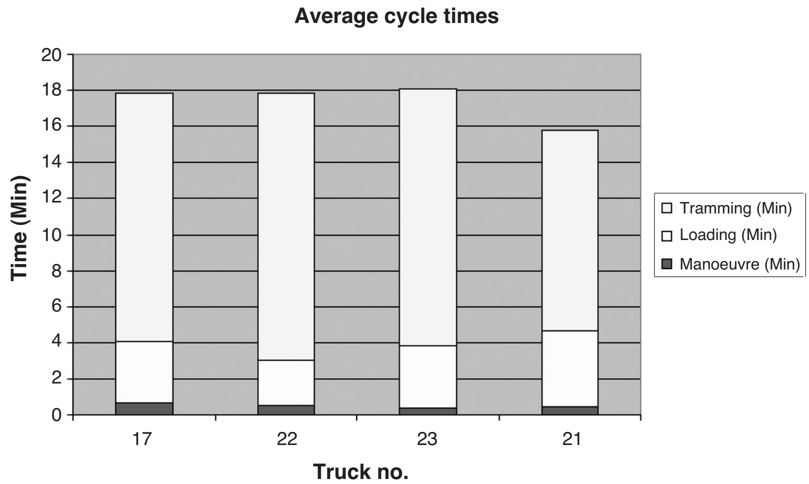


**Figure 5—Bar graph showing the contribution of the parameters in question to the haulage cycle**

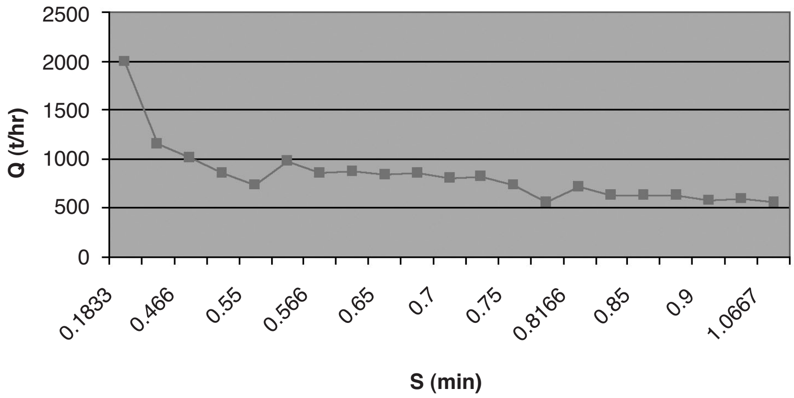


**Figure 6—Relationship between excavator working cycle (S) and output (Q)**

*Table II*

**Haulage cycle for a constant S**

| W (tons) | N | tn | T/tn | $t_w$ | $t_{La}$ | $t_{Ra}$ | $L_f$ | S | Q | $L_v$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 8.50 | 14.67685 | 4.088072 | 12.95 | 1.326847 | 0.4 | 11.305 | 0.5 | 1042.362 | 7 |
| 30 | 9.59 | 16.85685 | 3.559385 | 15.1 | 1.326847 | 0.43 | 11.305 | 0.5 | 1024.563 | 7 |
| 30 | 8.95 | 14.82355 | 4.047614 | 13.1667 | 1.326847 | 0.33 | 11.305 | 0.5 | 1086.401 | 7 |
| 30 | 6.89 | 12.80985 | 4.683897 | 10.95 | 1.326847 | 0.533 | 11.305 | 0.5 | 967.8218 | 7 |
| 30 | 8.06 | 15.39345 | 3.897763 | 13.4833 | 1.326847 | 0.5833 | 11.305 | 0.5 | 942.3361 | 7 |
| 30 | 8.91 | 15.67655 | 3.827374 | 13.9167 | 1.326847 | 0.433 | 11.305 | 0.5 | 1022.816 | 7 |
| 30 | 10.25 | 17.69285 | 3.391201 | 15.966 | 1.326847 | 0.4 | 11.305 | 0.5 | 1042.362 | 7 |
| 30 | 6.34 | 15.07685 | 3.979612 | 12.7 | 1.326847 | 1.05 | 11.305 | 0.5 | 757.3059 | 7 |
| 30 | 9.11 | 15.27685 | 3.927512 | 13.6 | 1.326847 | 0.35 | 11.305 | 0.5 | 1073.443 | 7 |
| 30 | 10.87 | 18.59315 | 3.226995 | 16.883 | 1.326847 | 0.3833 | 11.305 | 0.5 | 1052.541 | 7 |
| 30 | 7.87 | 15.63685 | 3.837091 | 13.65 | 1.326847 | 0.66 | 11.305 | 0.5 | 905.9582 | 7 |
| 30 | 6.26 | 12.59645 | 4.763248 | 10.583 | 1.326847 | 0.6866 | 11.305 | 0.5 | 893.9895 | 7 |
| 30 | 8.95 | 15.61015 | 3.843654 | 13.8667 | 1.326847 | 0.4166 | 11.305 | 0.5 | 1032.438 | 7 |
| 30 | 8.82 | 15.07615 | 3.979797 | 13.366 | 1.326847 | 0.3833 | 11.305 | 0.5 | 1052.541 | 7 |
| 30 | 9.06 | 15.00685 | 3.998175 | 13.35 | 1.326847 | 0.33 | 11.305 | 0.5 | 1086.401 | 7 |
| 30 | 6.39 | 12.95985 | 4.629684 | 10.933 | 1.326847 | 0.7 | 11.305 | 0.5 | 888.0791 | 7 |
| 30 | 6.97 | 16.10985 | 3.72443 | 13.8 | 1.326847 | 0.983 | 11.305 | 0.5 | 779.2726 | 7 |
| 30 | 9.70 | 16.59315 | 3.615951 | 14.883 | 1.326847 | 0.3833 | 11.305 | 0.5 | 1052.541 | 7 |
| 30 | 9.45 | 16.31015 | 3.678692 | 14.5833 | 1.326847 | 0.4 | 11.305 | 0.5 | 1042.362 | 7 |
| 30 | 6.55 | 12.50985 | 4.796222 | 10.6 | 1.326847 | 0.583 | 11.305 | 0.5 | 942.4841 | 7 |
| 30 | 9.55 | 17.12285 | 3.50409 | 15.33 | 1.326847 | 0.466 | 11.305 | 0.5 | 1003.99 | 7 |
| Average | 8.430345 | 15.3528 | 3.952403 | 13.50765 | 1.326847 | 0.518305 | 11.305 | 0.5 | 20692.01 | 7 |

25 km/h, shown in Table III, to 35 km/h (Table IV). The graph in Figure 7 is used to determine the optimum speed of the trucks as a function of resistance. The increase in speed, shown in Table IV, results, as expected, in a decrease in the number of trucks required in the haul cycle and a further decrease in the time required for performing the haul cycle.

However, the increase in speed does not affect the hourly output. The hourly output remains constant since it depends on both the excavator capacity and the working cycle.

Therefore, an optimum condition can be reached when the average speed is increased and the excavator working cycle reduced simultaneously. This condition is shown in Table V. The result is an increased output while decreasing the number of trucks required to serve the loading point.

Due to rain, muddy conditions are predominant in the northern block. As a result, there is an average travelling speed of 19 km/h. Proper grading of the haul roads has proven to increase the travelling speed of the trucks due to a reduced total resistance. Therefore, a similar methodology was used for this block–distance of 1.8 km from the crusher. There was, however, no need to decrease the excavator working cycle as it already remained below 0.5 minutes. Further, the total resistance was the only parameter to be decreased in order to increase the speed of the haulage trucks. After simulating these conditions, the result remained consistent with the previous finding.

## Analysis and evaluation of research results

The basic elements, which were considered in the evaluation of the excavator and haulage truck system, include:

- ➤ Production schedules, haulage routes (distance) and operating conditions
- ➤ Equipment productive capacity, which includes availability and the effects of the interaction between excavators and haulage trucks on the output.

From Table II, it is noticed that the highest output in t/h is achieved when eight trucks are in operation and the total haulage time is about 15 minutes. However, a smaller fleet size of five trucks would achieve an almost similar output at a shorter haulage period—the effect of increased speed (Table V). Further, the output can be increased by decreasing the excavator working cycle, but it would again increase the number of trucks needed for performing the haulage cycle. Therefore, an optimum condition can only be reached when the speed is increased while reducing the excavator working cycle.

Availability is a crucial parameter for excavator/truck systems, as they dictate the utilization and subsequently the output (productivity) of the units.

Therefore, an effective maintenance plan has to be in place to guarantee maximum availability. According to. Crawford[2], the maintenance facilities at the mine should be tailor–made to provide adequate support to the equipment fleet assigned to the mine. He further added, 'A major segment in successful heavy equipment maintenance and repair program is the provision of a well–laid out and equipped shop and service facilities'.

Achieving shovel productivity is dependent on having adequate truck coverage to minimize excavator delays. Further, the excavator fill factor approaches 100 per cent in well–blasted material.

Results from the simulation have shown that the operator working cycle is the major determinant of productivity

*Table III*

**Haulage cycle as a function of speed**

| W (tons) | N | tn | T/tn | $t_w$ | $t_{La}$ | $t_{Ra}$ | $L_f$ | S | Q | $L_v$ | a | v |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 7.09 | 15.0749 | 3.980126 | 12.95 | 1.7249 | 0.4 | 11.305 | 0.65 | 847.0985 | 7 | 2.7324 | 25.31954 |
| 30 | 8.31 | 17.16643 | 3.495195 | 15.1 | 1.636426 | 0.43 | 11.305 | 0.61666 | 871.069 | 7 | 2.7324 | 21.71444 |
| 30 | 6.27 | 15.66371 | 3.830511 | 13.1667 | 2.167006 | 0.33 | 11.305 | 0.8166 | 720.8634 | 7 | 2.7324 | 24.90282 |
| 30 | 7.19 | 12.71962 | 4.717122 | 10.95 | 1.236621 | 0.533 | 11.305 | 0.466 | 1017.167 | 7 | 2.7324 | 29.94411 |
| 30 | 5.75 | 16.32224 | 3.675966 | 13.4833 | 2.255639 | 0.5833 | 11.305 | 0.85 | 634.0397 | 7 | 2.7324 | 24.31808 |
| 30 | 5.93 | 16.73802 | 3.584653 | 13.9167 | 2.388324 | 0.433 | 11.305 | 0.9 | 637.9984 | 7 | 2.7324 | 23.56076 |
| 30 | 6.23 | 19.01969 | 3.154625 | 15.966 | 2.653693 | 0.4 | 11.305 | 1 | 589.4502 | 7 | 2.7324 | 20.53664 |
| 30 | 5.00 | 15.87295 | 3.780015 | 12.7 | 2.122954 | 1.05 | 11.305 | 0.8 | 567.2946 | 7 | 2.7324 | 25.81795 |
| 30 | 8.34 | 15.45199 | 3.882995 | 13.6 | 1.50199 | 0.35 | 11.305 | 0.566 | 971.9274 | 7 | 27324 | 24.10941 |
| 30 | 8.53 | 19.12389 | 3.137438 | 16.883 | 1.857585 | 0.3833 | 11.305 | 0.7 | 803.254 | 7 | 2.7324 | 19.42119 |
| 30 | 7.44 | 15.76953 | 3.804806 | 13.65 | 1.459531 | 0.66 | 11.305 | 0.55 | 849.2444 | 7 | 2.7324 | 24.0211 |
| 30 | 4.65 | 13.48013 | 4.450997 | 10.583 | 2.210526 | 0.6866 | 11.305 | 0.833 | 621.3053 | 7 | 2.7324 | 30.98252 |
| 30 | 16.36 | 14.76972 | 4.062365 | 13.8667 | 0.486422 | 0.4166 | 11.305 | 0.1833 | 1993.307 | 7 | 2.7324 | 23.64571 |
| 30 | 7.34 | 15.4742 | 3.877422 | 13.366 | 1.7249 | 0.3833 | 11.305 | 0.65 | 853.8087 | 7 | 2.7324 | 24.5315 |
| 30 | 7.10 | 15.53759 | 3.861604 | 13.35 | 1.857585 | 0.33 | 11.305 | 0.7 | 822.8251 | 7 | 2.7324 | 24.5609 |
| 30 | 4.54 | 14.02132 | 4.279197 | 10.933 | 2.388324 | 0.7 | 11.305 | 0.9 | 582.8404 | 7 | 2.7324 | 29.99067 |
| 30 | 6.65 | 16.24253 | 3.694006 | 13.8 | 1.459531 | 0.983 | 11.305 | 0.55 | 736.9404 | 7 | 2.734 | 23.76 |
| 30 | 5.63 | 18.09699 | 3.315468 | 14.883 | 2.830694 | 0.3833 | 11.305 | 1.0667 | 560.0508 | 7 | 2.7324 | 22.03104 |
| 30 | 10.41 | 16.13315 | 3.719052 | 14.5833 | 1.149845 | 0.4 | 11.305 | 0.4333 | 1161.406 | 7 | 2.7324 | 22.4838 |
| 30 | 6.08 | 12.68499 | 4.73 | 10.6 | 1.50199 | 0.583 | 11.305 | 0.566 | 863.3134 | 7 | 2.7324 | 30.93283 |
| 30 | 7.24 | 17.78627 | 3.373389 | 15.33 | 1.99027 | 0.466 | 11.305 | 0.75 | 732.8185 | 7 | 2.7324 | 21.38865 |
| Average | 7.242855 | 15.86428 | 3.828902 | 13.50765 | 1.838322 | 0.518305 | 11.305 | 0.692741 | 17438.02 | 7 | 2.7324 | 24.66541 |

*Table IV*

**The effect of increased speed on the haulage cycle**

| W (tons) | N | tn | T/tn | $t_w$ | $t_{La}$ | $t_{Ra}$ | $L_f$ | S | Q | $L_v$ | a | v |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 5.43 | 11.53885 | 5.199823 | 9.413953 | 1.7249 | 0.4 | 11.305 | 0.65 | 847.0985 | 7 | 2.7324 | 34.8 |
| 30 | 5.56 | 11.48038 | 5.226308 | 9.413953 | 1.636426 | 0.43 | 11.305 | 0.61666 | 871.069 | 7 | 2.7324 | 34.8 |
| 30 | 4.77 | 11.91096 | 5.037378 | 9.413953 | 2.167006 | 0.33 | 11.305 | 0.8166 | 720.8634 | 7 | 2.7324 | 34.8 |
| 30 | 6.32 | 11.18357 | 5.365011 | 9.413953 | 1.236621 | 0.533 | 11.305 | 0.466 | 1017.167 | 7 | 2.7324 | 34.8 |
| 30 | 4.32 | 12.25289 | 4.896803 | 9.413953 | 2.255639 | 0.5833 | 11.305 | 0.85 | 634.0397 | 7 | 2.7324 | 34.8 |
| 30 | 4.34 | 12.23528 | 4.903853 | 9.413953 | 2.388324 | 0.433 | 11.305 | 0.9 | 637.9984 | 7 | 2.7324 | 34.8 |
| 30 | 4.08 | 12.46765 | 4.812456 | 9.413953 | 2.653693 | 0.4 | 11.305 | 1 | 589.4502 | 7 | 2.7324 | 34.8 |
| 30 | 3.97 | 12.58691 | 4.766858 | 9.413953 | 2.122954 | 1.05 | 11.305 | 0.8 | 567.2946 | 7 | 2.7324 | 34.8 |
| 30 | 6.08 | 11.26594 | 5.325786 | 9.413953 | 1.50199 | 0.35 | 11.305 | 0.566 | 971.9274 | 7 | 27324 | 34.8 |
| 30 | 5.20 | 11.65484 | 5.148076 | 9.413953 | 1.857585 | 0.3833 | 11.305 | 0.7 | 803.254 | 7 | 2.7324 | 34.8 |
| 30 | 5.44 | 11.53348 | 5.202244 | 9.413953 | 1.459531 | 0.66 | 11.305 | 0.55 | 849.2444 | 7 | 2.7324 | 34.8 |
| 30 | 4.25 | 12.31108 | 4.873659 | 9.413953 | 2.210526 | 0.6866 | 11.305 | 0.833 | 621.3053 | 7 | 2.7324 | 34.8 |
| 30 | 11.42 | 10.31698 | 5.815658 | 9.413953 | 0.486422 | 0.4166 | 11.305 | 0.1833 | 1993.307 | 7 | 2.7324 | 34.8 |
| 30 | 5.47 | 11.52215 | 5.20736 | 9.413953 | 1.7249 | 0.3833 | 11.305 | 0.65 | 853.8087 | 7 | 2.7324 | 34.8 |
| 30 | 5.30 | 11.60154 | 5.171728 | 9.413953 | 1.857585 | 0.33 | 11.305 | 0.7 | 822.8251 | 7 | 2.7324 | 34.8 |
| 30 | 4.05 | 12.50228 | 4.799126 | 9.413953 | 2.388324 | 0.7 | 11.305 | 0.9 | 582.8404 | 7 | 2.7324 | 34.8 |
| 30 | 4.48 | 11.85648 | 5.060522 | 9.413953 | 1.459531 | 0.983 | 11.305 | 0.55 | 736.9404 | 7 | 2.734 | 34.8 |
| 30 | 3.93 | 12.62795 | 4.751366 | 9.413953 | 2.830694 | 0.3833 | 11.305 | 1.0667 | 560.0508 | 7 | 2.7324 | 34.8 |
| 30 | 7.07 | 10.9638 | 5.472556 | 9.413953 | 1.149845 | 0.4 | 11.305 | 0.4333 | 1161.406 | 7 | 2.7324 | 34.8 |
| 30 | 5.52 | 11.49894 | 5.217871 | 9.413953 | 1.50199 | 0.583 | 11.305 | 0.566 | 863.3134 | 7 | 2.7324 | 34.8 |
| 30 | 4.83 | 11.87022 | 5.054665 | 9.413953 | 1.99027 | 0.466 | 11.305 | 0.75 | 732.8185 | 7 | 2.7324 | 34.8 |
| Average | 5.342877 | 11.77058 | 5.109957 | 9.413953 | 1.838322 | 0.518305 | 11.305 | 0.692741 | 17438.02 | 7 | 2.7324 | 34.8 |

(output). However, this cycle depends heavily on the condition of the rock after blasting as well as on the design of the benches. Cramped working room and low bank height reduce the efficiency of large excavator units. Therefore, the shovel (excavator) point sheaves should be 1.5 m or less above the bank crest with a 45° to 50° boom angle. This defines the minimum bank height for efficient excavator operation.

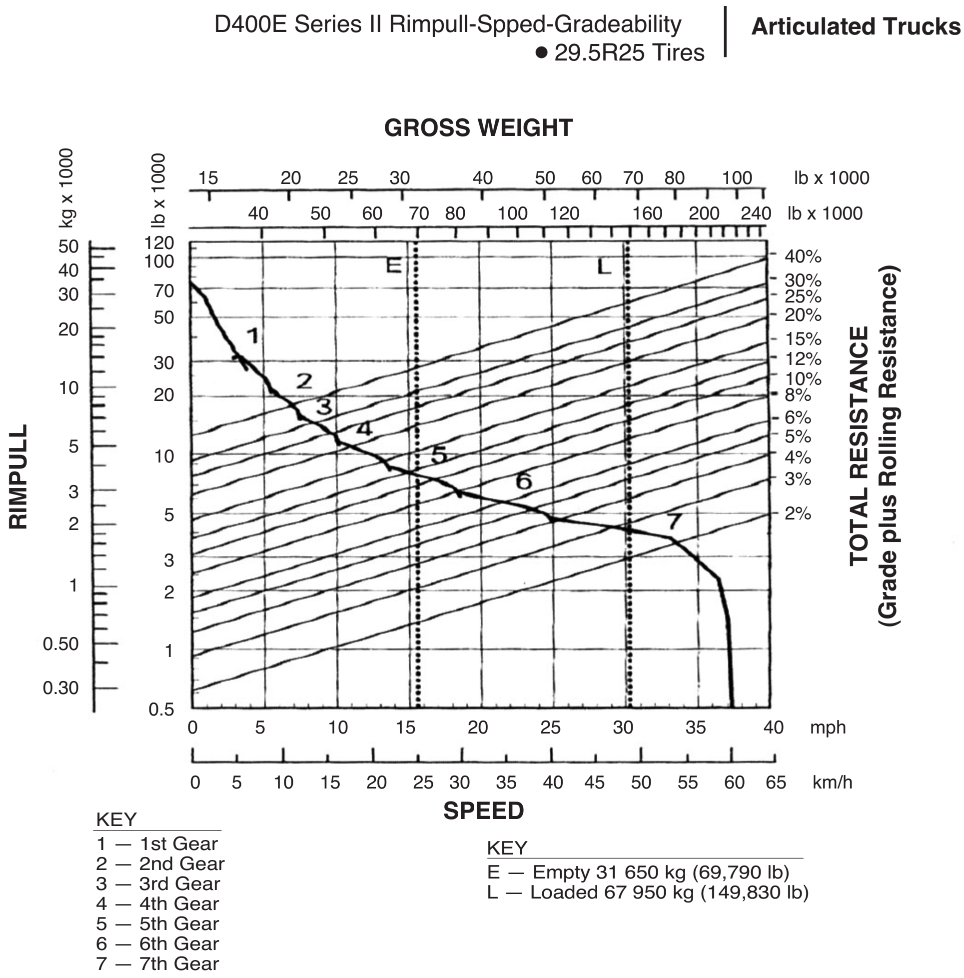


**Figure 7—D400E series 2 Rimpull-Speed-Gradeability (*Caterpillar Performance Handbook*)**

*Table V*

**Optimum condition—increased speed and reduced excavator working cycle**

| W (tons) | N | tn | T/tn | $t_w$ | $t_{La}$ | $t_{Ra}$ | $L_f$ | S | Q | $L_v$ | a | v |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 6.45 | 11.1408 | 5.38561 | 9.413953 | 1.326847 | 0.4 | 11.305 | 0.5 | 1042.362 | 7 | 2.7324 | 3 |
| 30 | 6.36 | 11.1708 | 5.371146 | 9.413953 | 1.326847 | 0.43 | 11.305 | 0.5 | 1024.563 | 7 | 2.7324 | 3 |
| 30 | 6.68 | 11.0708 | 5.419663 | 9.413953 | 1.326847 | 0.33 | 11.305 | 0.5 | 1086.401 | 7 | 2.7324 | 3 |
| 30 | 6.06 | 11.2738 | 5.322074 | 9.413953 | 1.326847 | 0.533 | 11.305 | 0.5 | 967.8218 | 7 | 2.7324 | 3 |
| 30 | 5.93 | 11.3241 | 5.298434 | 9.413953 | 1.326847 | 0.5833 | 11.305 | 0.5 | 942.3361 | 7 | 2.7324 | 3 |
| 30 | 6.35 | 11.1738 | 5.369704 | 9.413953 | 1.326847 | 0.433 | 11.305 | 0.5 | 1022.816 | 7 | 2.7324 | 3 |
| 30 | 6.45 | 11.1408 | 5.38561 | 9.413953 | 1.326847 | 0.4 | 11.305 | 0.5 | 1042.362 | 7 | 2.7324 | 3 |
| 30 | 4.96 | 11.7908 | 5.088713 | 9.413953 | 1.326847 | 1.05 | 11.305 | 0.5 | 757.3059 | 7 | 2.7324 | 3 |
| 30 | 6.61 | 11.0908 | 5.409889 | 9.413953 | 1.326847 | 0.35 | 11.305 | 0.5 | 1073.443 | 7 | 27324 | 3 |
| 30 | 6.50 | 11.1241 | 5.393695 | 9.413953 | 1.326847 | 0.3833 | 11.305 | 0.5 | 1052.541 | 7 | 2.7324 | 3 |
| 30 | 5.74 | 11.4008 | 5.262789 | 9.413953 | 1.326847 | 0.66 | 11.305 | 0.5 | 905.9582 | 7 | 2.7324 | 3 |
| 30 | 5.68 | 11.4274 | 5.250538 | 9.413953 | 1.326847 | 0.6866 | 11.305 | 0.5 | 893.9895 | 7 | 2.7324 | 3 |
| 30 | 6.40 | 11.1574 | 5.377597 | 9.413953 | 1.326847 | 0.4166 | 11.305 | 0.5 | 1032.438 | 7 | 2.7324 | 3 |
| 30 | 6.50 | 11.1241 | 5.393695 | 9.413953 | 1.326847 | 0.3833 | 11.305 | 0.5 | 1052.541 | 7 | 2.7324 | 3 |
| 30 | 6.68 | 11.0708 | 5.419663 | 9.413953 | 1.326847 | 0.33 | 11.305 | 0.5 | 1086.401 | 7 | 2.7324 | 3 |
| 30 | 5.64 | 11.4408 | 5.244388 | 9.413953 | 1.326847 | 0.7 | 11.305 | 0.5 | 888.0791 | 7 | 2.7324 | 3 |
| 30 | 5.08 | 11.7238 | 5.117795 | 9.413953 | 1.326847 | 0.983 | 11.305 | 0.5 | 779.2726 | 7 | 2.734 | 3 |
| 30 | 6.50 | 11.1214 | 5.393695 | 9.413953 | 1.326847 | 0.3833 | 11.305 | 0.5 | 1052.541 | 7 | 2.7324 | 3 |
| 30 | 6.45 | 11.1408 | 5.38561 | 9.413953 | 1.326847 | 0.4 | 11.305 | 0.5 | 1042.362 | 7 | 2.7324 | 3 |
| 30 | 5.93 | 11.3238 | 5.298575 | 9.413953 | 1.326847 | 0.583 | 11.305 | 0.5 | 942.4841 | 7 | 2.7324 | 3 |
| 30 | 6.25 | 11.2068 | 5.353892 | 9.413953 | 1.326847 | 0.466 | 11.305 | 0.5 | 1003.99 | 7 | 2.7324 | 3 |
| Average | 6.153271 | 11.2591 | 5.330608 | 9.413953 | 1.326847 | 0.518305 | 11.305 | 0.5 | 20692.01 | 7 | 2.7324 | 3 |

## Conclusion

The simulation conducted provides a very good means of determining the production schedule and/or fleet size, as well as optimizing an already existing cycle. Further, success will be achieved by diligently following the correct design process. The parameters affecting the loading/haulage cycle were identified and simulated accordingly to determine the optimum operation cycle at SMC. The results have shown that for a distance of 2.7 km, six trucks should be used-for optimum efficiency. Further, the output can be increased if the excavator cycle is maintained at the suggested (simulation) optimum. For a distance of 1.8 km, the excavation cycle and thus the output cannot be optimized further. However, the speed can be optimized since it is very low when compared to the optimum as defined by the Caterpillar performance handbook (2001). The present haulage trucks, schedule for this distance shows that 10 trucks should be used if the current speed is maintained. However, increasing the speed would reduce the number of trucks to five.

One matter, which was not discussed, is the monitoring of the trucks. Software packages such as VMCS3 (vehicle monitoring and control systems) are available and in use in some opencast mines. The software uses GPS to monitor the trucks. Ongoing monitoring of the truck and excavator units is essential to avoid pauses in the working cycle and thus bottlenecks. With a system such as this, different assignments can be given instantaneously to the truck/excavator units when refuelling or in the case of breakdowns.

This report can be used as a tool for simplifying any loading/haulage cycle and the successful application of its finding will depend on proper management (leadership and control) of the operators involved as well as their competency and obedience.

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