The determination of haulage-truck requirements for an open-pit operation

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SYNOPSIS

A method of forecasting the haulage trucks required for a large open-pit operation is described. Emphasis is placed on the effects of changes in planning and on the complexities of a mining operation that involves many benches and dumping areas.

SAMEVATTING

'n Metode vir die vooruitskatting van die ertstrok benodigdhede van 'n groot dagboumyn word beskryf. Klem word gelê op die uitwerking van veranderinge in beplanning, en op die kompleksiteite betrokke in 'n multibank mynbou en stortingsproses.

Introduction

The open pit of Palabora Mining Company Limited (P.M.C.) is situated 4 km south of the town of Phalaborwa, in the north-eastern Transvaal of the Republic of South Africa. The Company was incorporated in 1956, and during the period 1957 to 1962 carried out an extensive drilling programme to evaluate the Loolekop copper ore-body. Structurally, the ore-body consists of an annular carbonatite pipe, which is elliptical in plan. Copper values in the carbonatite core grade outwards into a concentric zone of phoscorite, which in turn gives place to a barren pyroxenite wall rock.

Ore is delivered to the crushers at the rate of 86 000 t/d six days a week to feed the mill at a rate of 74 000 t/d, milling seven days a week.

The broken material in the pit is divided into ore and waste composites, the copper values of which are determined from the sample results of individual blast holes. The copper cut-off grade is currently 0,25 per cent, but this will be reduced to 0,20 per cent in early 1980 in line with approved expansion plans.

Discard material is split into several different groups based on the various copper and phosphate values present. Each group is either dumped or stockpiled separately for recovery at a later stage. Approximately 210 000 t of discard material is currently mined each day.

Pit benches run on east–west axes, with the main entrance ramp on the east side of the pit. From this ramp, haulage roads lead to the primary crushers and the main discard dumps, all the roads being designed with a maximum adverse grade of 8 per cent. The average haulage distance is approximately 1800 m to the primary crusher and approximately 4000 m to the discard dumps. One new bench is opened up at the pit bottom every nine months. On the basis of current planning, the final pit size will be 1655 m by 1458 m on surface and 508m in depth, with a finished slope of 45°.

The pit is run on a three-shift basis six days a week. The shift change takes place 'on the job'. When necessary, primary blasting is carried out during the day shift.

The loading equipment consists of a total of thirteen electric shovels — five of 4,6 m³ (6 yd³), three 7,6 m³ (10 yd³), four 9,2 m³ (12 yd³), and one 13,8 m³ (18 yd³). The haulage fleet currently consists of sixty-two Lectra Haul diesel electric trucks — twenty-three of 90 t capacity and thirty-nine of 150 t capacity. The pit is run in an undertrucked condition. As loading capacity exceeds hauling capacity, the operation is extremely sensitive to any inadequacies in the haulage fleet. A computerized truck-control system is in use that assists in the efficient utilization of the trucks.

The described method has been developed to forecast truck requirements in a changing complex operation. Generally, the projection of truck requirements can be achieved through two basic methods: from the extrapolation of historical performance statistics such as tons per truck shift and ton-kilometres per truck shift, or from calculations of cycle times that require a basic mining simulation.

Unlike the latter method, performance projections cannot reliably account for planning details that may significantly affect truck requirements. Such details include sinking rate, material reclassification, grade changes, dump expansion and/or re-siting, all of which alter haulage routes and thus cycle time and truck requirements. However, the statistical approach is often useful for checks, particularly in the short term, when operating conditions and planning criteria are known not to differ markedly.

The cycle-time method has the advantage of extreme flexibility, permitting any planning and operational intricacies to be included to any degree required.

Description of Method

The basic equation for the calculation of the haulage-truck requirement for any open-cast earthmoving operation is both straightforward and simple, being

$$\text{Trucks required} = \frac{\text{Total desired extraction rate}}{\text{Extraction rate per truck}}.$$

The following equation can be promptly resolved:

$$N = T \times \frac{1}{P} \times TCT \times \frac{1}{TF} \text{ - - - - - - - - - } (M) \times (T)^{-1} \times (T) \times (M)^{-1},$$

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where N =number of trucks
T =tonnage
P =period
TCT=truck cycle time
M =mining rate
TF =truck tonnage factor.

Alternatively, common sense dictates that the truck requirement should be directly proportional to the tonnage and truck cycle time, and inversely proportional to the period (or time) and to the truck tonnage factor, thereby directly providing the above equation.

The application of the equation is best illustrated by a simple example. For a mining rate of 2000 t/h, where the truck cycle time is 0,5 h and the truck factor 100 t, 10 such trucks are required.

The cycle time is discussed in detail later; however, it must be emphasized at the outset that confidence in the cycle times is of fundamental importance in providing a reliable truck requirement. Whereas the mining rate and truck factor in any calculation are specified, the cycle time must be calculated. Therefore, any inaccuracy or error in the cycle time provides the same percentage error in the calculated truck requirement.

In the above example, a difference in the cycle time of 5 minutes (10 per cent) would cause a difference of 1 truck unit.

The example also serves to introduce two important points concerning the application of the equation, both involving the truck cycle time.

(1) Open pits are generally operations requiring many benches and many dumping areas, often involving varying unit capacities for digging and haulage. At P.M.C., as many as eight benches may be mined simultaneously to ten dumping areas, using four different shovel capacities and two types of haulage trucks. For these reasons, haulage-truck cycle times vary widely, and thus dictate that the truck requirements should be calculated incrementally, each tonnage increment having a unique cycle time. The summation of the incremental truck requirements provides the total truck requirement. At P.M.C.'s annual mining rate of some 93 million tons, the enormity of the problem can be appreciated. This was overcome through the use of a system of 'blocking', which is described later.

(2) An allowance for truck efficiency must be included in the calculation, either as a final adjustment to the 'theoretical' truck requirement (i.e. at 100 per cent efficiency) or as a constant in the total cycle time.

Early exercises at P.M.C. adopted the latter method, by which field observations of waiting times, maintenance downtime, and service statistics enabled an inefficiency increment to be included in the total cycle time. This method has now been discontinued.

The alternative method employing an 'overall' truck efficiency is thought to be far more comprehensive in that the total operational delays are identified from the truck tachographs. Thus, the whole fleet can be examined over a long period with the confidence that every delay that was incurred is included. The efficiency includes the following: mechanical and electrical breakdowns, planned maintenance, daily service and refuelling, tyre failures, and operational delays.

Thus,

$$\text{practical truck requirement} = \text{theoretical truck} \div \text{efficiency requirement} = \sum_{0}^{n}\left(\frac{Tn \times TCTn}{P \times TF}\right) \div \text{efficiency}.$$

A computer programme has been developed at P.M.C. to minimize the time required for the large number of calculations.

The frequency of trucking exercises and the total period and number of sub-periods considered in each exercise are largely dictated by the mine planning. The alteration of planning parameters such as mining rate, grade cut-off, sinking rate, and material classification generally necessitate a review of the fleet requirement.

At P.M.C. it is customary to provide a yearly forecast for five years, with a quarterly forecast for the first year. Should any change in major planning parameters occur, the periods for examination would be changed to agree with these.

Preparation of Plans

For each period to be considered, mining plans must detail the mining faces at the start and the end of each bench to be mined. The objective of the blocking system (or section system) employed is to identify areas on each bench that have a common haulage route on the bench to the exit ramp. Haulage routes for blocks on the same bench will inevitably differ, being subject to the mining sequence on that bench and particularly to the sequence of the bench immediately below. When face advance on a bench is considerable, owing either to concentrated mining activity or to the length of the period being examined, the intricacies of the mining sequence may not always be apparent from the start and end face positions. It is thus of the utmost importance that the planning concepts determining the mining sequence should be thoroughly understood if realistic haulage routes, and thus bench cycle times, are to be determined.

When the haulage routes on each bench have been

TABLE I

DOCUMENTATION REQUIRED PRIOR TO DIGITIZING PLANS
(see Figs. 1 to 3)

Bench no.	Block no.	Block constant distance	Block reference point
10	A1	Nil	a1
9	B1	Nil	b1
	B2	b1 b2	b2
8	C1	Nil	c1
	C2	c1 c2	c2
6	D1	d1 d2	d2
	D2	d1 d2 d3	d3
	D3	d1 d2 d3	d3
	D4	d1 d2 d3 d4	d4
5	E1	e1 e2	e2
	E2	e1 e2 e3	e3
	E3	e1 e2 e3 e4	e4

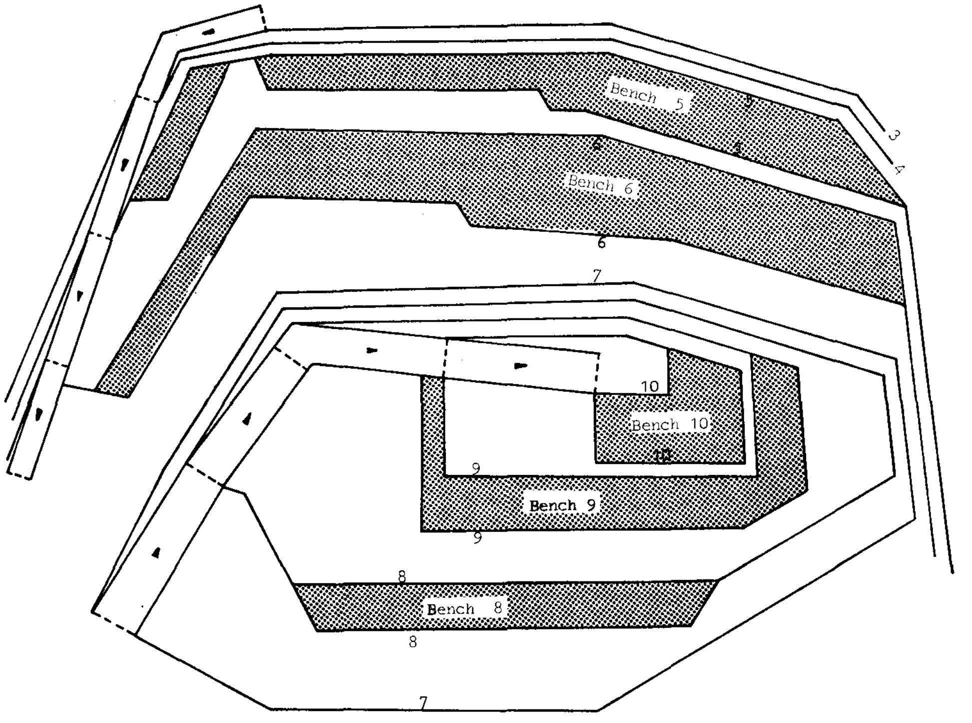

Fig. 1—Areas to be mined on each bench indicated by the start and end face positions

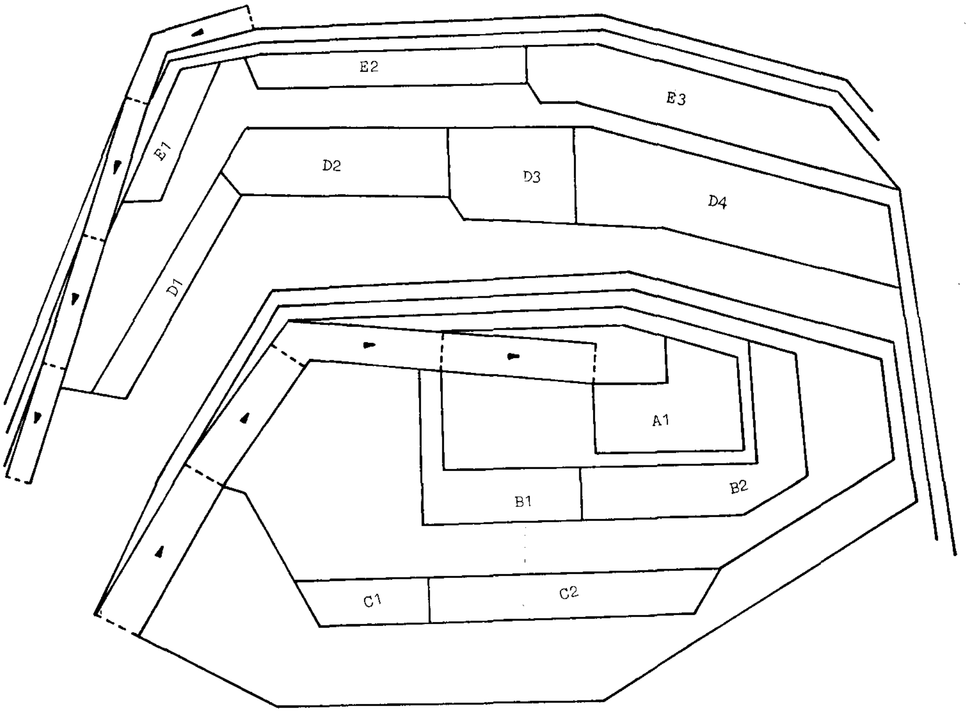

Fig. 2—Mining areas blocked according to haulage routes

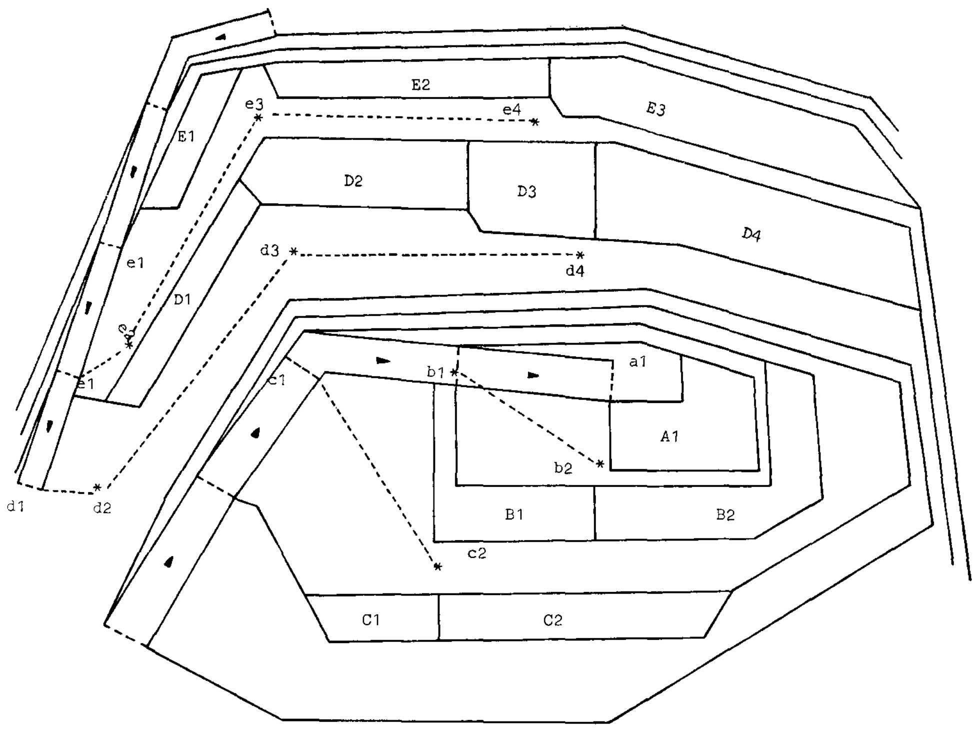

Fig. 3—Block reference points along the haulage route, the dotted lines representing likely haulage routes

ascertained and the respective areas to be mined have been blocked accordingly, each block must be numbered and referred to an arbitrary point along a straight line on the haulage route from the block. The remaining distance from the reference point along the determined haulage route to the bench exit at the toe of the ramp must be scaled and recorded for each block. This distance is referred to as the section or block 'constant'. Figs. 1 to 3 indicate the blocking and reference-point system, and the necessary documentation is shown in Table I.

Every block to be mined is then digitized, the computer printout detailing the following for each section:

(i) all the material classifications present and the respective ore-reserve tonnages, and
(ii) for each of the different materials, the distance from the section reference point to the computed centre of gravity of each tonnage, the addition of this distance and the respective section constant providing the total bench-haul distance.

Table II shows a typical computer printout.

The system of blocking thus achieves a major objective by defining a bench distance contributing to a unique cycle time for each of the tonnages of the same material classification within a section or block.

TABLE II

A TYPICAL COMPUTER PRINTOUT

Date: Digitized name: eg. 1982

Average distances of material from points in digitized sections/blocks

Report for Bench X Section A1

RAMP ONE

Rock type	Tons	Average distance (m)
C1	234 687	104,37
M7	0	0,00
H7	0	0,00
A5	0	0,00
B3	0	0,00
L7	0	0,00
H10	383 215	606,48
D4A	6 198 061	637,29
D4B	38 164	604,10
E2	0	0,00
J8	0	0,00
K9	4 042	442,39
Waste totals	6 623 482	615,06

Checks of Tonnage

Checks must be made to ensure that there are no discrepancies between the digitized tonnages obtained for the trucking exercise and the known digitized tonnages of the mining plan. Errors should not occur since both the plans and the ore-reserve programme are the same. The total tonnage and the ore and waste tonnages for every individual bench must also agree. Any known factors relating ore-reserve and *in situ* tonnages can be built into the computer programme to adjust the digitized tonnages to actual mining and milling rates.

Truck Cycle Times

The components of the truck cycle time at P.M.C. are shown in Fig. 4.

1. Truck Loading Cycle

The total loading cycle is defined as the return time taken from a common point 100 m from the shovel. The distance of 100 m was arbitrarily chosen to avoid the

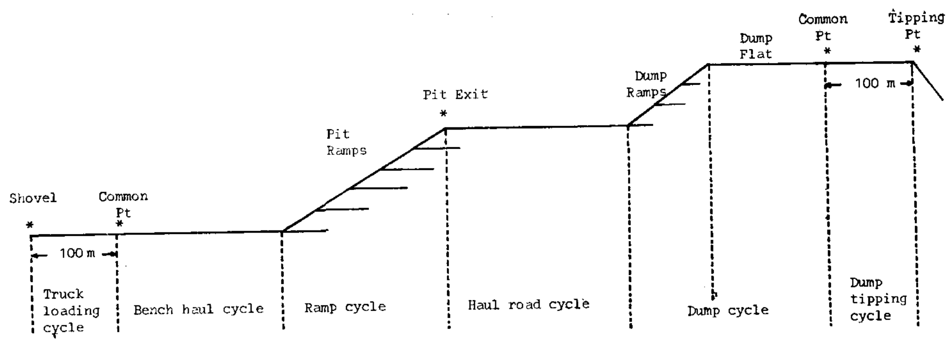

Fig. 4—Components of the total truck cycle

inclusion of acceleration and deceleration times in the bench haul cycle.

The total cycle can be reduced to three major components: running, waiting, and loading. The running component can be further reduced into three sub-components, these being

(a) time to travel from the common point to the turning point,
(b) time to reverse to the loading point, and
(c) time required to accelerate from the shovel and pass the common point.

Similarly, the waiting component can be reduced to four sub-components, these being

(i) waiting at the turning point to reverse into the loading position,
(ii) waiting in the loading position,
(iii) waiting after loading has been completed while the driver examines for spillage under the tyres, and
(iv) waiting while the driver returns to the cab.

Waiting points (i) and (ii) are excluded from the theoretical loading cycle, but points (iii) and (iv) are included because these are considered to be unavoidable operational delays. The total running component and points (iii) and (iv) of the waiting component were both found to be consistent and independent of the type of truck or shovel serviced. An average value was determined for each of these for use in the loading cycle.

The remaining major component, loading, is measured as the time taken from the placement of the first dipper to the completion of placement of the last dipper. An average value of pure loading time for each type of truck was determined for each shovel. In view of the variety of shovels in use at P.M.C., this is the most variable component of the total truck cycle. An extensive survey was carried out on each of the four shovel groups so that an average loading time could be determined for each type of truck.

Since for every tonnage increment it is necessary to specify a loading time for inclusion in the truck loading cycle, the planned tonnage of each shovel unit must be allocated in accordance with the mine planning. Tests conducted to ascertain the variation in total truck requirement with alternative random shovel positions showed differences of up to one truck unit over a year.

In summary, the theoretical loading cycle time for shovel X and truck type Y is

running constant + accepted waiting constant + loading time for shovel X, truck type Y

2. Bench Haul Cycle

The time of the bench haul cycle (BCT) is the return truck time taken from the common point 100 m from the shovel to the bench exit, and is calculated as follows:

BCT = (return haulage distance—200) ÷ speed for the specified truck type
= 2(block constant + digitized distance —100) ÷ speed.

The average speeds for both types of truck were obtained from exhaustive field observations encompassing the diversity of operating conditions experienced. The speed of the trucks varies significantly with the weather, the state of the roads, and the fragmentation and density of the material in the load.

3. Ramp Cycle

This cycle time is simply the product of the number of benches to be hauled and the single ramp cycle time applicable for each respective type of truck. The former figure can be calculated from a knowledge of the bench on which the material was loaded and the bench number at the pit exit; the average ramp cycle times for a single bench were determined from field observations of hauling loaded up-grade and empty down-grade. All the ramps at P.M.C., both pit and dump, are constructed at a grade of 8 per cent and are of the same material and construction method. Field observations of ramp speeds were thus considered generally applicable.
Thus,

ramp cycle time = no. of benches hauled × ramp cycle time.

4. Haul Road Cycle

This cycle is the return truck time taken from the pit exit along the haulage road to a common point on or at the toe of the dump. Where haulage roads to the dumps from each pit exit are established, actual cycle times from field observations can be used. These have been found to be far more accurate than cycle times calculated from average speeds and known haulage profiles. This is because the speeds observed were for either flat hauls or a constant grade of 8 per cent, and are thus not applicable to the range of gradients found in most haulage profiles, truck speeds being extremely sensitive to gradient.

5. Dump Cycle

For each period considered, a constant value can be determined for each dump, calculated from the distance from the centre of gravity of the material dumped in the period to the common point at the end of the haul road cycle. The standard-level truck speeds and ramp cycle times are then used for the calculation of the cycle time.

Plans detailing dump-lift face positions at the start of each period are a prerequisite. The known total tonnage to be dumped within the period can be blocked out, thereby obtaining the end face position for each lift. Dump 'construction' in this manner, if a representative dump constant is to be obtained, must follow and be consistent with the normal operational procedure involving multi-lift dumping where required.

The procedure is thus somewhat analagous to the blocking procedure employed for the bench extraction cycle.

Thus,

dump cycle = 2 (distance from common point at end of haul road cycle to the start of dump ramps) ÷ truck speed
+ no. of ramps × time per ramp cycle
+ 2 (distance from centre of gravity—100) ÷ truck speed of dumped material.

6. Dump Tipping Cycle

The tipping cycle is determined in a similar manner to that employed for the loading cycle, where field observations of the cycle components permit the determination of a theoretical cycle from a common point 100 m from the tipping point.

The dump tipping cycle at P.M.C. was found to be very consistent, there being little difference in the time required to empty the two types of truck. In the case of the crusher cycle, cycle times differed because of the reduced reversing speed of the larger type of truck, extra caution being required in the more restricted crushing-bay area.

Trucking Programme

The programme was developed to minimize the time required by the calculations, which, although very simple, are lengthy because of the number of variables involved. The variables can be classified as follows.

1. General, i.e. for any period
   — haul truck speeds
   — ramp cycle times
   — waste tipping cycle
   — ore tipping cycle
   — haul road cycle times for each dump and pit exit
   — common load cycle components
      — running time
      — accepted waiting time
2. For a specific period
   — no. of pit operating days
   — no. of mill days
   — ore and waste correction factors
   — dump cycle times for each dump and truck type
3. Unique to every individual tonnage increment
   — truck type
   — shovel
   — bench distance
   — bench number
   — pit exit
   — dump (rock type)
   — tonnage

The procedure followed by the programme is illustrated by the following logic flow:

Variables under 1 and 2 above

input

TRUCK TYPE?

input —— 99 —— Print out

SHOVEL LOAD TIME?

input

(calculates total load cycle)

BENCH DISTANCE?

input

(calculates bench cycle)

BENCH NUMBER?

input

PIT EXIT?

input

(calculates total ramp cycle)

ROCK TYPE?

input

(recalls haul road cycle, dump cycle and tipping cycle having specified dump and truck type)

(Calculates total truck cycle time)

TONNAGE?

input

Calculates no. of trucks required

—— Print out

Summary: truck type 1 required
truck type 2 required
Total tonnage

Calculates: Mining rate, ore and waste

End of programme

Conclusion

The method as described is a reasonably simple and practical approach to the determination of haulage-truck requirements. It has given meaningful results in the large and complex open-pit mining operation at P.M.C. The method is adaptable to any earthmoving operation.

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