Planning Open Pit Mining Operations Using Simulation

SYNOPSIS

The complexity of modern open pit load-haul-dump systems is described, and the need for realistic working models is pointed out. Both standard and probabilistic simulation procedures are discussed, probabilistic simulation being indicated as the more powerful and practical technique. Acquisition of the necessary pit operating data required for simulator construction and general modeling procedures are described. Finally, results from a typical open pit simulator are used to indicate the scope of the technique.

INTRODUCTION

Modern large-scale mining operations are in reality complex materials load-haul-dump systems consisting of many interdependent entities. The production by a mining shovel, for example, is dependent on rock type, quality of muck fragmentation and the size and number of trucks arriving to be loaded. The number of loads hauled by a truck in a shift depends on queueing conditions at the shovel and dump points and the number and speed characteristics of other trucks in the circuit. The dump point usually has a limited capacity and is subject to blockages and other delays. Such an operation cannot be planned effectively using average shovel outputs and estimated truck cycle times. It is often unclear, for example, whether the introduction of additional operating trucks to the system will increase overall production markedly or simply congest the system further. Obviously, an accurate working model of the system is needed, on which optimum operating procedures can be established without costly experimentation in the operating mine. Simulation techniques can provide such a model.

SIMULATION

Simulation is basically a modelling technique. It is an attempt to predict the changes in the performance of a complex operating system which will result if the system is changed, without actually changing the system. Simulation can be performed manually or by computer, the choice depending on the complexity of the problem.

There are two basic types of simulation, probabilistic or Monte Carlo simulation and standard simulation. Standard simulation involves the representation of system parameters, such as truck haul speed for a given road grade and rolling resistance, etc., by a series of mathematical equations. Standard simulation has been used by O’Neill, et al (1967) for truck circuit simulation studies and by Nikiforuk, et al (1966) to model the operation of a walking dragline. Many haulage truck manufacturers use standard simulation computer programs to predict the performance of haulage units over given road profiles, Morgan (1968). These studies tend to give optimistic results as the effects of queueing and other factors present in real situations cannot be represented adequately.

Since standard simulation is difficult to apply to systems with many interdependent variables, it has not been used widely in open pit mine planning.

The Monte Carlo approach is a much more powerful technique for this purpose. This method of simulation involves the random selection of event times for operations, such as the time required for a given shovel to load a given truck, from actual field time study data of that operation. This type of approach is almost essential for the study of cyclic queues where the equations required for standard simulation would become much too complex to manage. Madge (1964), Calder, et al (1965) and Manula, et al (1967) have described early uses of this technique in studying open pit truck fleet problems.

LOAD-HAUL-DUMP CIRCUITS

In an open pit mine ore is moved from the various muck piles to the dumping areas along a network of haulage routes, as represented schematically in Fig. 1. To illustrate the nature of the system let us follow a typical haulage unit through a complete cycle, starting with its arrival at a shovel location.

Shovel locations

Depending on the system of loading, that is, drive by, single back up or double back up, there may be one or two loading positions at the shovel. If one of these is open, the unit will proceed to that position. Otherwise it will join or form a queue for a load position, on a first-in, first-out basis. When a loading position becomes available to the truck, it is positioned and loaded. The time required for loading depends on many factors including truck box capacity, shovel bucket capacity, rock type, quality of muck fragmentation and shovel-truck compatibility.

Haul routes

When the truck is loaded it proceeds along the branch route from the shovel location to the main haul route. If it meets another vehicle travelling in the same direction at a slower speed, a decision is required as to whether to attempt passing. In many open pit situations passing is prohibited or impractical. If this is the case, haul speed is affected not only by the characteristics of the truck and the road, but also by the characteristics of other vehicles in the circuit. Each time the truck approaches an intersection consideration must be given as to right of way, and slowing or stopping may be involved. The more vehicles there are on the haul circuits the more the "interference", or inefficiency due to congestion, there will be.

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Fig. 1. Typical load-haul-dump circuit in open pit.
Dump points

There may be one or more dump points available to the truck. If there is more than one dumping point within visual range the truck should proceed to the one which will allow the fastest turn around time. In some cases a dumping point may be assigned to the truck by a dispatcher, either for the duration of the shift or on a trip-by-trip basis. If other trucks are waiting the truck must join or form a queue. The dumping point will usually be a crusher or a loading pocket. Both of these are subject to blockages and have limited storage capacities if their output is halted. Any delay of this sort adds to truck queuing time. Alternative dumping points such as at stockpiles may be used during breakdown of dumping facilities.

Operating procedures

After dumping its load, the truck will normally return to the pit for another. The truck may be assigned to a particular shovel for the duration of the shift, in which case it will simply return to that shovel. On the other hand, a dispatcher may be used to assign the truck as it enters the pit to the shovel in greatest need of it. In addition, routines for refuelling, shift change and lunch break must be established and play an important part in truck movements. Mechanical breakdowns of shovels and trucks are inevitable and procedures to be followed for re-assignment during breakdowns are very important in determining overall efficiency.

MODELLING LOAD-HAUL-DUMP CIRCUITS

Consider a typical open pit load-haul-dump circuit as shown in Fig. 1. Before modelling the system, it is necessary to know the operating characteristics of the units involved in that environment. The only practical way to acquire this information is by observation in that or a similar environment. The independent operating characteristics of the individual units are required. For example, we wish to know the speed of a haul unit along a certain section of road when it can move at its own speed, unaffected by slower units.

Operating data

For a given shovel, truck size, road circuit and rock material, the most important variable is the quality of muck fragmentation. Some method of classification of blasted muck based on size distribution is required. In Fig. 1 examples of loading data for good, fair and poor digging conditions are given. Curves such as this are required for each shovel and truck combination and each loading arrangement. They represent the time taken by the shovel to load the truck once the truck is in the current loading position.

Haul times must be sampled for each truck type along each section of haul road, going and coming. The haul road circuit should be sub-divided into sections for this purpose. For example, in Fig. 1, shovel location No. 1 to Junction No. 1, Junction No. 1 to dump point No. 1, etc., would be logical sub-divisions. Only the times of lead trucks, that is, those which are not being slowed by other trucks, should be taken. Dumping times at the various dump points should also be sampled extensively for each type of truck.

Storage of data

The operating data can either be stored in computer memory or plotted as a cumulative frequency plot versus operation time for each action if a manual simulation is to be performed. In the latter case, times are chosen from the plot by selecting a number between 1 and 100 from a random number table. When a computer is used the data are obtained by selecting a number randomly from a range equal to the total number of data points for that operation. This would correspond to the address location of the data point in the memory of the computer.

Model operation

Once all the operating data are collected, the simulation can be made. The operator must select the number and location of shovels to be operated, the dump points to be used, the number and types of trucks assigned to each shovel, the digging conditions at each shovel and the number of shifts to be simulated. In addition procedures to be used during start-up of shift, lunch break, truck dispatching, refuelling, mechanical breakdowns, end of shift, etc., must be specified.

If the simulation is performed manually, the simplest method is to chart the movements using colored lines on graph paper, one line representing each operating unit (shovel, truck, crusher, etc.). For example, when a truck is positioned at a shovel for loading, a loading time is selected randomly from the operating data of that shovel truck combination in that digging condition. The time representing that shovel is then marked off for that period of time indicating it is loading a truck. At the end of that time one load is added to its production. Following this will be a time of waiting for another truck which can be represented by another color. Cumulative waiting times, loading times and total loads can be kept easily.

If the simulation is performed on a computer much the same procedure is used except movements are performed at high speed automatically according to the rules of the program, and appropriate records are kept. The simplest way to program a simulation is to use a computer language designed for that purpose such as I.B.M.'s General Purpose Simulation System (GPSS) language (I.B.M. 1970).

RESULTS OF SIMULATOR STUDIES

Once a true working model of the pit operations has been developed, optimum operating procedures can be established.

Figure 2 is a plot of the number of trucks loaded by a particular shovel per shift versus the number of trucks assigned to that shovel from a twelve-truck operating fleet. Results for good, fair and poor digging are shown. Cumulative waiting time for shovels and for trucks is also indicated, on the right axis.

Figure 3 shows the total number of loads per shift produced by the pit versus the number of operating trucks, for good and poor digging conditions. With good digging conditions, for example, 200 loads per shift can be produced by 10 trucks and two shovels. If three shovels were operated the production would not be increased. However, if digging conditions are poor, 200 loads per shift could not be achieved with three shovels regardless of the number of trucks available. It is also evident that the system saturates at 275 loads per shift and increasing the number of shovels or trucks would not increase production beyond that point. This would probably correspond to maximum practical utilization of the dump points. The effect of adding an additional crusher could be evaluated readily on the model.

Figure 4 gives total load and haul costs/ton versus the number of operating trucks in the system, for one, two, three and four shovels and for good and poor digging. The lowest operating cost condition is obviously one shovel with the maximum number of trucks below the beginning of saturation of the shovel. As other shovels are added, inter-
ference on shared haul roads will increase overall costs. This increase could obviously be used in some cases to justify additional haul road construction. As is evident in Fig. 3, for good digging there is no increase in production for four over three shovels. The costs of operating four shovels are higher of course, as indicated in Fig. 4. For poor digging the optimum cost does not vary greatly with the number of operating shovels but is much greater in each case than for good digging. The advantages of spending additional money on blasting procedures and control to achieve all good digging are apparent.

These are only a few of the valuable insights into a complex pit operating system that can be obtained using the simulation technique. When a simulation is based on operating data and procedures that truly represent those in the real situation, then it becomes a true working model on which major decisions can be based with confidence. As such it should play an essential part in every open pit planning operation.

Fig. 2. Shovel production and shovel-truck waiting time versus number of assigned trucks from 12-truck fleet.

REFERENCES


Fig. 3. Total loads per shift versus the number of operating trucks for good and for poor digging conditions.
Fig. 4. Loading and haulage costs per ton versus the number of operating trucks for good and for poor digging conditions.