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Truck Dispatching by Computer Simulation

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LKW-Einsatzsteuerung durch Computer Simulation
Contrôle de l'expédition des camions par simulation sur ordinateur
Simulación del despacho de camiones mediante un ordenador
コンピュータシミュレーションを利用した台車運搬
卡车运货的计算机模拟
تحميل الشاحنات باستخدام الاستقصاء بالحاسب الالكتروني

LKW-Einsatzsteuerung durch Computer Simulation

Der Beitrag beschreibt die Ergebnisse einer Computer-Simulationsstudie, in der der Einfluß einer vorgeschlagenen LKW-Einsatzsteuerung auf die Gesamtproduktivität eines bestehenden Tagebaues untersucht wurde.

In dieser Studie wurde der Tagebaubetrieb zuerst über einen Monat lang simuliert, auf der Basis der tatsächlichen und der berechneten LKW-Zeitpläne. Anschließend wurde der Betrieb mit LKW-Einsatzsteuerung nochmals gerechnet und mit den tatsächlichen Werten verglichen. Es ergab sich eine 10%ige Produktivitätserhöhung für den Fall der LKW-Einsatzsteuerung.

Contrôle de l'expédition des camions par simulation sur ordinateur

Cet exposé décrit les résultats d'une simulation sur ordinateur dans laquelle on a étudié l'impact de l'expédition des camions sur la productivité d'ensemble d'une mine pour une mine à ciel ouvert en cours d'exploitation. Le système existant a été comparé avec l'utilisation de l'expédition des camions. Les résultats montrent une amélioration substantielle de l'ensemble de la productivité avec contrôle de l'expédition; un gain d'environ 10% pour l'exploitation.

Simulación del despacho de camiones mediante un ordenador

Este artículo describe los resultados de un estudio realizado con un ordenador con el fin de investigar el impacto del despacho organizado de camiones en la productividad global de una mina a cielo abierto en explotación actual. Se simuló el sistema existente durante un periodo de un mes y se hicieron comparaciones con la explotación utilizando el nuevo sistema de despacho de camiones. Los resultados arrojan una mejora importante de una productividad total con el nuevo sistema de despacho organizado, con una mejora del 10% aproximadamente.

Summary

This paper describes the results of a digital computer simulation study in which the impact of the proposed truck dispatching on the overall mine productivity was investigated for an operating open pit mine.

In the study, the existing operation was first simulated for a one-month period, using both the actual time study data and the computed cycle times. By adjusting certain input parameters to the simulation program, the actual one month production was duplicated through simulation. Afterwards the operation was again simulated in the dispatch mode.

Comparison of the simulation results under the dispatch mode, with the initial base case simulation results, showed a definite improvement in overall productivity with dispatching; that is, approximately 10% gain for the operation. As expected, the results also showed that the extent of possible improvement did vary with the particular pit configuration being investigated.

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1. Introduction

Truck haulage is the most widely used means of transportation in an open pit mining operation, but is often the single most expensive process in a truck-shovel mining system. According to Michaelson (1974), truck-fleet productivity in open pit copper mines has the lowest improvement rate among the three major unit operations: drilling, loading and hauling. In addition, trucks require much labor, high maintenance and relatively frequent replacement making them sensitive to inflation. Most operating shovels experience either some insufficient or excessive truck capacity or a combination of both in truck-shovel mining systems. To meet required production with increasing depth of pit or changing ore-waste stripping ratios, additional equipment is required each year. As a result, management is faced with the problem of buying additional trucks or shovels if there is an improper balance of equipment in the mining operation. This problem usually results from inadequate use of haulage resources. Recent increases of the energy cost together with projected future increases will further increase truck-fleet capital and operating costs in the future. Therefore, it seems appropriate to test any strategy for optimizing truck-fleet performance.

The state-of-the-art in computing technology has advanced to a point where there are several truck dispatching systems which offer the potential of improved truck productivity and subsequent savings. Truck dispatching systems in the mining industry can solve the problem of inefficient use of resources by reducing waiting times in the haulage operation. Several open pit mines around the world have successfully implemented truck dispatching systems in their haulage Baron [1], Beaudoin, [2]; Crosson, Tonking, and Moffat, [3], Hobday, [4] Ibarra, [5]; Naplatanov, et.al., [9]; Naplatanov, Sgurev, and Petrov, [10]; Mueller, [8]; Schlosser, [12]. The ultimate question, of course, is whether the savings are sufficient to warrant the cost of such systems.

The effects of implementing a truck dispatching system in any mining operation can always be observed by physical implementation of the proposed system. This could be very costly. Computer simulation is probably the best tool that can be used to predict changes in system behavior for any contemplated changes to the existing system. This study investigated the impact on productivity by employing a truck dispatching system in an open pit mining operation.

2. General Steps in the Simulation Study

To obtain the end results of any simulation study, the following three basic tasks, as presented by Pritsker [11], should be performed:

1. Determine that the problem requires simulation.
2. Build and program a model to solve the problem.
3. Use the computer simulation program as an experimental device to solve the problem.

In Task One, the analyst is concerned with a possible mathematical solution to the problem under consideration. A system analysis of a truck-shovel open pit mining operation is usually far too complex to be conducted analytically. Therefore, it is safe to say that the problem requires simulation.

Task Two, consisting of building and programming a truck-shovel open pit mine operations model, was not performed since a Mine Operations Analysis Model developed by Kim and Dixon (1977), was available. The first two segments of this model are Haul-Cycle Simulation Program and GASP IV Open Pit Simulation Program.

Consequently, the main emphasis of this investigation was given to Task Three in which real data from an open pit mine were used to simulate stochastically the haulage under two different systems of truck control: one with a non-dispatching system and one with a dispatching system.

The real haulage system operates in a non-dispatching mode in which a certain number of trucks are assigned to each operating shovel throughout the entire shift unless a significant event occurs such as a shovel or truck breakdown. The proposed change to the real system is to operate in a dispatching mode. In a dispatching mode, the trucks will be allowed to serve different operating shovels throughout the entire shift. Each time a truck becomes empty, it is assigned from a dispatch point to the next available operating shovel or to the shovel that has been idle the longest.

In this study, the real system plays an important role as an integral part of the analysis because the parameters input to the simulator are first adjusted and validated by comparing the generated results with the real results of the system in a non-dispatch mode. When the non-dispatch simulation results appear representative of reality, the simulator is switched to operate in a dispatch mode. The results between non-dispatching and dispatching are compared. Consequently, the analyst relies heavily on comparative results between non-dispatching and dispatching rather than in advanced statistical techniques.

3. Data Collection, Analysis and Generation

Production and operating data needed for the study were obtained from a large mining operation which currently operates under a non-dispatching system of truck control. These data included the following:

1. Haulage road profiles and characteristics, i.e., distances, grades, rolling resistances, efficiencies, speed limits, right-of-way rules.
2. Equipment characteristics and availabilities, i.e., speed-rimpull curves, motor-current curves, mechanical availabilities, empty weights.
3. Field observations of shovel's loading time, truck's dumping time and load weights.
4. Pit configuration, equipment configuration and associated production during the time simulated.

The amount of data collected was considered sufficient to simulate the operation stochastically. Furthermore, access to a number of reports proprietary to the mining company made possible a more accurate adjustment and validation of input data later during the study.

Next, the obtained data were analyzed for their respective distributions.

3.1 Shovel Loading Time

The loading time observation starts when an empty truck begins backing up to the shovel and ends when the same truck starts on its way to an unloading point (or material destination). Because the operation currently utilizes a single truck type and a single shovel size, data from only one loading combination were collected. A total of 527 loading observations are grouped into the histogram shown in Fig. 1a. The shape of the histogram suggests that the loading time may be approximated by a lognormal distribution. Fig. 1b illustrates the histogram of transformed loading time data that confirmed the lognormality assumption.

3.2 Truck Dumping Time

Similarly, the dumping time observation starts when a loaded truck begins backing up to the dumping point and ends when the empty truck starts the return trip to a shovel. Three types of materials are mined in this operation: ore, waste and leach. Densities of ore and waste are 2.57 t/m^3 and 2.54 t/m^3, respectively. All unloading points present about the same dumping conditions. Therefore, it was considered valid to group all dumping observations in one having a single truck-shovel-material combination. The histogram of untransformed data (Fig. 1c) suggests that the 679 dumping time observations may also be approximated by a lognormal distribution. Fig. 1d shows the histogram of transformed dumping time data that also confirmed the lognormality assumption previously made.

3.3 Load Weights

Measurements of load weights were obtained from a field application weighing study performed by WABCO field applications engineering. Again, these data include a single combination of truck-shovel-material type in the mining operation. A total of 77 payloads was first analyzed in the study. Fig. 1e illustrates that grouped data in a histogram form. As may be noticed, this histogram presents suspicious underloading and overloading situations for the trucks (see left and right tails of histogram). Further investigation revealed a possible bias in the observed data. At the time of the

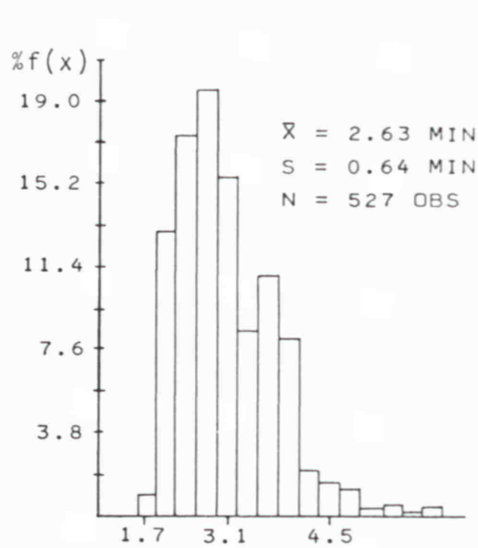

Fig. 1a: Loading Data

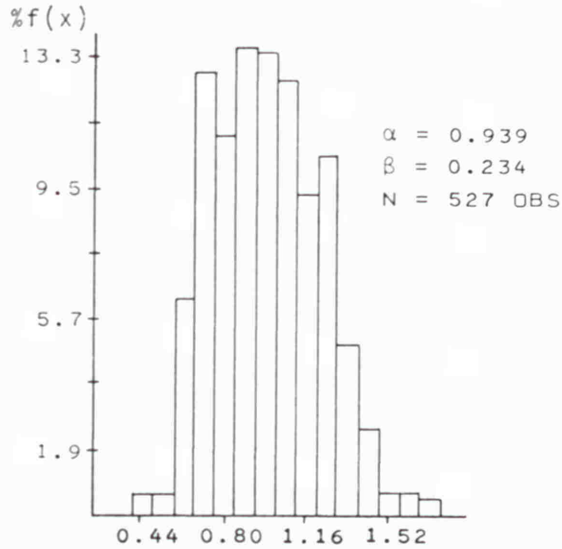

Fig. 1b: Transformed Loading Data

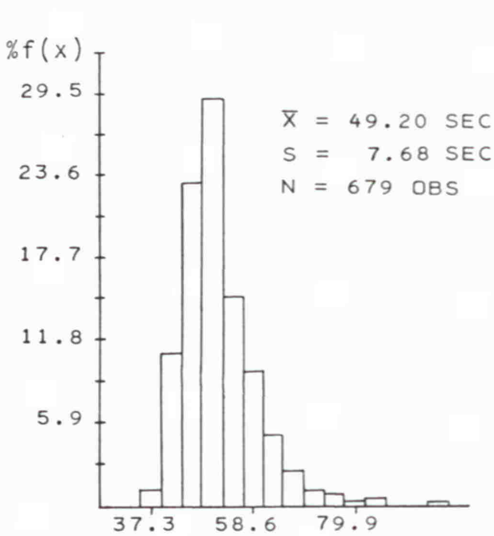

Fig. 1c: Dumping Data

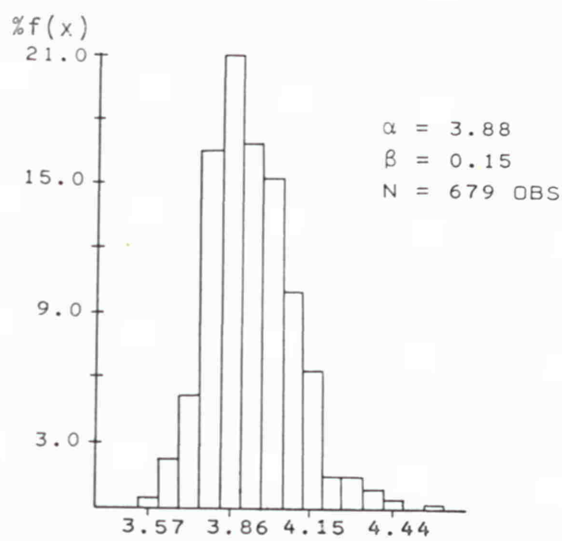

Fig. 1d: Transformed Dumping Data

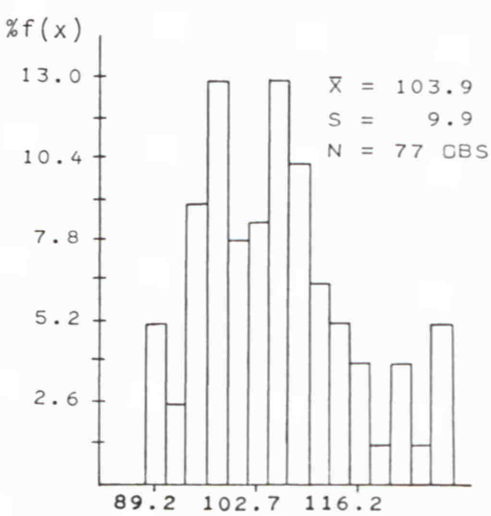

Fig 1e: Load Weight Data

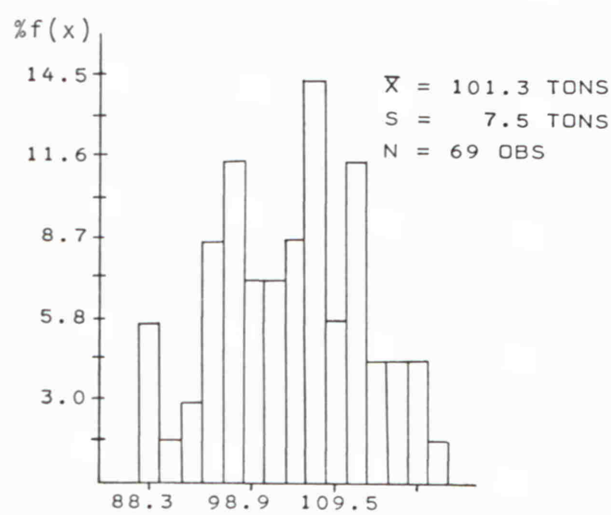

Fig. 1f: Reduced Load Weight Data

Fig. 1: Histograms of input data before and after transformation

weighing study, the operation had just returned to normal after a 3-month labor strike. As a consequence of that strike, most of the experienced shovel operators had been laid off. Consequently, new operators were on the shovels. This fact probably accounts for the obvious observed underloading and overloading of trucks. To correct for the bias in the load-weight data, a total of 11 high payloads were arbitrarily not included in the second load-weight analysis. Fig. 1f shows these grouped data, which suggests that the load weights are distributed normally.

To determine how well the assumed distributions fit the actual data, the Kolmogorov-Smirnov (K-S) test was performed on each set of data for goodness of fit. For each set, the 0.05 critical value of the K-S test was always greater than the K-S computed value, thus confirming the validity of each assumed distribution.

The analysis of the obtained data for their respective theoretical distributions was required because these distribution parameters are part of the input data to the Open Pit Mine Simulation Program which is the second segment of the Mine Operations Analysis Model.

3.4 Travel Time Generation

The travel times needed in the simulation study had to be calculated because the mining operation did not possess them. Knowing the exact amount and type of material to be mined at each shovel location and the respective material destination, it was easy to determine what travel times would be needed during the study. The use of a Haul Cycle Simulation Program (MCYCLE), which is the first segment of the mine operations analysis model, made possible the generation of travel times. This program uses the manufacturer's equipment performance characteristic curve and is designed to perform cycle time calculations in the discrete event simulation technique Pritsker [11]. The program considers the existence of switch-backs, interim stop points, and speed limits in the haul roads. This capability is possible by defining a set of velocity limits that overrides the truck's speed capabilities under appropriate situations. Other capabilities are the handling of multiple runs, deterministic or stochastic simulation, and generation of haul road profiles internally.

Next, the haulage roads were defined by breaking them into segments having equivalent characteristics as required by MCYCLE. A general layout of the segmented haulage roads in the mine being simulated is given in Fig. 2. By counting Node B3 twice because it appears in two haulage patterns, there are seven shovel locations (Nodes: D4, E2, C3, B3, N6 and N7) and four material destinations (Nodes: CRUSHER, LEACH, DUMP and RAMP).

A careful observation of the present pit and haul road configurations show that there are two well defined haulage traffic patterns in the pit (Fig. 2). The first pattern is located in what is called the north sector of the pit where three shovel locations exist (Nodes: N6, N7 and B3) with just one material destination (Node: RAMP). The second pattern covers the east, central and west sectors of the pit where there exists four shovel locations (Nodes: D4, E2, C3 and B3) and three material destinations (Nodes: CRUSHER, LEACH and DUMP). As mentioned earlier, travel times between each shovel location and its possible material destinations were calculated using the haul cycle simulation program.

The calculated results were always validated by comparing the *computed speeds* under various grades against the *actual speeds* of the trucks on the haulage roads of the mining operation. At first, it was noted that by allowing the trucks to go as fast as they could upgrade, the simulation results always underestimated the travel time. This result was probably due to such factors as the empirical truck manufacturer's speed-rimpull curve overestimating the performance of the trucks or unknown mechanical-electrical

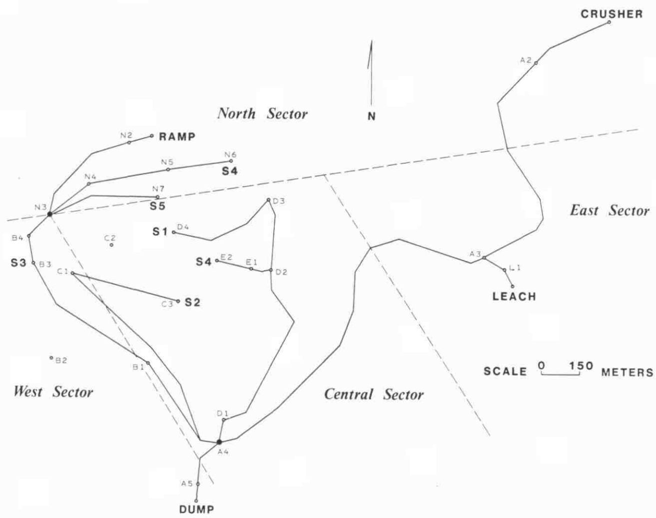

Fig. 2: Haul road layout

inefficiencies of the haulage units. To approximate the performance of the simulation model with the real system, the upgrade speed of the trucks was limited so that the *computed speeds* always matched the *real speeds* of the trucks on the mining operation. As a result of this adjustment, the *computed speeds* matched the *real speeds* under all conditions (level and incline) and the computed travel times were accepted as representing reality.

Because travel time distributions were required in the open pit simulation program, the multiple run capability of the haul cycle simulation program was utilized to obtain a distribution which approximated a normal distribution.

4. Simulation of Pit Configuration

To determine the impact on productivity of a dispatching system in the mine, the haulage operation was simulated first in a non-dispatch mode using the Open Pit Mine Simulation Program. The simulated results were next validated by comparing them with the results from the real system. If the two results did not match, certain adjustable parameters in the input data were varied and the haulage simulation using a non-dispatch mode was repeated. Only when the non-dispatch results were considered representative of reality was the haulage operation simulated in a dispatch mode and the differences between dispatching and non-dispatching observed.

At this point, it is important to note the presence of only one intersection in each haulage pattern mentioned earlier (Nodes: N3 for the north sector and A4 for the other sectors). Consequently, all trucks coming from any material destination have to pass one of these two points to get to any shovel location. These node intersections were, therefore, used as dispatch points in this study. In dispatching, trucks were assigned to the next available shovel.

During that month of operation which was being simulated in the study, some shovel either changed the location or handled the material from the same location but to different destinations. For example, shovel 4 began the month mining waste from Node N6 (North Sector) which was hauled to build a ramp on the north haulage road. By the middle of the month, the shovel was relocated at Node E2 (Central Sector) where ore was mined and was hauled to the crusher. Finally, by the 20th day of the month, this shovel started mining waste from the same location, which was hauled to the waste dump. As a result, six different cases involving various combinations between trucks and shovels had to be investigated separately during the operating month simulated.

As an example, one of the cases investigated is explained below. Pit configuration of this case is shown in Fig. 3a. There existed three shovels located at Nodes D4, C3 and B3 and two material destinations at CRUSHER and LEACH. Shovels 1 and 2 handled ore which was hauled to CRUSHER and shovel 3 handled waste which went to LEACH.

First, the non-dispatch mode was simulated. The output of the simulator included the total and daily ore and waste production and production statistics from each individual machine and from each location to which the material was hauled. Other outputs were statistics on truck and shovel down times and wait times.

The non-dispatch results were then compared with actual production of the real system, as shown below:

Production (metric tons)	Shovel 1	Shovel 2	Shovel 3
Actual	140,500	140,500	149,900
Simulated Non-dispatch	145,800	140,100	154,300

With less than a 4 % difference between actual and simulated production, the system simulation was considered representative of reality.

Next, the dispatch mode simulation was performed with the trucks allowed to serve any of the three shovels. The resulting production figures of each shovel are shown below:

Production (metric tons)	Shovel 1	Shovel 2	Shovel 3
Simulated Dispatch	148,500	159,600	171,300

Using the non-dispatch and dispatch output statistics as the basis for comparison of the two systems, dispatching improved productivity up to 14 % and reduced shovel and truck waiting times more than 30 %. Tables 1 and 2 show computer printouts for this illustrative case.

The same simulation procedures were used to determine the effects of dispatching in each one of the other five cases given in Fig. 3.

5. Analysis of Simulation Results

As discussed previously, the analysis relied heavily on comparative results between non-dispatching and dispatching. Furthermore, a decision was made to observe more closely the behavior of equipment waiting times with the introduction of dispatching in the haulage system. Any reduction of equipment waiting time means a possible production gain for the operation.

The results for each of the cases investigated showed a definite improvement in productivity with the dispatching system. Fig. 4, which summarizes the results, clearly shows this improvement. However, the extent of improvement varied with the particular pit configuration of each case. For instance, if the pit configuration contained a combination of long and short hauls (Cases a, b and c in Fig. 3) dispatching was definitely better than non-dispatching. When the pit configuration contained only long hauls or only short hauls (Cases d, e and f in Fig. 3), dispatching still showed a significant improvement over non-dispatching; however, the extent was not as great as in the combination of long and short hauls. Fig. 5 illustrates the equipment waiting time of the experimental results. A straight line connection between points on the plots does not mean fractional trucks from point to point. This connection merely helps to distinguish between the non-dispatching and dispatching results of the simulation. Furthermore, the position of the operating shovels was arranged in such a way that the shovel nearest the dispatch point starts from the left on these figures.

As expected, dispatching considerably reduces equipment waiting time. In addition to the overall reduction in truck-fleet waiting time, dispatching also reduces variability by evenly distributing the waiting time between the trucks.

From Fig. 5a and 5b, it is apparent that shovel 3 is overtrucked and the other two shovels are undertrucked during non-dispatching. In contrast, truck waiting time was evenly distributed among the trucks with the use of dispatching, and there was a reduction in shovel waiting time. However, the extent of reduction varied greatly depending on the length of travel from the dispatch point to the shovel locations. The more distant shovels seem to accumulate shovel waiting time more than the nearer ones. All the figures show a substantial reduction in equipment waiting time with dispatching. In Fig. 5c and 5d, however, non-dispatching seems to do as good a job as dispatching in terms of reducing the variability in waiting time for the equipment. Again, in these two pit configurations the most distant shovels accumulated a little more idle time than the shovels nearer the dispatch point.

The effects of dispatching on equipment waiting time for Cases e and f (Fig. 5e and 5f) are similar to the one obtained in Cases a and b (Fig. 5a and 5b) in that one of the two shovels is overtrucked. Notice that dispatching evenly distributed the waiting time among the trucks. In both pit configurations, shovel 5 accumulated substantial idle time with non-dispatching, but dispatching substantially reduced the amount of idle time for this shovel even though the other shovel maintained the same amount of idle time in both non-dispatch and dispatch simulations. Again, the more distant shovel accumulated more idle time than the one nearer the dispatch point.

Reduction of equipment idle times was achieved with the introduction of dispatching in all cases studied. However, the

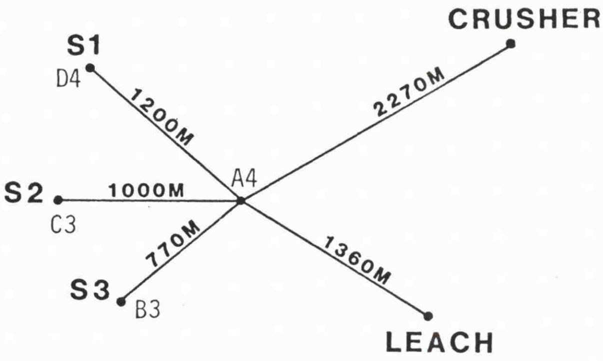

Figure 3a.

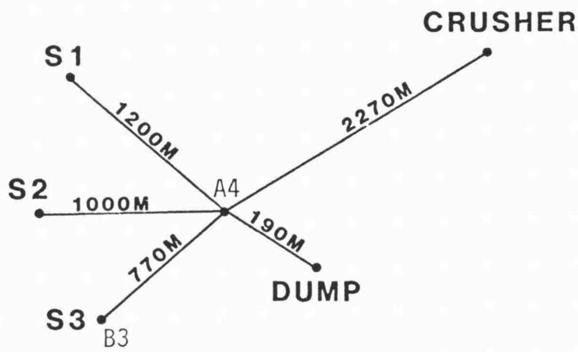

Figure 3b.

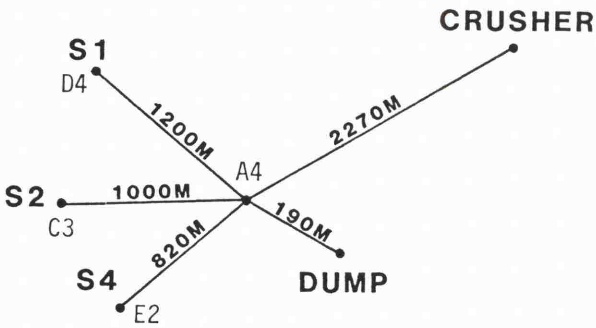

Figure 3c.

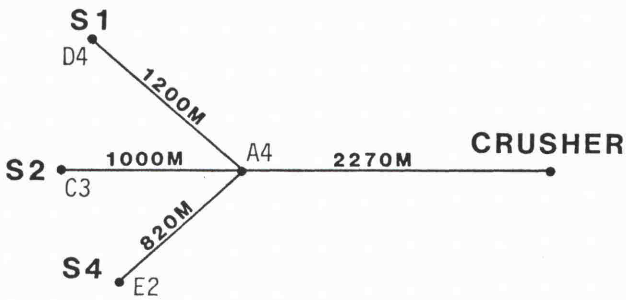

Figure 3d.

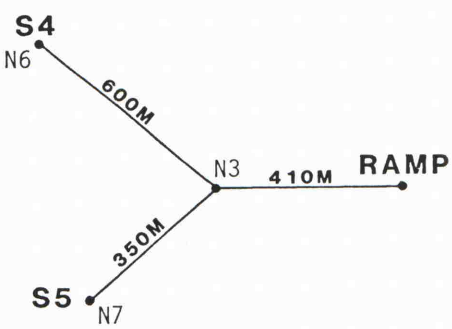

Figure 3e.

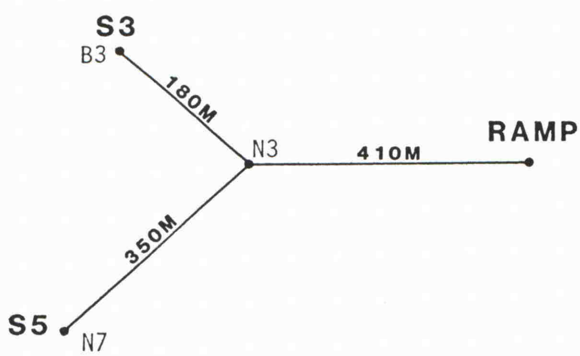

Figure 3f.

Fig. 3: Pit configuration of cases studied

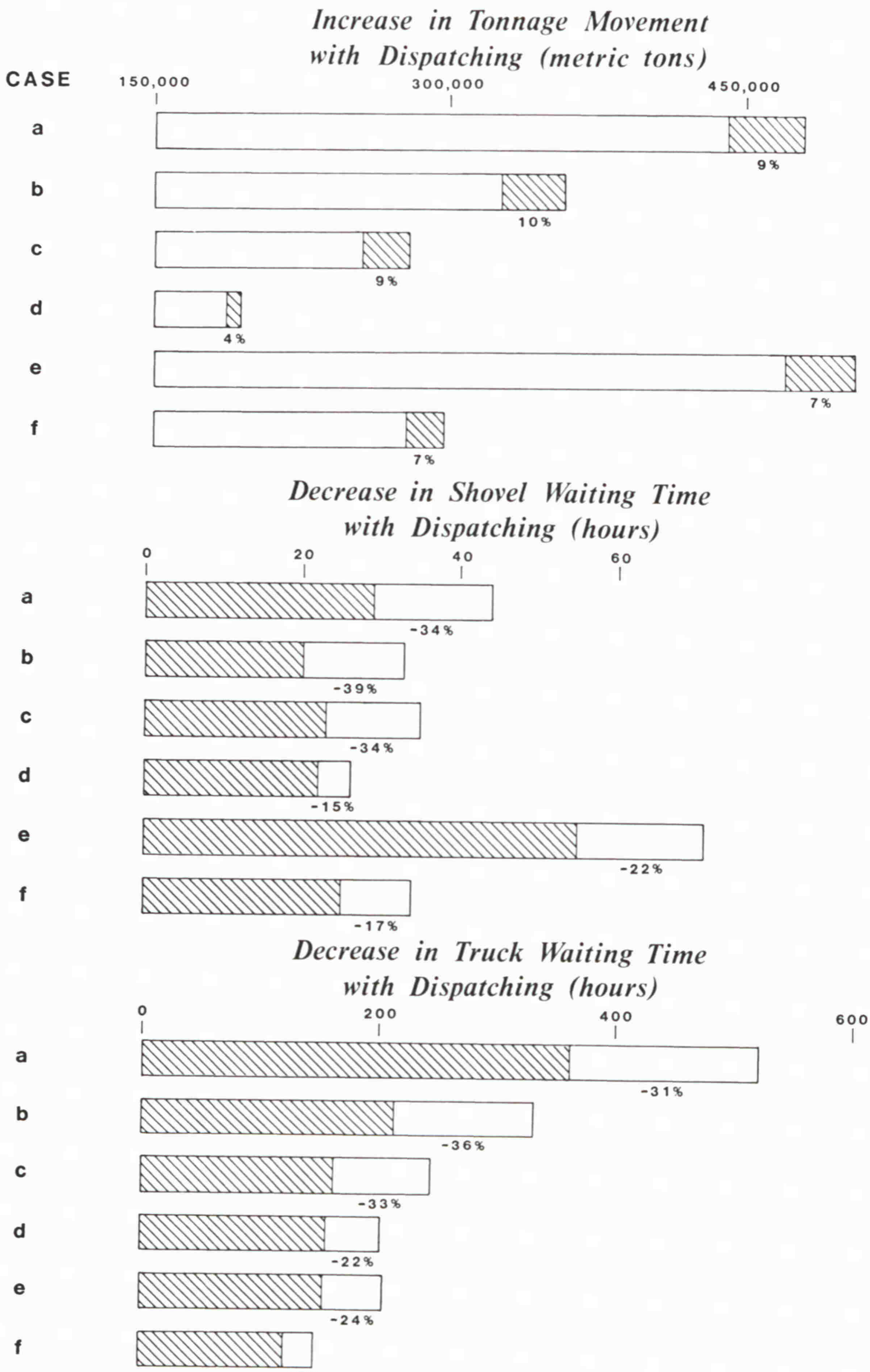

Fig. 4: Summary of simulation results for the 6 cases investigated

—— Nondispatching
---- Dispatching

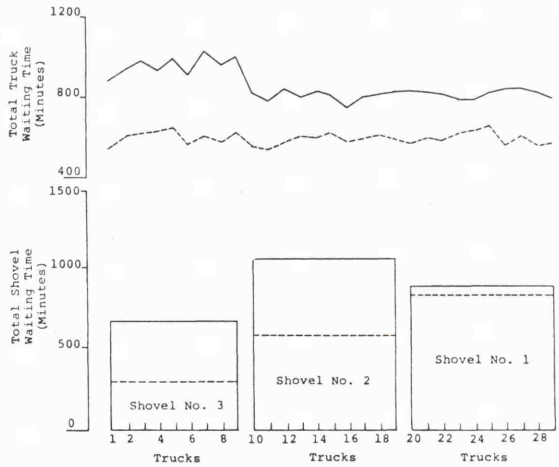

Figure 5a
(For Pit Configuration of Figure 3a)

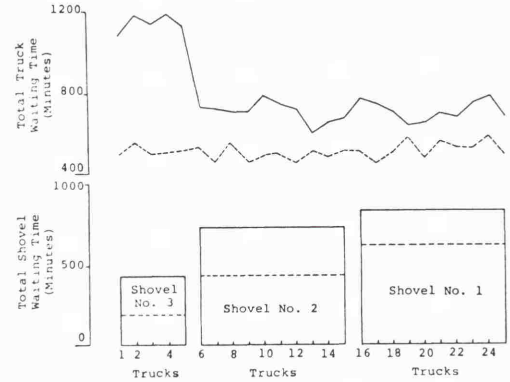

Figure 5b
(For Pit Configuration of Figure 3b)

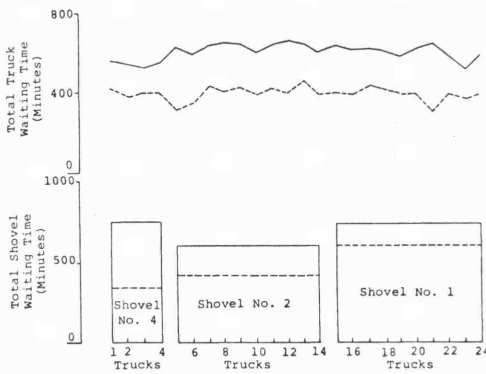

Figure 5c
(For Pit Configuration of Figure 3c)

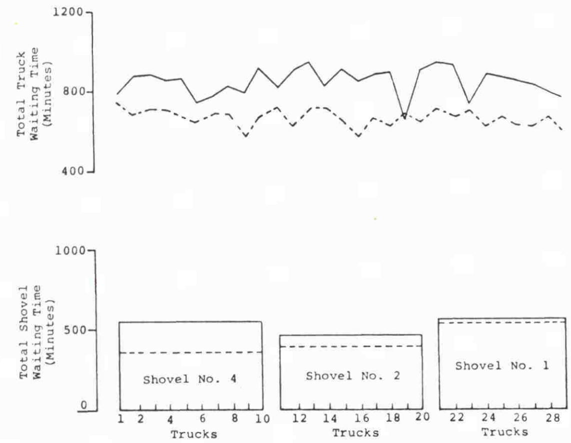

Figure 5d
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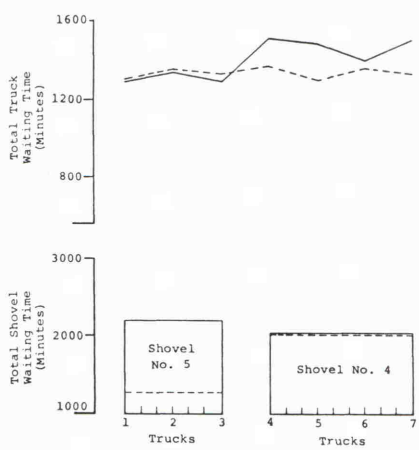

Figure 5e
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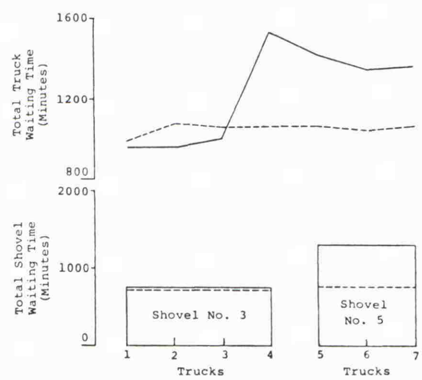

Figure 5f
(For Pit Configuration of Figure 3f)

Fig. 5: Equipment waiting times under nondispatching and dispatching

RESULTS OF SIMULATION RUN 1

ORE PRODUCTION DURING SIMULATION (TONS)	=	285950.
WASTE PRODUCTION DURING SIMULATION (TONS)	=	154343.
TOTAL SHOVEL WAITING TIME (MIN.)	=	2635.
TOTAL TRUCK WAITING TIME (MIN.)	=	31214.
TOTAL TRUCK QUEUING TIME ON HAUL ROAD	=	0.
TOTAL NO. OF TRUCKS LOADED	=	4351.

INDIVIDUAL SHOVEL STATISTICS:

SHOVEL	TOTAL ORE (TONS)	DAILY ORE (TONS)	TOTAL WASTE (TONS)	DAILY WASTE (TONS)	TOTAL ON TM (MIN)	DAILY ON TM (MIN)	TOTAL WT TM (MIN)	DAILY WT TM (MIN)
1	145820.	24303.	0.	0.	926.3	154.	911.	152.
2	140130.	23355.	0.	0.	930.4	155.	1059.	177.
3	0.	0.	154343.	25724.	931.8	155.	664.	111.

INDIVIDUAL TRUCK STATISTICS:

TRUCK	TOTAL ORE (TONS)	DAILY ORE (TONS)	TOTAL WASTE (TONS)	DAILY WASTE (TONS)	TOTAL ON TM (MIN)	DAILY ON TM (MIN)	TOTAL WT TM (MIN)	DAILY WT TM (MIN)
301	13364.	2227.	0.	0.	1340.3	223.	983.	164.
302	13274.	2212.	0.	0.	1331.9	222.	1023.	170.
303	13126.	2188.	0.	0.	1319.8	220.	1047.	175.
304	13142.	2190.	0.	0.	1300.7	217.	1071.	178.
305	13516.	2253.	0.	0.	1281.4	214.	1041.	174.
306	13420.	2237.	0.	0.	1299.0	217.	989.	165.
307	13311.	2218.	0.	0.	1361.2	227.	994.	166.
308	13327.	2221.	0.	0.	1333.2	222.	1019.	170.
309	13218.	2203.	0.	0.	1343.9	224.	1041.	173.
310	13047.	2174.	0.	0.	1355.9	226.	1042.	174.
311	13982.	2330.	0.	0.	1313.8	219.	1043.	174.
312	13912.	2319.	0.	0.	1331.8	222.	1017.	169.
313	13914.	2319.	0.	0.	1377.5	230.	1003.	167.
314	14152.	2359.	0.	0.	1376.9	229.	938.	156.
315	13997.	2333.	0.	0.	1337.8	223.	1010.	168.
316	14023.	2337.	0.	0.	1332.8	222.	1045.	174.
317	13991.	2332.	0.	0.	1347.0	225.	1006.	168.
318	13972.	2329.	0.	0.	1308.7	218.	1056.	176.
319	14259.	2377.	0.	0.	1320.5	220.	985.	164.
320	13927.	2321.	0.	0.	1330.8	222.	1039.	173.
321	0.	0.	19080.	3180.	1344.1	224.	1268.	211.
322	0.	0.	19525.	3254.	1335.4	223.	1193.	199.
323	0.	0.	19085.	3181.	1331.0	222.	1277.	213.
324	0.	0.	19477.	3246.	1369.7	228.	1154.	192.
325	0.	0.	19347.	3224.	1304.3	217.	1249.	208.
326	0.	0.	19712.	3285.	1331.0	222.	1177.	196.
327	0.	0.	18939.	3156.	1380.2	230.	1230.	205.
328	0.	0.	19179.	3196.	1371.5	229.	1175.	196.
329	13075.	2179.	0.	0.	1332.7	222.	1099.	183.

Table 1: Non dispatching cases computer printout

RESULTS OF SIMULATION RUN 1

ORE PRODUCTION DURING SIMULATION (TONS)	=	308144.
WASTE PRODUCTION DURING SIMULATION (TONS)	=	171307.
TOTAL SHOVEL WAITING TIME (MIN.)	=	1724.
TOTAL TRUCK WAITING TIME (MIN.)	=	21662.
TOTAL TRUCK QUEUING TIME ON HAUL ROAD	=	0.
TOTAL NO. OF TRUCKS LOADED	=	4732.

INDIVIDUAL SHOVEL STATISTICS:

SHOVEL	TOTAL ORE (TONS)	DAILY ORE (TONS)	TOTAL WASTE (TONS)	DAILY WASTE (TONS)	TOTAL ON TM (MIN)	DAILY ON TM (MIN)	TOTAL WT TM (MIN)	DAILY WT TM (MIN)
1	148533.	24755.	0.	0.	929.0	155.	860.	143.
2	159611.	26602.	0.	0.	882.2	147.	604.	101.
3	0.	0.	171307.	28551.	934.9	156.	260.	43.

INDIVIDUAL TRUCK STATISTICS:

TRUCK	TOTAL ORE (TONS)	DAILY ORE (TONS)	TOTAL WASTE (TONS)	DAILY WASTE (TONS)	TOTAL ON TM (MIN)	DAILY ON TM (MIN)	TOTAL WT TM (MIN)	DAILY WT TM (MIN)
301	11568.	1928.	4926.	821.	1345.9	224.	720.	120.
302	10867.	1811.	5876.	979.	1354.8	226.	703.	117.
303	9867.	1644.	6737.	1123.	1352.3	225.	761.	127.
304	10402.	1734.	6013.	1002.	1360.0	227.	706.	118.
305	10714.	1786.	5318.	886.	1325.4	221.	834.	139.
306	10512.	1752.	5947.	991.	1343.3	224.	807.	135.
307	10161.	1693.	6497.	1083.	1336.7	223.	777.	130.
308	11295.	1882.	5104.	851.	1326.6	221.	740.	123.
309	11100.	1850.	5167.	861.	1356.4	226.	746.	124.
310	11285.	1881.	5001.	833.	1363.8	227.	721.	120.
311	10830.	1805.	5725.	954.	1328.8	221.	752.	125.
312	10039.	1673.	6886.	1148.	1347.1	225.	768.	128.
313	9863.	1644.	6954.	1159.	1345.5	224.	751.	125.
314	10716.	1786.	6063.	1011.	1387.8	231.	676.	113.
315	10615.	1769.	5721.	954.	1331.9	222.	782.	130.
316	10514.	1752.	5704.	951.	1389.7	232.	759.	127.
317	9758.	1626.	6985.	1164.	1330.6	222.	767.	128.
318	10651.	1775.	5816.	969.	1348.7	225.	730.	122.
319	11110.	1852.	5788.	965.	1340.3	223.	691.	115.
320	10243.	1707.	7068.	1178.	1342.0	224.	691.	115.
321	9741.	1623.	6937.	1156.	1364.6	227.	777.	129.
322	10123.	1687.	6630.	1105.	1341.5	224.	723.	121.
323	10783.	1797.	5867.	978.	1323.9	221.	759.	126.
324	11337.	1890.	4848.	808.	1365.8	228.	722.	120.
325	10083.	1681.	6437.	1073.	1351.9	225.	821.	137.
326	10521.	1754.	6195.	1032.	1317.2	220.	775.	129.
327	11130.	1855.	4746.	791.	1342.9	224.	781.	130.
328	10606.	1768.	5486.	914.	1370.9	228.	750.	125.
329	11712.	1952.	4865.	811.	1343.8	224.	673.	112.

Table 2: Dispatching case computer printout

extent of reduction also varied with the particular pit and equipment configuration. If the shovels presented under-trucking or overtrucking conditions, dispatching balanced the truck-to-shovel ratio by evenly distributing idle time between the pieces of equipment. In addition, dispatching controlled variability of truck waiting times in some of the cases studied. The shovels farthest from the dispatch point accumulated more idle time than the nearer ones. This result can be explained by the differences in travel times. If a truck is dispatched to a nearby shovel and another to a more distant shovel at the same time, the nearer shovel will accumulate less idle time than the far one.

6. Conclusions

This study has shown that a truck dispatching system gives greater productivity than a non-dispatching system for this particular mining operation. The simulation results clearly show about a 10% improvement in truck-shovel productivity with dispatching. A 10% gain in productivity in this mining operation is equivalent to half the production of eight 109t trucks and one 16yd³ shovel under the present non-dispatching system or about 200,000t/month.

Analysis of the experiment results showed that combinations of long and short hauls are the most favorable to improvement with dispatching. Most open pit mining operations have combinations of long and short hauls, so they should find it advantageous to adopt a truck dispatching system for their haulage systems. On the other hand, the results revealed that if the hauls are of equal length, dispatching still produces substantial improvement in productivity over non-dispatching. Therefore, operations with these conditions, also, may find it advantageous to implement such system. In addition, the results show that use of dispatching reduces waiting time variability for the mining system under study. Most mining operations recognize that variability in waiting time reduces production. Variability is a natural consequence of complex systems and/or a consequence of inadequate planning, and can be reduced by dispatching.

In any open pit mine, the haulage operation will probably become more and more complicated year after year because of longer hauls and acquisition of more equipment. Therefore, it is likely that dispatching systems would have a greater impact on productivity later in the life of a mine.

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