Design and Implementation of a Semi-automated Truck/Shovel Dispatching System

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This paper describes the design and implementation of the dispatching system at LAB Chrysotile Inc.’s Black Lake Mine Operation, Quebec, Canada. The initial system uses a computer in a passive role, to record and display information in ongoing operations. Simulation studies were undertaken at McGill University to assess various heuristic dispatching rules which can be programmed and inserted into the dispatching system. The computer can then suggest to the operator where a truck should be sent to maximize productivity or improve fleet efficiency.

The study stresses the importance of considering the effects of implementing computerized systems on those individuals who must use these systems in their daily work. The roles of individuals from the industry and the university in this joint project are also highlighted.

Introduction

Truck/shovel operations are undoubtedly the major form of materials handling system used in open-pit operations throughout the world. Substantial progress has been made in alternative forms, most recently involving to a greater extent continuous systems. Nevertheless, truck/shovel systems will continue being important materials handling systems throughout this century.

Haulage costs in truck/shovel systems constitute a major portion of total expenditures. Costs have been reduced in the past by improving machinery performance, machinery reliability, operating procedures and increasing unit capacities to achieve economies of scale. One can only expect marginal cost reductions to be achieved by these methods in the future. Potentially larger savings can be realized by closer dynamic control of the on-going process. This goal can be only partly fulfilled by a ‘human’ supervisor: computer monitoring and control is indicated as a method of increasing fleet productivity and efficiency.

Investment in a computerized dispatching system is rapidly recovered by increasing productivities. Large systems developed in the late 1970s have been proved successful in large mining operations but cannot be economically justified for small to medium size operations. Fortunately, there have been tremendous decreases in computer hardware costs since the early 1980s, simultaneous with greater emphasis being placed on increasing mine productivity due to poor mineral commodity markets. Micro-computers have been well accepted by the mining industry.

Many of the features of expensive, fully automated dispatching systems can be incorporated into micro-computer based semi-automated systems. Accepting specific limitations, the computer system can assist a dispatcher in compiling production statistics and monitoring operations as well as suggest truck allocations for routine decisions. The Black Lake dispatching system is micro-computer based and is now being transformed from a passive system to one which can suggest truck allocations to increase fleet productivity and efficiency.

Dispatching systems

There are three principal types of dispatching systems in use in open-pit operations.

Manual dispatching

Since the early 1960s two-way radio communications have been used to keep dispatch operators in contact with production and support equipment personnel. Often manual dispatching systems involve operating trucks in ‘fixed’ or ‘locked-in’ dispatching; trucks are assigned to specific shovels for the duration of the shift and are only changed when equipment failure arises.

Mueller demonstrates the use of a dispatching board, used as an analog computer, to help dispatch operators keep track of truck locations and guide the operator for improving dynamic truck assignments.
Semi-automatic dispatching
In this form of dispatching the dispatch operator continues to communicate truck destinations directly to the operators based on information received by radio. The computer can simply record and display current information — passive role — or be programmed to suggest to dispatch operators ‘best’ assignments.

The system previously used at Bougainville Copper Ltd. (Swain) is an active system which recommends action to be taken throughout the shift. Hodson and Barker describe the upgrading of a semi-automated system from ‘passive’ to ‘active’ and detail an elaborate procedure tailor-made for their mining operation. Although the authors are aware of a few other semi-automated systems in operation, there are surprisingly few publications describing them. The system in use at Black lake since 1982 is semi-automated, soon to be upgraded from ‘passive’ to ‘active’.

Fully automated dispatching
No human intervention is necessary during routine operations with a fully-automated dispatching system. A mini- or mainframe computer is in communication with equipment, receiving status information and transmitting assignments. Numerous publications describe these systems: White et al., Byles, Crosson et al., Hagenbuch to name but a few. All of these systems have specific methods of deciding on best truck assignments. Dispatching procedures range from simple relative priority rules to solving linear programming-network flow formulations or, more recently, a three-part procedure involving consideration of long-term objectives, non linear programming and the classic assignment problem described by Soumis et al.

A fully-automated system is without doubt the best method of monitoring and controlling a production fleet. The system can virtually become a ‘mine management system’ and with dispatching procedures that have achieved a high degree of sophistication human intervention is seldom warranted. Unfortunately, a fully automated system requires a high capital outlay, ranging from $0,5 M to $3,6 M (US 1983 $s) according to Arnold and White.

This cost would include a mini-computer (at least) and electronic hardware capable of withstanding rugged con-

![Figure 1. Simplified main screen display of dispatching system](image)
A semi-automated truck/shovel dispatching system

The Black Lake dispatching system

The Black Lake Operation of LAB Chrysotile Inc. is a medium-size open-pit asbestos mine located in Black Lake, Quebec, Canada. Materials handling capacity is about 46 000 mt (ore and waste) per day. Mixed fleets of loaders and haulers have been used in the past: 4.5 and 11 cu.yd shovels, 10 and 11 cu.yd loaders, 45, 85 and 100 ton trucks. The Black Lake Operation was shared by all.

A Hewlett Packard 9845C was purchased in 1982. High resolution of the colour monitor was an important factor in the selection of this computer. The project was internally sponsored (by A. Leclerc) and all the software developed in-house. The success of the initial system is strongly attributable to this fact. At that time there was no other operating dispatching system based on such a small (187 K byte RAM) computer. The initial goal set was to develop a 'passive' system which could display materials handling machinery status and automatically produce (reliable) daily production reports.

From the outset the system was tailor-made for specific use at the Black Lake mine, with all the specific work procedures (idiosyncrasies) of a mine in production for nearly 30 years. Caution was exercised in presenting the system to the mine operators since it was their first exposure to computers. While the system was being developed, it was seen to that dispatch operator suggestions were rapidly implemented — insuring that a sense of participation was shared by all.

Figure 1 illustrates the main screen display, the most important feature of the 'graphic system', which appears throughout the shift. The dispatch operator knows all equipment status and approximate locations from one glance of the main screen display. Instead of a plan view representation, necessitating constant updating as haulage configurations are modified, a summary board-type of display was selected. Where the program indicates truck and shovel activity is available for the next assignment. Certain complexities were shared by all.

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The dispatcher uses the information displayed to reallocate trucks to shovels when shovel moves, shovel breakdowns, coffee breaks, lunches, etc. occur during the shift. Inasmuch as possible, trucks operate with a designated shovel for the shift (based on production schedule requirements) during routine operations. This policy relieves the dispatcher of constantly reassigning trucks so he can devote greater attention to the special circumstances which arise.

A menu at the bottom of the screen allows the dispatcher to switch to other screen displays by hitting dedicated function keys on the keyboard. When the program system is loaded, only numeric and function keys can be used as the dispatcher need not worry about inadvertently hitting the wrong key and crashing the system. The other screen displays show the production report information being compiled throughout the shift. The dispatcher can verify individual equipment performance and spot unusual trends. At the end of the shift, hard copy reports are printed showing productions, scheduled and unscheduled breaks, fuel reports, etc.

All of the operations were very satisfied with the system and it was demonstrated that the 'passive' system increased fleet production by approximately 5%, easily justifying a relative small capital outlay in less than one year. The logical step in improving the system is to make it 'active', to suggest to dispatchers 'best' truck assignments. Caution was to be exercised since any rejection from the operators would render the effort useless. The research component of this task was undertaken in collaboration with McGill University.

Simulation studies

A stochastic simulation program was developed in order to test, in a controlled environment, the effects of various dispatching procedures on fleet productivity and utilization. This approach is well indicated and several publications attest to the success of this method (Kim and Ibarra, Brake and Chatterjee, Wilke and Heck, Tu and Hucka, to name but a few). It was felt essential to use statistical distributions to represent activity times since the stochasticity of the real process is often the cause of the imbalances which occur during operations.

Figure 2 illustrates the general structure of the simulation program. An 'advance-clock' approach was adopted since dispatching procedures can easily be inserted into the 'second-by-second viewing' the program performs. The actual dispatching procedures tested are only visible in a single subroutine (DECISION) called when a truck is available for the next assignment. Certain complexities of the real operating system were not incorporated, bearing in mind that the objective was restricted to verifying results achieved on average with specific procedures. The impact of these simplifications was subsequently discussed when considering implementation of the procedures in the real system.

Dispatching procedures

From a purely scientific point of view the study of dispatching procedures is intellectually stimulating for individuals involved in Operations Research. Numerous at...
Attempts have been made at applying a multitude of O.R. techniques (heuristic rules, queueing theory, linear, non-linear and dynamic programming, etc.) and simulation is employed to study the procedures. In addition, the procedures must be implemented on real systems and be accepted by the operators using the results.

Most of the dispatching procedures were analyzed in the research done at McGill University. However it was decided to restrict the in-depth study to three relatively simple heuristic decision rules: maximize truck, maximize shovel and match factor. The study was restricted in this way for two reasons. Firstly, the computer capabilities at the mine precluded implementation of sophisticated procedures. Secondly, in view of the system development to date, only a suggestion was required by the computer: it could not replace the operator's intuitive abilities to consider certain factors influencing his decisions which cannot be translated into computer code. A simpler procedure which the dispatcher could easily understand had a greater chance of being accepted.

Maximize truck
This procedure involves constantly reassigning trucks, when available, to the shovel where it is most likely to
FIGURE 3. Maximize truck dispatching rule

FIGURE 4. Maximize shovel dispatching rule
be loaded first. It is a simple heuristic procedure which does not guarantee optimality since assignments are based on average conditions and future events (i.e. the next ‘n’ trucks to be assigned) are not considered. Figure 3 schematizes the decision process involved. Each time a truck is available calculations are performed, based on averaged values, to determine at which shovel a truck can be served first; travel times of empty trucks en route, trucks waiting and trucks being served must be considered for each shovel.

The maximize truck rule will produce substantial increases in total productivity compared to fixed dispatching, compensating for slow shovels by avoiding long waiting lines. However, shovel utilization is disbalanced because the procedure favors truck assignments to shorter circuits as stated by Tu and Hucka. Also, productivity is undifferentiated and specific desired production objectives, such as grade requirements and waste/ore ratios, are not accounted for. Hagenbuch attempts to compensate for this shortfall in an operating system by adding relative priority values to individual shovels.

Maximize shovel
This procedure dictates available truck assignment to the shovel which has been waiting the longest or expected to be idle next. Figure 4 schematizes the decision process involved. In this case truck travel to each shovel is not considered and the criterion adopted in case of conflicts is to allocate the truck to the shovel which has been idling the longest to best reflect the underlying intent of the procedure. A more uniform shovel utilization is expected with this procedure. A variation of the maximize shovel rule is used in Ebasco’s Automated Truck Dispatch (Sassos).

**Match factor**
Match factor (MF) is a dimensionless number which attempts to quantify the apparent balance which exists between the number of loading devices and the number of haulage devices in a system. It can be computed by:

\[ MF = \frac{\text{(No. of haulers)} \times \text{(Loader cycle time)}}{\text{(No. of loaders)} \times \text{(Hauler cycle time)}} \]

The cycle times in either case do not include any waiting time at the loading area for either unit. A MF below 1.0 indicates under-trucking, MF greater than 1.0 means system over-trucking.

The MF is used as a dispatching procedure by measuring MF values for sub-systems or individual shovels and assigning trucks accordingly in various ways. MF values have been applied explicitly in dispatching decisions by Swain and Hodson and Barker. Other authors have applied variations of the MF procedure, referring to it simply as a ‘shovel coverage’ rule. In this simulation study the procedure consisted in computing current MF values based on the last five event times for each cycle. Current MF values are compared to desired coverage, and the shovel with the lowest ratio is selected. Similar to the maximize shovel procedure, the MF rule tends to produce uniform shovel utilization.

**TABLE 1. summary of input data**

<table>
<thead>
<tr>
<th>Shovel number</th>
<th>Dump number</th>
<th>Travel time empty</th>
<th>Travel from other dumps</th>
<th>Travel time full</th>
<th>Initial truck assignment for 13 to 21 trucks</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
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<td>1</td>
<td>1</td>
<td>5.00</td>
<td>D2 – 7,15 D3 – 7,47</td>
<td>6,34</td>
<td>2</td>
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<tr>
<td>2</td>
<td>1</td>
<td>7,27</td>
<td>D2 – 12,24 D3 – 9,87</td>
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<td>2</td>
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<tr>
<td>3</td>
<td>2</td>
<td>6,20</td>
<td>D1 – 5,79 D3 – 8,25</td>
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<td>2</td>
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<tr>
<td>4</td>
<td>2</td>
<td>7,10</td>
<td>D1 – 9,64 D3 – 12,24</td>
<td>11,99</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>6,71</td>
<td>D1 – 4,25 D2 – 13,11</td>
<td>9,55</td>
<td>3</td>
</tr>
</tbody>
</table>

Duration of simulations: 400 minutes
Travel empty coefficient of variance: 0,10
Travel full coefficient of variance: 0,11
Average dump time = 0,74 minutes
Load parameters (Weibull): ALPHA = 1,475 BETA = 2,344 GAMMA = 2,150
Dump parameters (Weibull): ALPHA = 1,730 BETA = 0,232 GAMMA = 0,534

**NOTE:** Crusher is dump point number 1
North Dump is dump point number 2
South Dump is dump point number 3
Simulation results
Several simulations were performed to assess the effects of the dispatching procedures on fleet productivity and individual shovel productivity and utilization. The case study presented below is typical of these analyses. Because of the stochastic nature of the process it was necessary to base conclusions on average values, thus requiring several simulation program runs to obtain representative values.

Table 1 is the summary of the input data required for 400 simulation program runs. The initial truck assignments indicated in the table are used throughout the shift for the 'fixed' dispatching rule. It was decided to compare results to fixed dispatching since the intricacies of the real production system (including dispatcher decisions) could not be integrated into the simulation program. Travel times to and from shovels were modelled with normal distributions. To approximate the effects of such perturbations another study was accomplished using the data presented in Table 1. Table 3 summarizes the results of simulations in which travel time distributions are modified another study was accomplished using the data presented in Table 1. Table 3 summarizes the results of simulations in which travel time distributions are modified.

A summary of the simulation results is presented in Table 2. A range of 13 to 21 trucks was examined for fixed dispatching shown in Figure 7 which illustrates the maximum difference in shovel production encountered. For this purpose, the MF rule is more efficient than the maximize shovel rule. The irregularities of values for fixed dispatching shown in Figure 7 indicate the problem associated with being limited to 'integer' numbers of trucks assigned to shovels for entire shifts.

In all of the previous examples the activity times were only allowed to vary within the bounds of specific distributions. Since the fixed dispatching assignments were based on average values of these distributions, the full potential of the dispatching procedures could not be ascertained. In normal operations several occurrences can modify activity times, such as shovels experiencing difficulties in loading or sudden deterioration of haul road surfaces. To approximate the effects of such perturbations another study was accomplished using the data presented in Table 1. Table 3 summarizes the results of simulations in which travel time distributions are modified after half a shift. These results show that the 'active' rules cannot do. A dispatcher may not notice (and take adequate action concerning) these changes occurring during a shift until much later than the computer which can consistently monitor activity times and update with 'moving averages'.

A SEMI-AUTOMATED TRUCK/SHOVEL DISPATCHING SYSTEM

<table>
<thead>
<tr>
<th>Number of trucks</th>
<th>Dispatch rule*</th>
<th>Total production (tonnes)</th>
<th>Standard deviation</th>
<th>Average truck idle time (min.)</th>
<th>Shovel production (tonnes)</th>
<th>Shovel idle (min.)</th>
<th>Shovel idle (tonnes)</th>
<th>Total shovel idle (tonnes)</th>
</tr>
</thead>
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<td></td>
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<tr>
<td>13</td>
<td>A</td>
<td>168</td>
<td>111</td>
<td>3978</td>
<td>2163 2967 5032 4484</td>
<td>199</td>
<td>283 247 140 166</td>
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<tr>
<td></td>
<td>B</td>
<td>20056</td>
<td>15,9</td>
<td>5332</td>
<td>1335 5762 1175 6452</td>
<td>136</td>
<td>335 114 341</td>
<td>81 1007</td>
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<td>C</td>
<td>18517</td>
<td>6,9</td>
<td>4848</td>
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<td>161</td>
<td>240 186 246 252</td>
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<td>13,1</td>
<td>3366</td>
<td>2899 3957 3506 3770</td>
<td>229</td>
<td>255 208 228 211</td>
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<td>15</td>
<td>A</td>
<td>20898</td>
<td>11,7</td>
<td>3965</td>
<td>4225 4365 3821 4522</td>
<td>197</td>
<td>182 173 201 168</td>
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<td>18,9</td>
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<td>6537</td>
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<td>135 649</td>
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</table>

*Dispatching rules: A = Locked-in, B = Maximize Truck, C = Maximize Shovel, D = Match Factor
System integration and future research
Based on the results of the research project it was decided to integrate the dispatching rules into the semi-automated system. Although the maximize truck rule was recommended as the most appropriate at this time, it was felt that the additional programming effort to insert the other procedures as options was worthwhile. Since the system is to be modified to accommodate dispatching rules it was also felt worthwhile to restructure the entire system, inserting modules for analytical work as well as some degree of generalization. Experience gained from operating the system for nearly five years would be useful in this respect.

The preliminary structure of the integrated dispatching system is presented in Figure 8. The modules are logically divided into three types: dynamic, operational, and analytical. The dynamic components relate mainly to the set-up and operation of the main screen display previously described. This remains the 'heart' of the system. Only dynamic output required is for production reporting and occasionally for additional automated time studies. Dispatching procedures are integrated as modules, activated or not to suggest assignments. Modules for production reporting will be generalized.

The modules in the analytical component are of particular relevance to the University side of this University-
FIGURE 7. Maximum difference in shovel production

TABLE 3. Results of modified event times during shift

<table>
<thead>
<tr>
<th>Case</th>
<th>Dispatch rule*</th>
<th>Total production (tonnes)</th>
<th>Standard deviation</th>
<th>Shovel production (tonnes)</th>
<th>Shovel idle time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>25%</td>
<td>Decrease travel</td>
<td>A</td>
<td>23962</td>
<td>189</td>
<td>3910</td>
</tr>
<tr>
<td></td>
<td>times for</td>
<td>B</td>
<td>25925</td>
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<tr>
<td></td>
<td>Shovels</td>
<td>C</td>
<td>24837</td>
<td>228</td>
<td>6001</td>
</tr>
<tr>
<td>1 and 2</td>
<td>D</td>
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<td>4973</td>
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<td>25%</td>
<td>Increase travel</td>
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<td>times for</td>
<td>B</td>
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<td>6214</td>
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<tr>
<td></td>
<td>Shovels</td>
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<td>166</td>
<td>6077</td>
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<tr>
<td>1 and 2</td>
<td>D</td>
<td>22075</td>
<td>80</td>
<td>4871</td>
<td>4055</td>
</tr>
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</table>

*Dispatching rules: A = Locked-in  B = Maximize Truck  C = Maximize Shovel  D = Match Factor

Industry cooperation, although the integrated system will have these modules available at the mine site. Parts of these modules have already been developed. The focus of proposed research is to improve the dispatching procedures. A foreseen method of accomplishing this is to develop a mathematical programming module to study equipment locations and assignments to meet medium-term production planning objectives. Results could provide more refined parameters to integrate into the dispatching rules. For example, mathematical programming can indicate average desired shovel coverage which can be used to adjust match factor values or heuristic priority adjustment factors in the maximize truck rule. It is felt that the benefits achieved with costly fully automated systems could be strived for in this way.

Conclusions

A semi-automated dispatching system is a viable alternative for small to medium size open-pit operations. Economic analysis of alternatives should be done on an incremental cost basis. It is primordial to consider the human element in the system, both for initial system development and implementation of automated dispatching procedures.

Thus the development of a dispatching system is a complete Operations Research problem involving not only...
mathematical tools/formulations but also implementation in a real system. It can be postulated that a not so sophisticated but well tailor-made system may produce benefits comparable to top of the range systems.

**References**


