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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[1] 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[2]) is an active system which recommends action to be taken throughout the shift. Hodson and Barker[3] 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'.[4,5,6]

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.*,[7] Byles,[8] Crosson *et al.*,[9] Hagenbuch[10] 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[9] to solving linear programming-network flow formulations[10] 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.*[11]

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

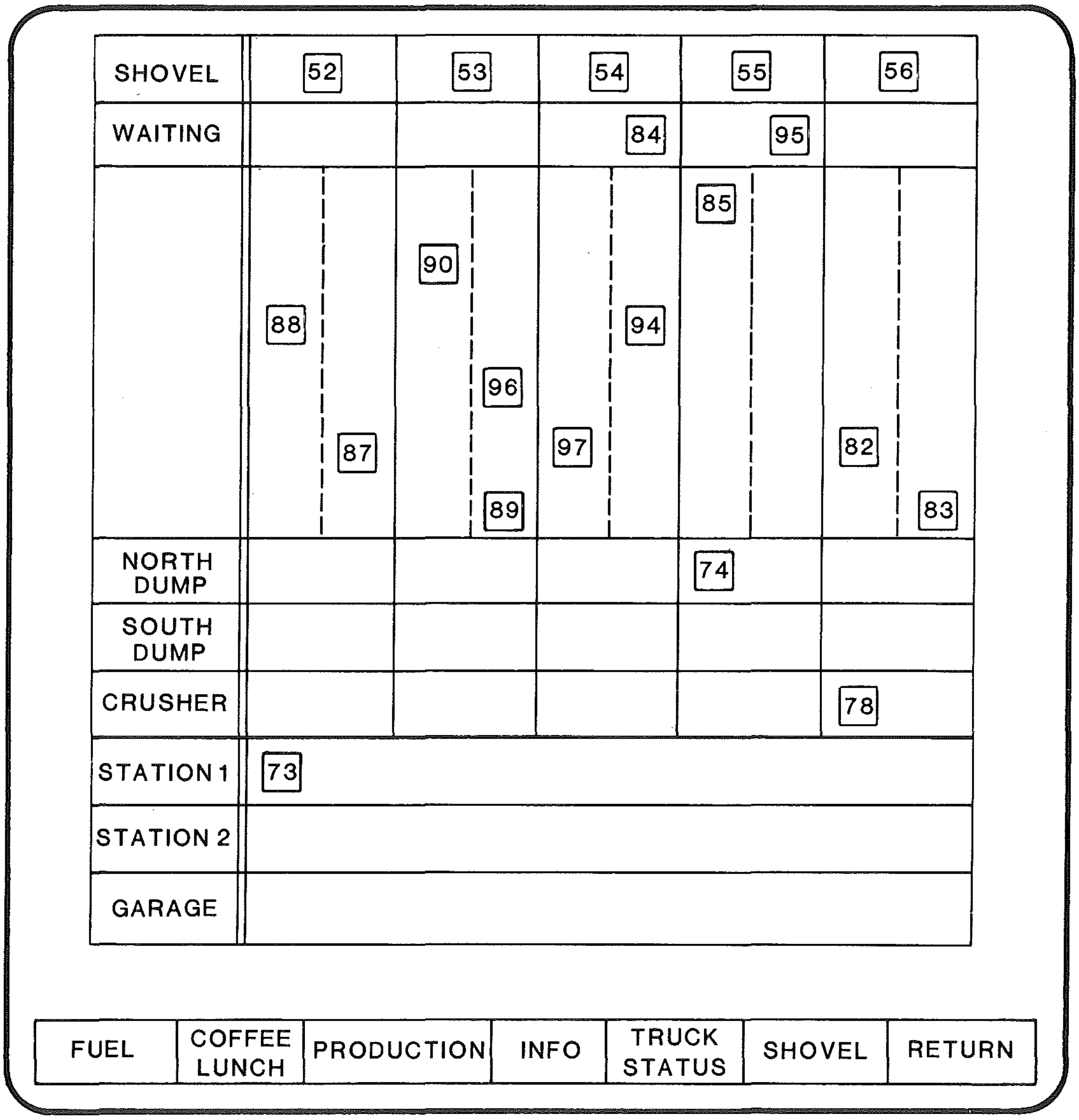

FIGURE 1. Simplified main screen display of dispatching system

ditions. The capital costs will most likely decline in the foreseeable future, but until then small and medium size open-pit operations cannot justify more than investment in semi-automated systems.

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 objective has been to gradually eliminate the smaller capacity equipment. The areal extent of the operation is approximately 1,6 km by 6 km. The average haulage distance is approximately 2 500 m with a 100 m lift in elevation.

A Hewett 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. It is similar to a 'dispatch board' where the program indicates truck and shovel activity based on information manually input by the dispatcher. Truck and shovel numbers are displayed on the screen. Since dispatch operators are familiar with daily operations (shift bosses alternate as dispatchers), shovel locations and travel distances are known without actually appearing on the screen. Truck travel times are estimated and truck numbers are moved up or down the screen when updating is done. Figure 1 is a simplification of the main screen display since colour is used to add information and make the display pleasant to look at for an eight hour shift. Blue indicates waste removal handling, red indicates ore handling and white is used for returning empty trucks. A soft green background is used.

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,[13] Brake and Chatterjee,[14] Wilke and Heck,[15] Tu and Hucka,[16] 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-

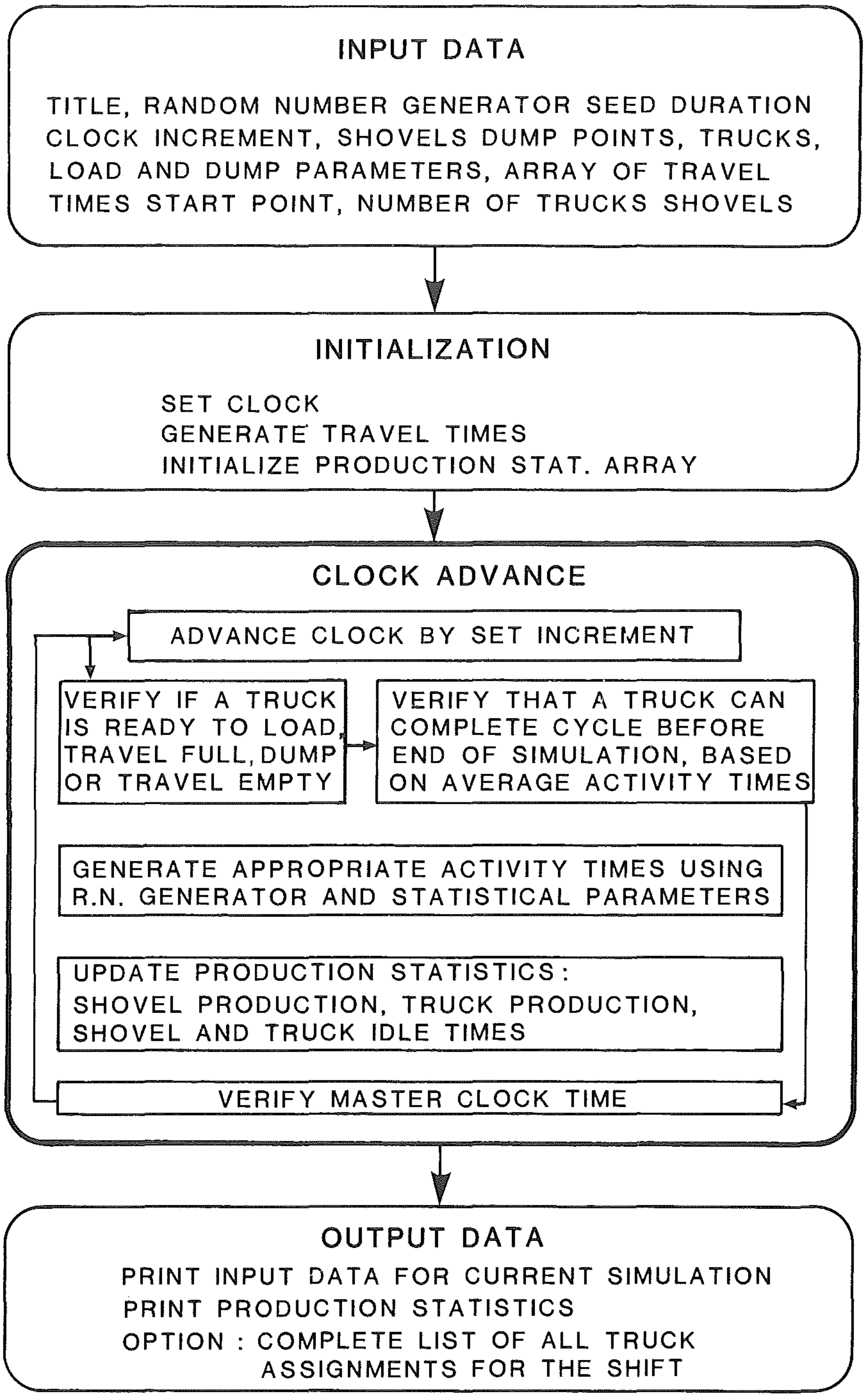

FIGURE 2. General structure of simulation program

tempts 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

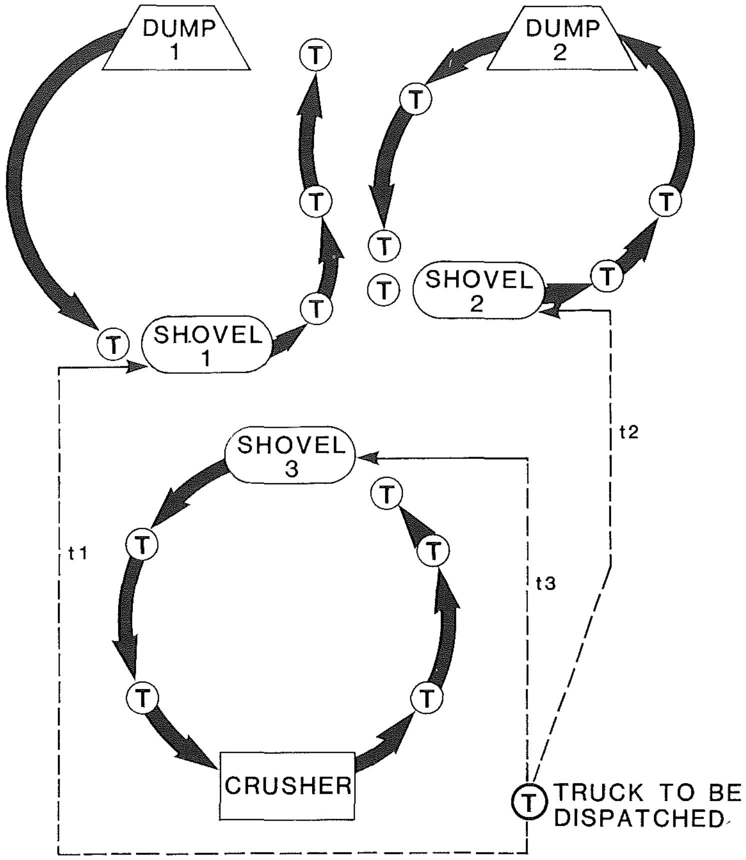

FIGURE 3. Maximize truck dispatching rule

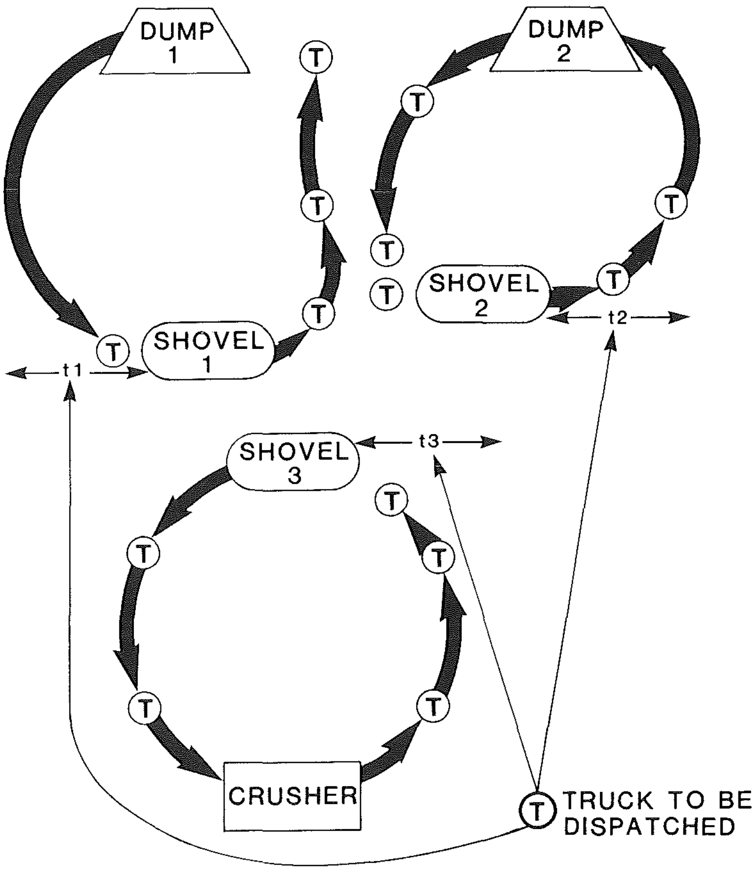

FIGURE 4. Maximize shovel dispatching rule

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.[16] Also, productivity is undifferentiated and specific desired production objectives, such as grade requirements and waste/ore ratios, are not accounted for. Hagenbuch[10] 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[17]).

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:

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

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[2] and Hodson and Barker.[3] 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[6]

Shovel number	Dump number	Travel time empty	Travel from other dumps	Travel time full	Initial truck assignment for 13 to 21 trucks				
					13	15	17	19	21
1	1	5,00	D2 – 7,15 D3 – 7,47	6,34	2	2	2	3	3
2	1	7,27	D2 – 12,24 D3 – 9,87	17,28	2	4	4	4	4
3	2	6,20	D1 – 5,79 D3 – 8,25	10,73	2	3	4	3	4
4	2	7,10	D1 – 9,64 D3 – 12,24	11,99	4	3	4	4	4
5	3	6,71	D1 – 4,25 D2 – 13,11	9,55	3	3	3	5	6

Duration of simulations: 400 minutes
Travel empty coefficient of variance: 0,10
Travel full coefficient of variance: 0,11
Average load time = 4,17 minutes
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

TABLE 2. Summary of simulation results[6]

Number of trucks	Dispatch rule*	Total production (tonnes)	Standard deviation	Average truck idle time (min.)	Shovel production (tonnes) 1	2	3	4	5	Shovel idle time (min.) 1	2	3	4	5	Total shovel idle time (min.)
	A	18624	168	11,1	3978	2163	2967	5032	4484	199	283	247	140	166	1035
13	B	20056	179	15,9	5332	1335	5762	1175	6452	136	335	114	341	81	1007
	C	18517	171	6,9	4848	3230	4352	3086	3001	161	240	186	246	252	1085
	D	17498	171	13,1	3366	2899	3957	3506	3770	229	255	208	228	211	1131
	A	20898	176	11,7	3965	4225	4365	3821	4522	197	182	173	201	168	921
15	B	22624	222	18,9	5912	2129	6252	1624	6707	106	295	90	313	72	876
	C	21148	169	10,3	5525	3659	5053	3396	3515	124	220	152	235	228	959
	D	20316	186	16,8	4790	3664	4157	3727	3978	164	220	196	212	201	993
	A	23503	189	14,7	3961	4246	5703	5058	4535	196	181	106	142	167	792
17	B	24956	261	22,6	6116	2814	6702	2435	6889	95	261	66	278	58	758
	C	23741	236	14,7	6146	3974	5784	3914	3923	95	205	117	207	208	832
	D	22704	205	19,8	4921	4059	4777	4467	4480	157	197	166	175	181	876
	A	25879	348	33,6	5725	3196	4365	5024	7569	105	230	171	141	11	658
19	B	27256	319	27,5	6537	3430	6821	3251	7217	77	226	61	240	44	648
	C	26146	284	20,6	6719	4275	6248	4322	4582	69	189	88	15	173	704
	D	24956	204	22,6	5096	4620	5308	4773	5159	146	171	135	164	149	765
	A	28325	237	33,7	5802	4220	5733	5027	7543	102	179	106	138	11	536
21	B	29402	350	32,2	6792	4127	7059	4097	7327	67	194	47	195	32	535
	C	28407	208	25,1	7102	4760	6809	4760	4976	50	165	63	163	150	591
	D	27340	227	27,3	5814	5041	5695	5295	5495	114	150	116	134	135	649

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

Simulation results

Several simulations were performed to assess the effects of the dispatching procedures on fleet productivity and individual shovel productivity and utilization.[6] 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 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, values obtained with time study results and completed with a deterministic simulator. Load and dump time distributions were modelled with three-parameter Weibull distributions assessed with time study results. The study was further simplified by assuming only one truck and one shovel capacity.

A summary of the simulation results is presented in Table 2. A range of 13 to 21 trucks was examined for locked-in dispatching, maximize truck, maximize shovel and match factor dispatching rules. Figure 5 illustrates total fleet productivity for each dispatching rule; these results are as expected but only show the general tendency. Figure 6 indicates much better the effect of each dispatching procedure compared to fixed dispatching. The maximize truck rule generates as much as 8% higher productivity than fixed dispatching. Surprisingly, the MF rule consistently yields a lower fleet productivity than fixed dispatching. This is explained by the fact that the decision is made based on a ratio computation for shovels requiring quite different coverages. However the benefit of the MF rule is apparent 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 compensate for changes – which the fixed dispatching 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 constantly monitor activity times and update with 'moving averages'.

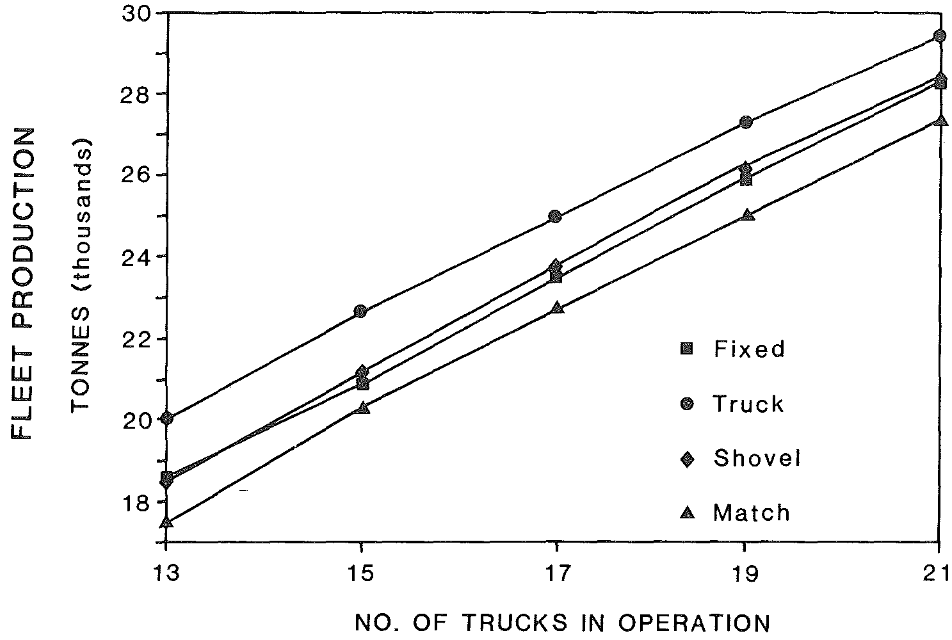

FIGURE 5. Total system production results of simulations[6]

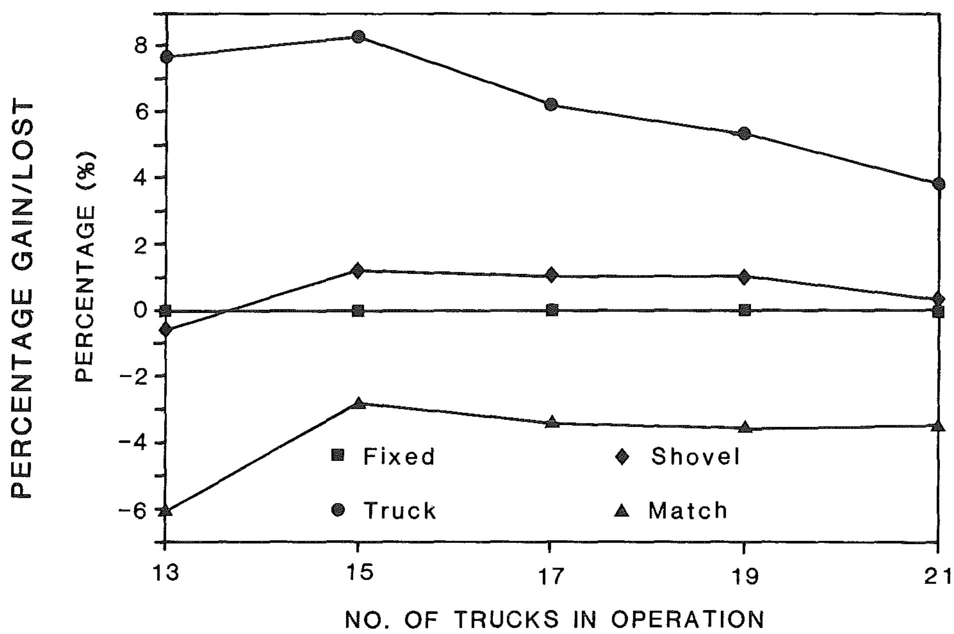

FIGURE 6. Percentage change in system production compared to fixed dispatching

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-

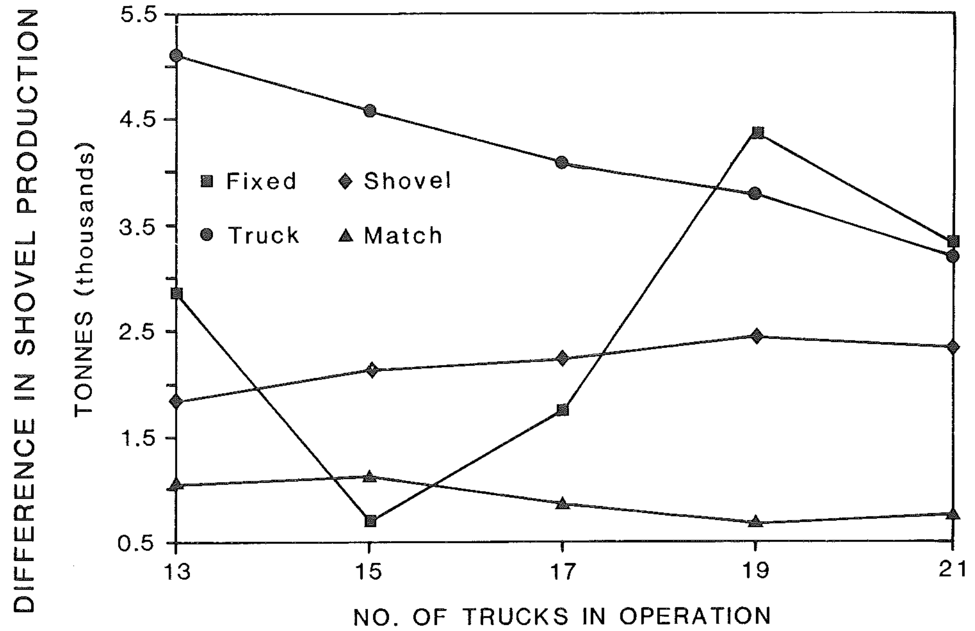

FIGURE 7. Maximum difference in shovel production[6]

TABLE 3. Results of modified event times during shift[6]

Case	Dispatch rule*	Total production (tonnes)	Standard deviation	Shovel production (tonnes) 1	2	3	4	5	Shovel idle time (minutes) 1	2	3	4	5
25% Decrease travel times for Shovels 1 and 2	A	23962	189	3910	4097	5078	5457	4420	196	179	80	112	166
	B	25925	292	5602	2167	7089	4641	6426	123	298	51	165	82
	C	24837	228	6001	3978	6375	4522	3961	109	210	92	173	215
	D	23613	142	4973	4224	4956	4845	4615	161	195	154	165	173
25% Increase travel times for Shovels 1 and 2	A	21956	191	3927	4055	5134	4454	4386	199	181	128	156	165
	B	24327	308	6214	3170	5984	2023	6936	96	248	107	298	61
	C	23188	166	6077	4131	5338	3604	4038	103	200	148	218	210
	D	22075	80	4871	4055	4607	4259	4283	166	204	175	195	189

*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 resarch 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

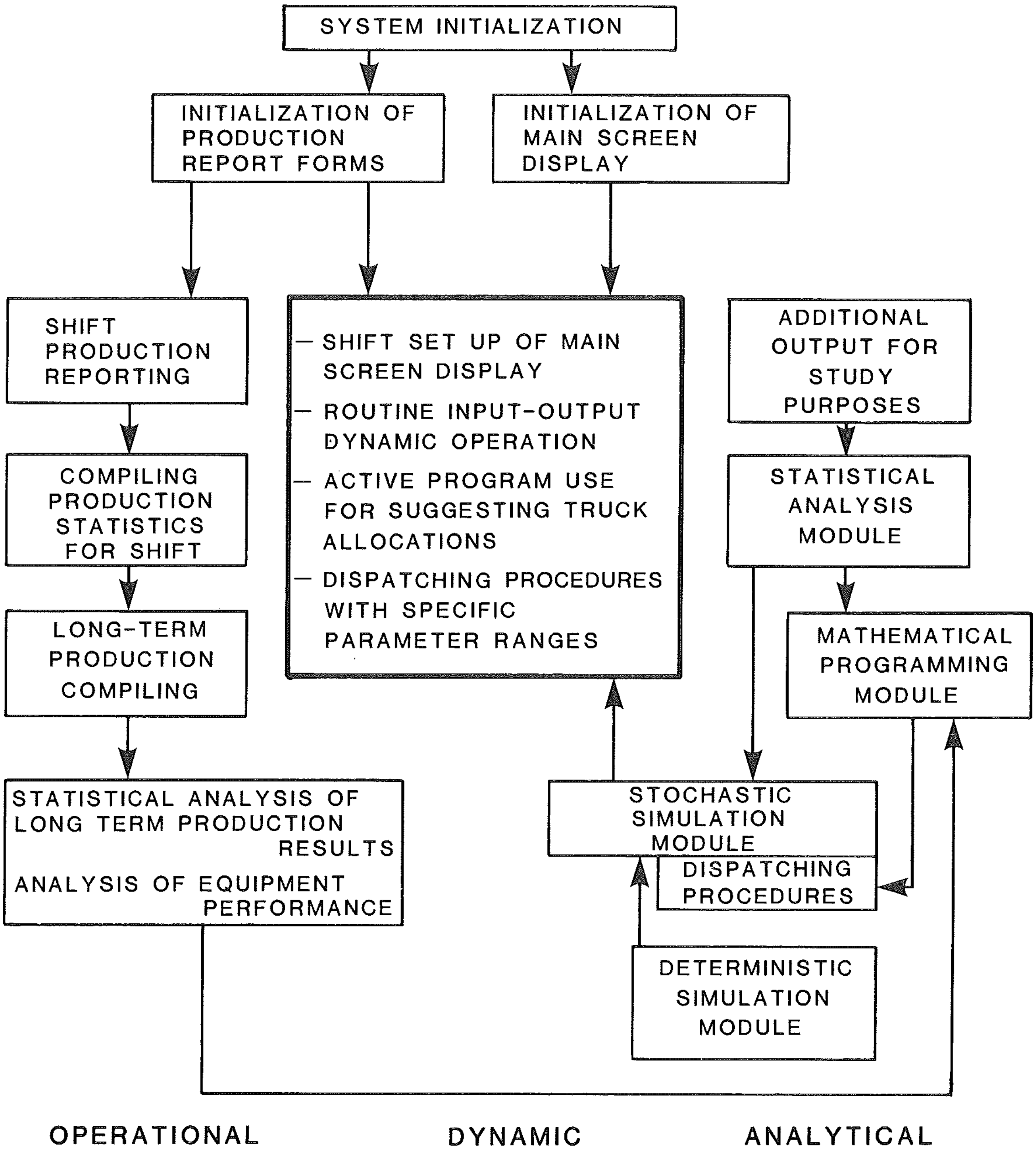

FIGURE 8. Structure of integrated dispatching system

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.

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