1981 Winter Simulation Conference Proceedings
T.I. Ören, C.M. Delfosse, C.M. Shub (Eds.)

INTERACTIVE COMPUTER MODELLING OF TRUCK/SHOVEL OPERATIONS IN AN OPEN-PIT MINE

L.K. Nenonen
P.W.U. Graefe
A.W. Chan
National Research Council Canada
Division of Mechanical Engineering
Ottawa, Ontario

An interactive computer model of truck/shovel operations in an open-pit copper mine has been developed to aid in the design and evaluation of a computer-based truck dispatching system. Interactive features include computer graphics and alphanumeric displays of on-going simulation results and a facility for user command entry. These interactive features allow the model user to act as the decision maker during simulation experiments. A non-interactive option allows execution of high speed simulation experiments with no displays and with automatic decision making.

1. INTRODUCTION

In an open-pit mine, frequent redeployment of the truck/shovel fleet is required to maximize equipment utilization in the face of varying operating conditions and equipment availabilities. In recent years, mine operators have become interested in computer-aided dispatching systems, and, in fact, a number of such systems have been installed (Anon 1975, Beaudoin 1977, Crosson 1977, Himebaugh 1980, Naplatanov 1977).

This paper describes an interactive computer model of a truck/shovel operation in an open-pit copper mine. The model was developed to aid in the design and evaluation of a new computer-based truck dispatching system. The model development work involved approximately two man-years of effort over a six-month period. Glenayre Electronics Ltd. of Vancouver used the model to design a prototype computer-based mine dispatching support system (acronym MIDISS) for the Lornex Mining Corp. open-pit mine at Logan Lake, B.C. The prototype system was installed at the mine in Spring 1981 and was undergoing rigorous field tests at the time of writing of this paper.

2. OVERVIEW OF THE MINING OPERATION AND ITS MODELLING

2.1 Description of Mining Operations and Problems

Open-pit mining involves drilling and blasting, ore and waste loading, hauling and dumping and various auxiliary operations.

Loading of ore and waste is carried on simultaneously at several different sites in the pit. Electrically powered shovels and front-end loaders of various capacities are used to load the trucks, loading times depending on shovel capacity, digging conditions and truck capacity. Since trucks of different sizes are used, "mixed trucking" at individual shovels can occur with trucks of different sizes hauling from the same shovel. Loading times may vary considerably for different truck sizes, thus queues may form while a big truck is being loaded. Digging conditions refer principally to the size of the material being loaded which influences the speed of shovel operation, the degree of filling of the bucket, and the amount of "clean-up" effort required between loads. The shovel must also move periodically along the mine face to maintain proper mine contours.

Road links between shovels and their respective dumps are of various lengths and grades. Individual segments can be shared by more than one shovel-dump link. Because passing is not permitted, travel times are strongly influenced by the slower trucks. Travel times are also affected by road conditions which in turn depend on road maintenance and weather conditions.

Dumping of waste at dumps, or of ore at a stockpile, is relatively straightforward. Queueing of trucks may occur at the ore crusher since it only has two dumping platforms and only one truck can dump at a given time.

A truck cycle comprises a loading operation, travel to the dump, a dumping operation, and a return trip to the shovel. Efficient mining operations are strongly dependent on the proper allocation of trucks to shovels. Generally, the number of trucks which should be assigned to a particular shovel is equal to the ratio of the average truck cycle time to the average shovel loading time. However, this ratio is seldom an integral number and ideal trucking is difficult to achieve partly for that reason. Due to equipment breakdowns, varying digging conditions, and ore blending considerations, frequent truck reassignments are required to maintain efficient operation. To maintain an up-to-date view of the operations of all shovels in a mine, the shift boss must circulate continually around the mine site observing queue lengths, digging conditions, etc. at each shovel and reassign trucks as required.

2.2 Brief Description of Model Logic

The required level of model detail was determined principally by the need to simulate known causes of operating difficulties, and to generate truck status change information to be gathered and analysed by a model of the proposed dispatching system. The mine road network is specified by a number of road sections interconnecting nodes. For each road section a length, grade and road condition factor is specified. Trucks are not allowed to pass and are allowed to turn around only at specified nodes. The trucks are of different sizes and makes, each type being characterized by the amount of material it can carry and the nominal speed at which it can travel as a function of load status and road grade. Fixed deviations from the nominal performance figures are used to represent variations in truck condition and driver habits. Deviations which vary on each trip are used to represent effects of variations in loading. The no passing rule combined with truck speed variations causes bunching of trucks in the model, particularly on long steep hills.

Shift changes, lunch breaks and coffee breaks are included. Not only do they result in direct losses of production but trucks congregate at shovels and dumps at these times, causing formation of truck convoys, queueing at shovels, followed by shovel idle periods.

Truck movements at loading sites include queueing, movement to preload and load position and finally departure from the loading site. Space availability at a loading site allows either single or double sided loading with resulting differences in maneuverability and time spent at the loading sites. A fuel truck is included in the model which parks at key intersections in the mine to fuel all unloaded trucks once per shift. Since trucks may be reassigned to different shovels during a shift, logic is required to direct the fuel truck to the various prespecified fueling sites and to decide when the fuel truck should move on to the next site.

The dispatching system gathers truck status change information required to calculate truck cycle times, loading times and dumping times. Thus, the model included the data collection functions of variable range radio beacons at the shovels, forward/reverse and box up/box down status sensors for trucks. During simulation experiments, to add realism to the decision making process of the dispatcher, only estimates of shovel repair durations are provided.

3. OVERALL MODEL STRUCTURE

The overall model comprises two basic sub-models synchronized by a common event-scheduling and time-keeping executive program. (Figs. 1, 2 from McIntyre 1980.) The truck/shovel sub-model can be utilized with or without the MIDISS sub-model which comprises the MIDISS Data Collection and MIDISS Central Control Prototype models. The MIDISS sub-model simulates the collection of data, communications between subsystems, interpretation of data and interactions with the dispatcher.

4. INITIALIZATION

Due to the large number of variables and attributes required in the mine model, considerable effort was devoted to develop a systematic and sectionalized approach to simplify its initialization. The initialization of model data was grouped into five main areas: shovel, truck, road network, dump, and statistics.

Probability distributions of shovel loading times and preparation times are derived based on actual field data on specific shovels under various types of digging conditions. Other shovel dependent data such as location, digging conditions, beacon range, loading and moving practices, and the times for all significant events such as startup, breakdown, move, etc. are entered, shovel by shovel, in a data set.

Each truck in the mine is initialized by entering information on the shovel to which the truck is assigned, initial location, operating and load status and starting time. Any significant events such as breakdown and reassignment may also be entered.

The road network is initialized by specifying the number of nodes, sections, any loops in the network and any special routing instructions between any two points. Also initialized are the data for each section such as connectivity, length, grade, etc. Due to frequent changes in the road network, a subroutine is incorporated which determines a routing matrix for directing truck movements between shovels and dumps.

Initialization data for the dumping sites, crusher and stockpile include the dump names, locations, types and capacities.

The manner in which statistics are gathered for

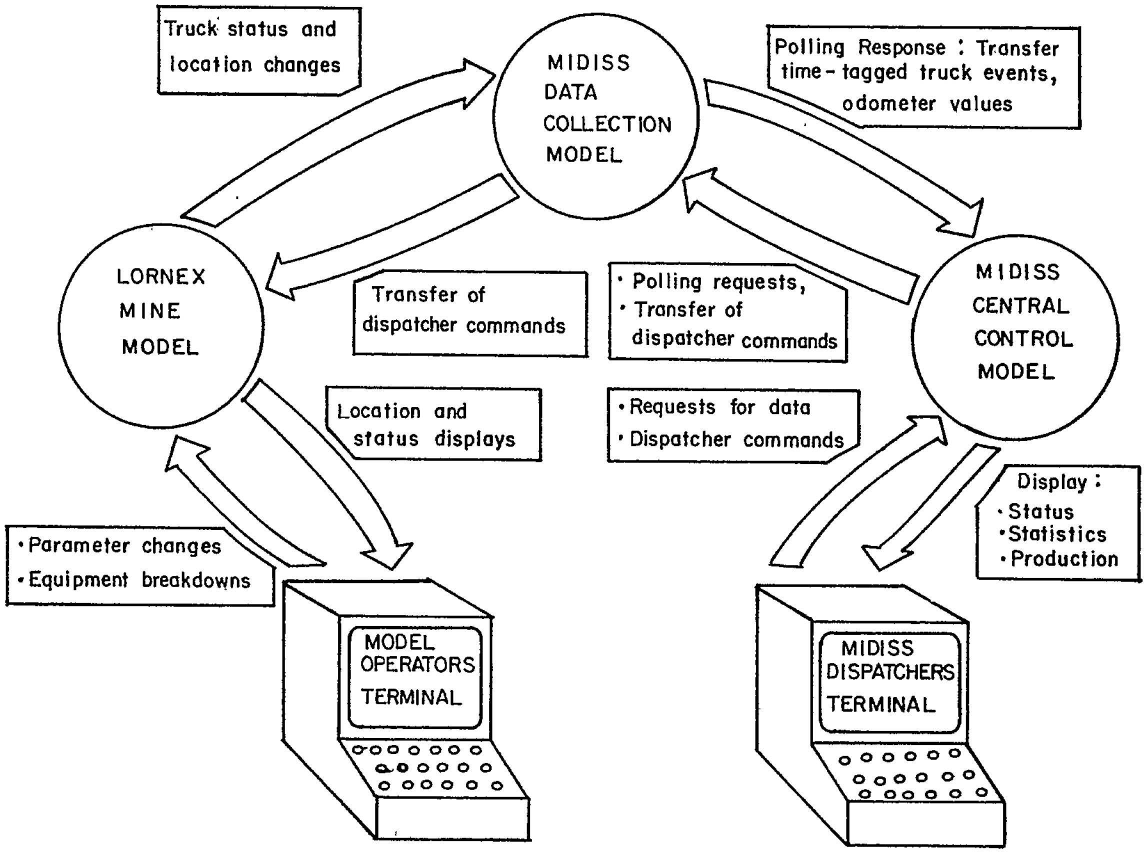

Fig. 1 Overall Model Structure and Information Flow

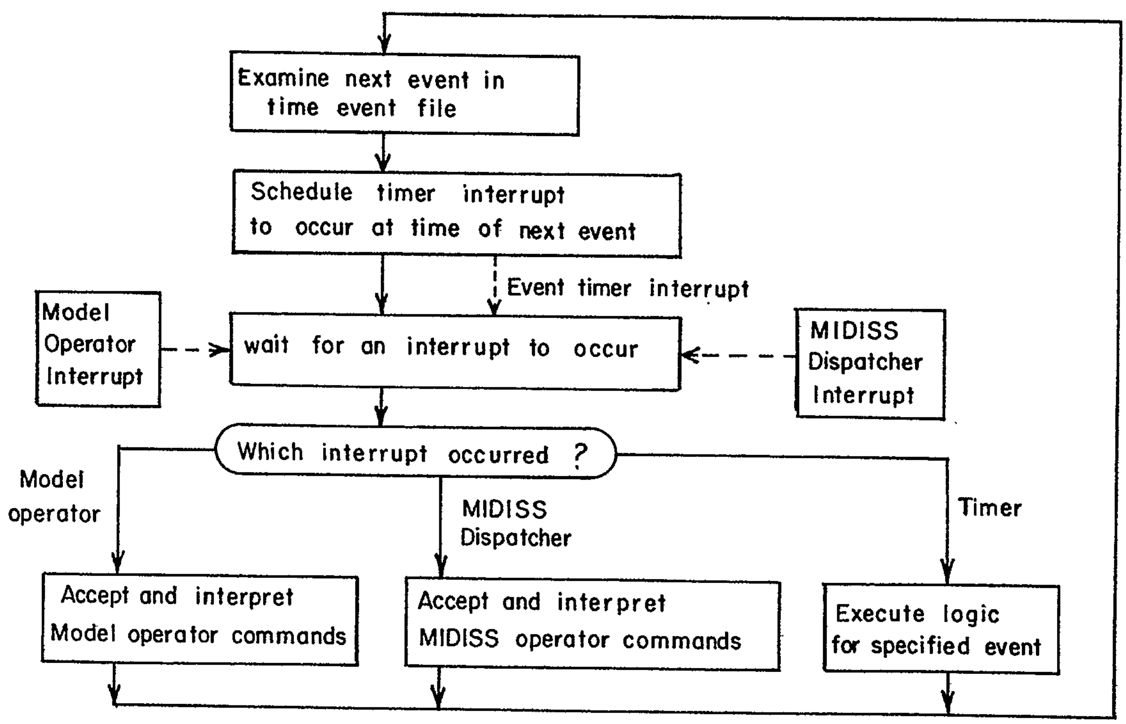

Fig. 2 Flow Diagram of Model Operation

the simulation run is also specified through initialization data. Accumulated times spent by trucks and shovels in the various operating states can be assigned to different categories of operating statistics. Up to 25 histograms are available for accumulating statistics on cycle times, etc. as specified by initialization data.

Initial condition reports are provided to facilitate the verification of initial conditions and the documentation of simulation runs.

5. INTERACTIVE FEATURES

A great deal of emphasis was placed on the incorporation of interactive features such as graphics and alphanumeric displays of ongoing simulation results and a facility for command entry to redeploy equipment and to request report printouts.

The model operates on a PDP-11/60 computer with a DEC VT-11 graphics terminal. A dynamic graphics display was developed (see Fig. 3) using a high-speed graphics software package (Evans 1980) to permit monitoring of truck movements and shovel operations.

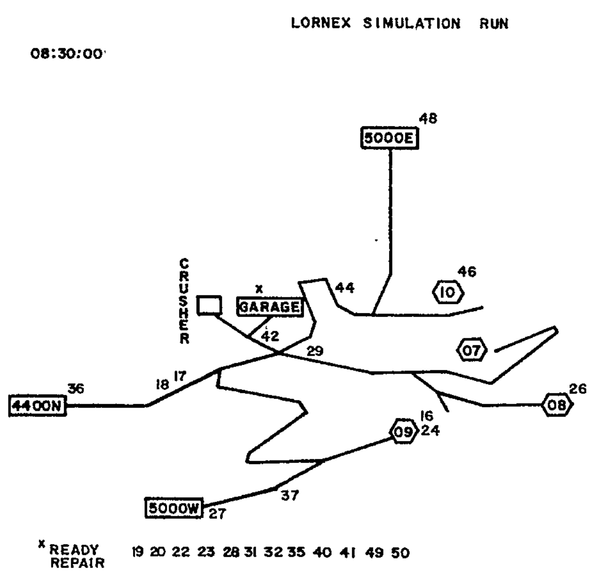

Fig. 3 Mine Model Display on Graphics Terminal

Two alphanumeric displays were developed based on a cursor controlled CRT, one of which is shown in Fig. 4. At specified time intervals during the simulation, each of these displays is updated, thus providing snapshots of the ongoing truck movements and shovel operations. The nature of the status information provided by the two differ, thus permitting two different forms of interaction (Fig. 1). While the model operator can access all status information provided by the model, the dispatcher is allowed access only to the status information gathered by the monitoring and dispatching system. Thus, alternative formats and information content of the dispatcher's display can be evaluated.

Other features to facilitate monitoring of the simulation include detailed time history printouts of truck and shovel operations and terminal messages concerning "significant" model events such as start of shift, coffee and lunch breaks, truck reassignments, equipment breakdowns and fuel truck activities.

Another essential mode of model interaction allows the model operator to freeze the model at any time and to issue commands via a terminal. A partial list of truck commands includes: send a truck from the ready line; breakdown; reroute after dump; reroute now; monitor the activities of a specific truck. The menu of shovel commands includes: change digging condition; breakdown; move along the face; change beacon range; shovel reports; histogram printout; monitor the activities of a specific shovel. A "Save and Recall" command is also provided which permits the user to save the current model status at any time during a simulation run for later recall. For example, he could use this feature to experiment with two or more different strategies to correct a chaotic situation which has developed during a simulation run. In addition to the time-history reports, the operator can request the printing of other production reports and histograms at regular time intervals such as at the end of each hour/shift. Detailed statistics on cycle times, loading times, queueing, equipment utilization and production are provided.

With the numerous interactive features, the computer model provides the capability for carrying out interactive simulation experiments to evaluate possible benefits in terms of production and equipment utilization from improved dispatching resulting from more accurate and up-to-date information.

6. PROGRAMMING DETAILS

The mine model utilizes a suite of programs based on the discrete event simulation language GASP II, enhanced and modified by the authors to facilitate the interactive modelling of processes and operations in various industries including copper smelters, steel plants and transportation systems (Graefe et al 1974, 1975, 1978). General options available include synchronous mode, asynchronous mode, interactive mode and the ability to model combined discrete and continuous systems.

In the synchronous mode, simulation time is incremented in fixed model time units and a "speed-up" factor is used to relate simulation time to real time. The computer clock is used to advance simulation time between successive discrete events.

In the asynchronous mode, time is instantaneously advanced to the time of the next discrete event.

In the interactive mode, the model usually runs in the synchronous mode, provides one or more

```
S0/POOR/QUEUE 0        S07/GOOD/QUEUE 0       S08/POOR/QUEUE 0
---------------        ----------------       ----------------
T45 MOVING ORE         T15 MOVING WST         T33 MOVING ORE
T47 MOVING ORE         T36 @4400N WST         T26 STOP'D ORE
T44 MOVING EMP         T17 MOVING EMP
T48 MOVING EMP         T25 MOVING EMP

S09/AVER/QUEUE 1       S10/POOR/QUEUE 0       S11/AVER/QUEUE 0
----------------       ----------------       ----------------
T34 @ SHOV EMP         T45 LOAD'N EMP
T16 LOAD'N EMP         T43 @5000E WST
T27 @5000W WST
T21 MOVING EMP

CRUSHER / OPERATIONAL / QUEUE 0 :
TRUCKS AT GARAGE:
/RDY/ 18 19 20 22 23 24 28 29 30 31 32 35 37 40 41 42 49 50
/RPR/
SIMTIME:09000    RESET NUMBER:00000    TIME: 000:13:00:00
```

Fig. 4 Mine Model Display on Alphanumeric Terminal

graphical or alphanumeric displays, and allows a model operator to interrupt the simulation at any time to request information by giving commands to the model. Combined discrete and continuous systems can also be simulated by running the program package on a hybrid computer where the continuous part of the model is implemented on an analog computer (Graefe et al 1978).

The current mine model has been principally applied in the interactive and synchronous mode to allow a model operator or a truck dispatcher to monitor mine operations and to reassign trucks as required to minimize queues and to obtain a specified ore production. To evaluate general truck assignments and dispatch policies the model has also been run in the much faster, non-interactive, asynchronous mode, where the occurrences of equipment breakdowns are randomly generated based on specified probability distributions.

7. COMPUTER IMPLEMENTATION

The model has been implemented on three types of computer systems, a PDP-11/60 with a VT-11 based graphics system, a VAX 11/780 and an IBM 3033.

7.1 PDP-11/60 Version

Limited high-speed memory capacity required that the overall model (250K words) be subdivided into tasks (Jeng 1981a). The model comprises ten tasks divided according to the model logic (each accessing a global common region for data), i.e. one task handles all command entry and interpretation, another handles updates of the graphics display (Jeng 1981b), etc. The graphics display task utilizes high-speed dynamic graphics software developed by NRC (Evans 1980). While the speedup factor of ten is normally used, the effective speedup factor, including delays for updating displays and printing reports, is 6.4, 1¼ hours being required to simulate one eight-hour shift of operation. In this implementation of the model, time is advanced in even increments to create a sense of continutiy for the operator.

7.2 VAX 11/780 Version

A non-interactive, asynchronous version of the model has been implemented on a VAX 11/780 computer at the National Research Council Canada. This version can simulate one shift in one minute.

7.3 IBM 3033

A non-interactive, asynchronous version has also been implemented on an IBM 3033 time-sharing system at the National Research Council Canada. While efforts are underway to develop an interactive version, performance of the model in the interactive mode on a time-sharing system may turn out to be unacceptable without adequate servicing priorities for the task.

8. MODEL VALIDATION

Loading times, shovel preparation-to-load times and truck travel times were collected during a one-week period in January 1979. Additional field data was supplied by Lornex Mining Corp. for conditions in April and July. Using non-parametric methods (Phan 1979) programs were developed to generate histograms from field data and to use the histograms to derive scaled cumulative distributions, which are then used to generate random samples of loading and preparation-to-load times used in the simulation runs. Calibration or validation of the model for different operating conditions involves adjustment of shovel digging condition parameters to reproduce loading and preparation-to-load times and of road segment condition factors to reproduce travel times and overall cycle times. However, it was not always

SHOVEL NUMBER	NUMBER OF LOADS				TONNAGES	
	MINE		MODEL		MINE	MODEL
	120T LOADS	235T LOADS	120T LOADS	235T LOADS		
6	0	54	0	60	11016	12240
7	99	0	103	0	10098	10506
8	64	0	64	0	6528	6528
9	72	0	68	0	7344	6936
10	20	42	19	40	10608	10098
TOTALS	255	96	254	100	45594	46308

TABLE 1 MODEL VALIDATION: COMPARISON OF NUMBERS OF LOADS, TONNAGES

SHOVEL NUMBER	AVERAGE TRUCK CYCLE TIMES (MINUTES)	
	MINE	MODEL
6	24.9	23.5
7	14.1	13.2
8	19.3	20.6
9	9.0	9.5
10	16.5	15.8

TABLE 2 MODEL VALIDATION: COMPARISON OF TRUCK CYCLE TIMES

possible to satisfactorily reproduce total tonnages loaded by each shovel even though loading, preparation-to-load and travel times were sufficiently close. In some instances, errors were attributable to unrecorded changes in truck deployment and availability during the associated shift which were not duplicated by the model. However, following careful study of the validation results by Lornex Mining Corp. and Glenayre engineers, the model was considered to be a valid representation of the actual operations at the Lornex open-pit mine. In Tables 1 and 2, numbers of loads, tonnages and truck cycle times are shown for the actual mine and for the model.

9. MODEL APPLICATIONS

The model has been applied by Glenayre Electronics to design a prototype of their MIDISS system. Alternative data display and command entry formats useful to the dispatcher were evaluated and beacon deployment and range options were studied during simulation experiments duplicating actual mine conditions. These experiments also provided an opportunity to evaluate alternate criteria the dispatcher could use to redeploy trucks.

Once Glenayre Electronics had developed a satisfactory data display format and dispatcher command repertoire, they used the model to demonstrate potential MIDISS capabilities to Lornex personnel. Based partly on the outcome of these experiments, Lornex decided to commit funds for the installation of a prototype MIDISS system at their mine which involved equipping about one-half of their operating trucks with the necessary monitoring equipment, including the central control computer and a set of beacons.

10. FUTURE WORK

Work is underway to generalize the model described in this paper. Ultimately, the user will be able to interactively select from a wide variety of loading and hauling equipment, materials to be excavated, and strategies to be followed re shift change, breakdown and repair policies, etc. Furthermore, the user will be provided with a more flexible means of prescribing the road network associated with his simulation run. In addition, the procedures for gathering statistics and generating reports will be improved.

REFERENCES

Anon (1975), Computer Drops Quarry Truck Turnaround to Five Minutes, Materials Management and Distribution, November, pp. 25-27.

Beaudoin, R. (1977), Automatic Truck Dispatching: Mount Wright Operations, Canadian Institute of Mining and Metallurgy, First Open-Pit Operators Conference, May.

Crosson, C.C., M.J.H. Tonking and W.G. Moffat (1977), Palabora System of Truck Control, Mining Magazine, February, pp. 74-82.

Evans, K.B., P.P. Tanner and M. Wein (1980), A Fast Dynamics Graphics Package. National Research Council Canada Report ERB-910, May.

Graefe, P.W.U., L.K. Nenonen and K. Strobele (1974), Simulation of Combined Discrete and Continuous Systems on a Hybrid Computer, Simulation, Vol. 22, No. 5, pp. 129-137.

Graefe, P.W.U. and L.K. Nenonen (1975), An Interactive Computer Modelling Approach to the Study of Materials Processing and Handling in the Mineral Industry, In: 13th International Symposium on the Application of Computers and Mathematics for Decision Making in the Mineral Industries, Clausthal, Fed. Rep. of Germany, pp. S-II 1-16.

Graefe, P.W.U., G.F. Crate and A.W. Chan (1978), Operations Study of an Intermediate Capacity Transit System on a Hybrid Computer, In: Joint Automatic Control Conference, Philadelphia, PA, Vol. 3, pp. 271-280.

Himebaugh, A.E. (1980), Computer-Based Truck Dispatching in the Tyrone Mine, American Mining Congress 1980.

Jeng, G. (1981a), A Simple Multi-Tasking Scheme to Resolve Large Memory Problems Under RSX-11 (M/D) Systems, National Research Council Canada Report LTR-CS-214, March.

Jeng, G. (1981b), A Graphics Display System for Interactive Computer Modelling, National Research Council Canada Report LTR-CS-215, March.

McIntyre, L.W. (1980), MIDISS Phase I Report, Glenayre Electronics Ltd. Report GL-2072-007, February 5.

Naplatanov, N.D., V.S. Sgurev and P.A. Petrov (1977), Truck Control at Medet, Mining Magazine, July, Vol. 137, No. 1.

Phan, C.S. (1979), Generation of Random Samples Using Non-Parametric Method, National Research Council Canada Report LTR-CS-199, March.