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COMPUTER SIMULATION OF MINE RAIL HAULAGE SYSTEM[1]

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ABSTRACT

The operation of an underground coal mine haulage system has been simulated using SIMSCRIPT II.5 on the CDC Cybernet System. The software was developed using structured programming techniques and is composed of 19 interacting events and routines. The simulation program and some of the results to test various train configurations and dispatching strategies are described.

Simultaneous movement of several trains, the operations of multiple load stations and the dump station, and their interactions are managed by this closed-system, event-oriented simulator. Dispatch decisions, such as timing and selection of train and destination are made on the basis of a user-selected strategy to optimize coal production.

1. INTRODUCTION

In a typical underground coal mine, the working sections are located several miles from the mine entrance. One common method for hauling the mined coal from the face area to the above ground preparation plant is by a combination of conveyor belt systems and rail transportation. Coal generated by the mining machinery at the face is moved by conveyor to one of several underground loading stations. At the loading station, the coal is loaded into mine cars which are pulled by electric locomotives along a "mainline" rail network to a dumping station. Another conveyor belt system moves the coal from the dump station to the preparation plant.

The coal transportation system is critical to the mine operation as any haulage delay can cause reductions in mine production. Consequently, an efficient rail haulage operation is key to productivity improvements in the coal mine industry.

Presently, mine personnel are making complex decisions for haulage operations such as train dispatching, routing and traffic coordination. As part of an effort to develop technology suitable for automation of haulage operations (Booz, Allen, 1981), simulation was used to model train movements.

Existing simulation programs for conventional above ground rail systems (T. F. Folk, 1973, Dunbar, et.al, 1978) cannot be readily utilized since the overall configuration and requirements of mine rail haulage are quite different. Simulators that were developed specifically for the coal mining industry typically encompass the total mining system with rail haulage playing only a minor role in the overall software system (Manula, 1974, Bucklen, VPI, 1968, Turpin, 1976). Since simplifying assumptions were made to keep the simulator within manageable size, features of the rail haulage portions were somewhat limited. For example, one simulator used in an earlier phase of the study (Booz, Allen, 1979) did not provide for slack time dispatch and dispatching from an intermediate wait area. The dispatch rules and parameters remained fixed under all conditions and could not easily incorporate other dispatch strategies necessary for an in-depth analysis of the mine haulage systems. Thus, a completely new mine haulage simulator was developed.

Although the simulator has been designed to validate action of a particular automated rail system, this simulator can be used as an effective industrial engineering tool to improve present manual rail haulage systems at various domestic mines.

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2. MINE HAULAGE DISPATCH MODEL

There are several elements to the operating strategy which are derived from the unique characteristics of domestic coal mines. These elements are briefly described in the sections to follow as background to the description of the simulation program.

2.1 Traffic Coordination On A Single-Track System

Most domestic coal mines operate with a single-track system interspersed with limited passing tracks. For a single-track mine haulage system, a reservation strategy is needed to resolve the contention for the track while avoiding collisions and standoffs. The reservation strategy rules are listed as follows:

- The haulage system tracks are divided into a series of blocks.
- Only one train can occupy a block at any time.
- Passing tracks are wait blocks with one-way traffic.
- A train route is a sequence of blocks between the wait blocks.
- Blocks have "assigned" or "available" status.
- Assigned blocks are occupied by or reserved for only one identified train.
- Blocks are assigned only when the complete route is available.
- Blocks become available upon departure of the assigned train.

The above rules were implemented in the train movement section of the simulator to regulate and maintain safe traffic flow.

2.2 Route Assignments

In a typical coal mine a dispatcher uses a scratch pad to record track allocations to various trains which travel the track system. He often does not allocate the entire track from the load station to the dump station to a single train. Instead, he grants partial allocations of a route to the train to allow it to go to the next passing track (wait block). The contention for route assignment is typically resolved in favor of the train waiting the longest, although a dispatcher may grant priority to some trains to keep a load station from shutting down. The request for the next route is made by the train operator when the train finishes the old route by reaching the wait block (passing track). The route assignment processing is performed in the simulation program by the train assignment section.

Sample routes for the haulage system are shown in Figure 1. The illustration shows a part of a mine composed of five wait blocks and three regular blocks. Each route is established as a sequence of blocks that starts and ends with a wait block. By sequencing the whole route, the train is assured of a passage to a wait block without causing collision with another train or blocking other trains.

2.3 Slack-Time Scheduling

Besides traffic coordination and route assignments, the dispatcher must attempt to utilize the trains as effectively as possible. As such, station service strategies may incorporate sending a train to a station before the train is really required to sustain production. Such scheduling of trains allows production to be sustained by fewer locomotives than would be required otherwise, since the stations can work off its backlog of cars delivered during slack time.

The service strategies for slack time must be carefully structured so that the early train dispatch does not adversely affect the response time of the trains during the peak production. Slack time scheduling is performed in the simulation program by the dispatch function of the train assignment section.

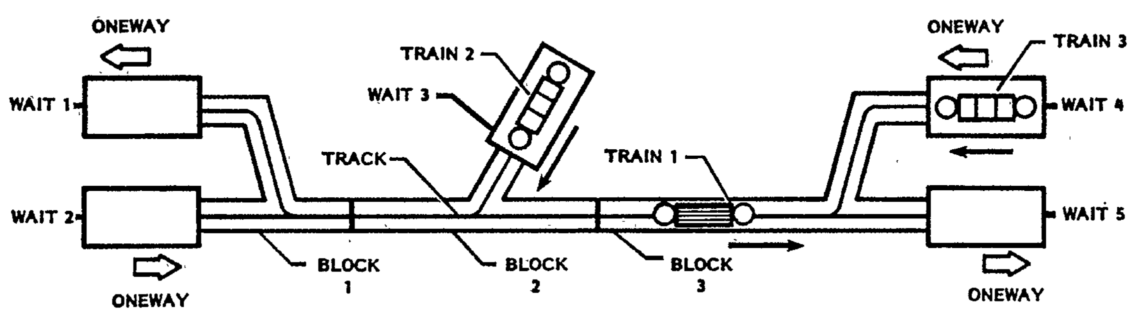


Figure 1 Typical Sample Routes

A sample slack time scheduling strategy is shown in Figure 2. Each load station communicates two events to the dispatcher. The first event indicates that the load station is ready to receive a train. The second event indicates that the load station requires a train in order

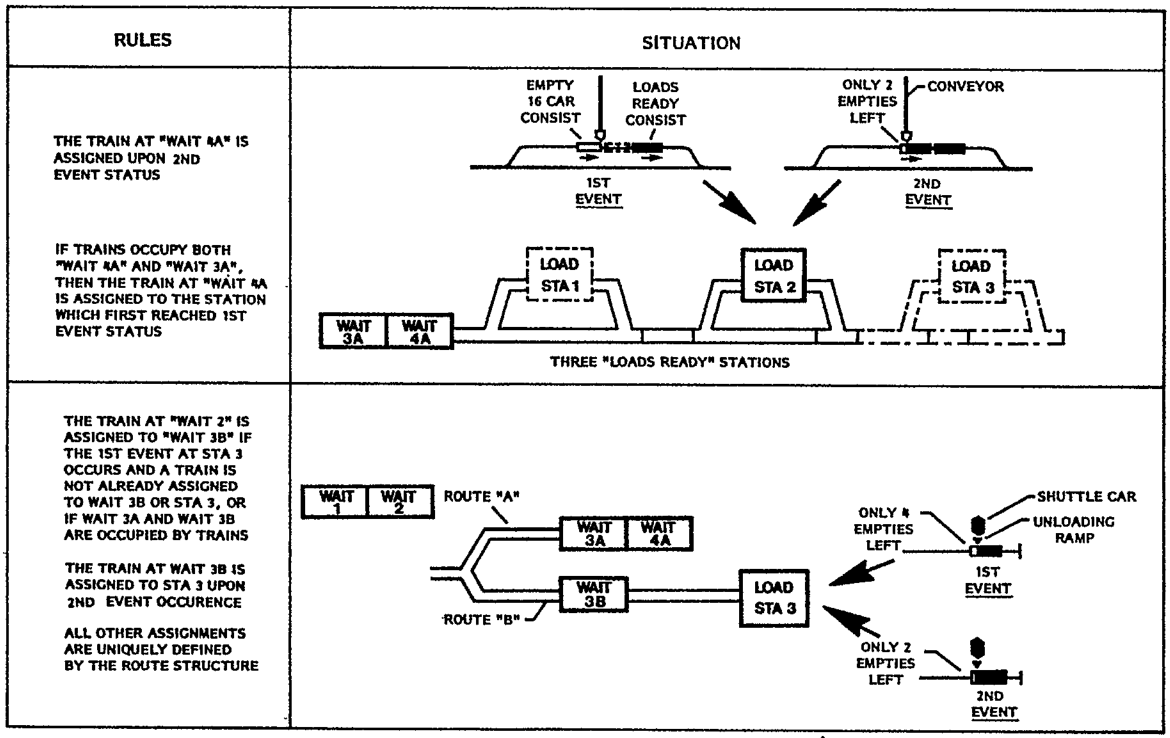


Figure 2 Sample Slack Time Scheduling

to sustain production. A train will be assigned to the first load station that has reached the second event even if there is no second train in the adjacent wait block. In addition, if none of the stations has reached the second event, the train will be assigned to the first station that has reach the first event if another train is in position to respond to the second event. Thus the trains will be utilized during the slack time as well.

3. SIMULATOR SOFTWARE

The computer simulation program incorporates the dispatch strategy models discussed earlier. The program was written in SIMSCRIPT II.5 to take advantage of its flexible programming ability, structured language format and simulation related features. The features that have been used in this program include event-oriented scheduling, automatic queuing and statistics gathering abilities. The input for the program has been designed so that the changes to the mine or the strategy can often be made by changing the input variables.

3.1 Modules and Module Interactions

The major portion of the simulation program was divided into four sections:

- Dump station
- Load Station
- Train Movement
- Train Assignment.

How these sections interact with others are shown in Figure 3. Each section is subdivided into many modules. The structure of each module is shown in Figure 4.

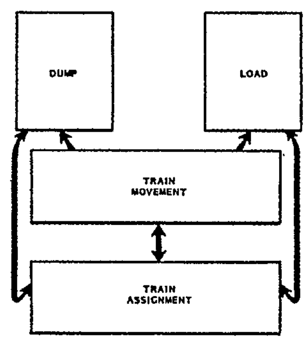


Figure 3 Major Elements of the Computer Simulator

MODULE NAME	TYPE	INPUT ARGUMENT	CALLS: EVENT	CALLS: ROUTINE	CALLED BY
ADUMP	EVENT	-	BGNDUMP		ENDROUTE
ALOAD	EVENT	STATION ID	BGNLOAD		ENDROUTE
AVAIL	ROUTINE	PRIORITY NO.		MATCH	SERVICE
BGNBLOCK	EVENT	TRAIN ID	BGNBLOCK ENDROUTE	SERVICE MATCH	DISPATCH BGNBLOCK
BGNDUMP	EVENT	-	ENDDUMP		ADUMP ENDDUMP LDUMP
BGNLOAD	EVENT	STATION ID	ENDLOAD		ALOAD ENDLOAD LLOAD
DISPATCH	ROUTINE	ROUTINE ID	BGNBLOCK	LDUMP LLOAD	MATCH
ENDDUMP	EVENT	-	BGNDUMP	AVAIL SERVICE	BGNDUMP
ENDLOAD	EVENT	STATION ID	BGNLOAD	AVAIL SERVICE	BGNLOAD
ENDROUTE	EVENT	BLOCK ID		ADUMP ALOAD AVAIL	BGNBLOCK
LDUMP	ROUTINE	-	BGNDUMP		DISPATCH
LLOAD	ROUTINE	STATION ID	BGNLOAD		DISPATCH
MATCH	ROUTINE	-		DISPATCH	AVAIL SERVICE
SERVICE	ROUTINE	DESTINATION BLOCK ID		MATCH	BGNBLOCK ENDLOAD ENDDUMP

Figure 4 Simulation Module

Dump Station

The dump station was modeled as a set of events that dumps coal from cars at a fixed rate. BGNDUMP removes one loaded car from a buffer and empties it. BGNDUMP schedules ENDDUMP which places newly empty car into another buffer and reschedules BGNDUMP if another loaded car is available. The ENDDUMP event also calls routines in the train assignment section if the first or the second event is reached. ADUMP and LDUMP routings are called if a train arrives or leaves the dump station. These routines adjust the number of coal cars in the station by an appropriate amount. ADUMP or LDUMP may reactivate the dump station by scheduling BGNDUMP. The flow of the dump section is shown in Figure 5.

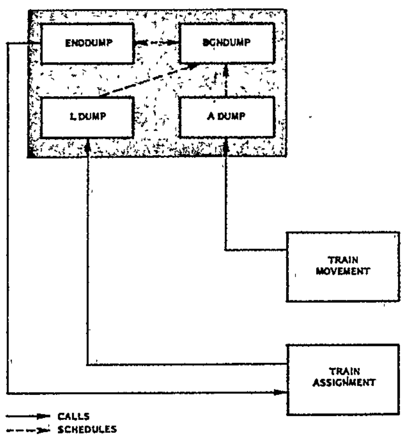


Figure 5 Dump Modules

Load Station

Each load station was modeled in a similar manner to the dump station. BGNLOAD, ENDLOAD, ALOAD and LLOAD are quite similar to BGNDUMP, ENDDUMP, ADUMP and LDUMP, respectively. The one major difference is that the BGNLOAD schedules ENDLOAD by using not a fixed rate, but by the input production rate profile. This scheduling allows for variable rate production that is found in mine operations. The illustration of section interactions are shown in Figure 6.

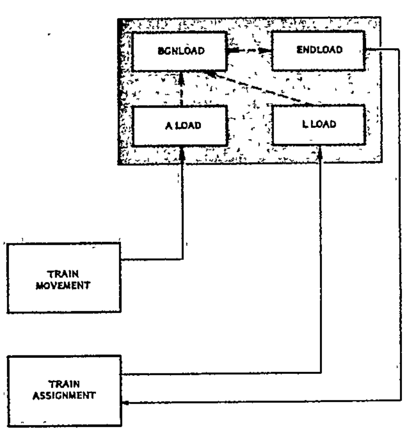


Figure 6 Load Modules

Train Movement

The simulation of each train movement is accomplished by the use of two modules. The train movement is initiated from the train assignment section. The movement of a train from one block to a new block is simulated by BGNBLOCK. The termination of a route is simulated by ENDROUTE. The module interactions are shown in Figure 7.

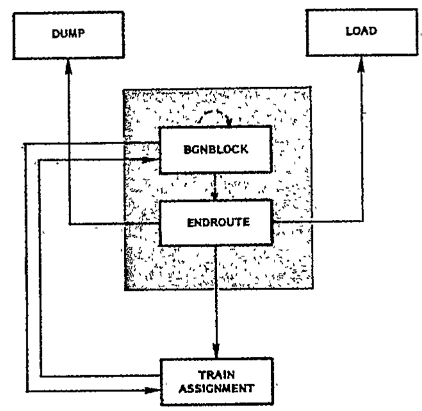


Figure 7 Train Movement Modules

Train Assignment

The modules in this section are involved in assigning an idle train to a wait block that is requesting a train. The SERVICE routine places train request into service queues. The AVAIL routine places an idle train notice into the train queue. The MATCH routine attempts to assign a train in the train queue to a wait block that has requested a train through the service queues. If the match was found, the DISPTCH routine removes the train and the wait block from queues and initiates train movement. The module interactions are shown in Figure 8.

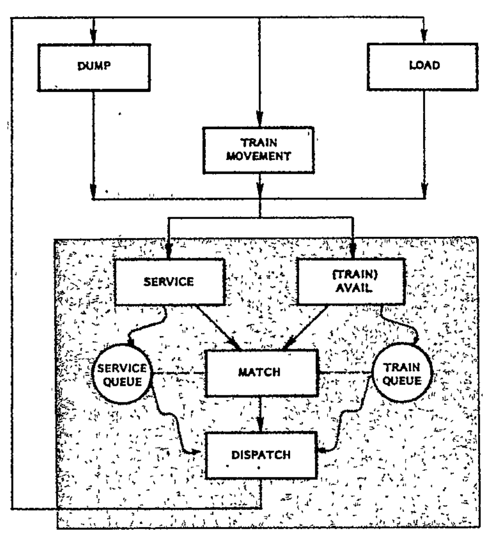


Figure 8 Train Assignment Modules and Queues

3.2 Input/Output Descriptions

The input/output of the program is made to accommodate various mine configurations and data analysis. The input variables allow for testing various dispatch strategies and haulage parameters. The outputs can be varied from a brief summary to a detailed movement-by-movement description of each train.

Input Description

The input to the program can modify many parameters of the mine as well as the type of output. The input variables can modify:

- Haulageway layouts
- Initial conditions
- Coal production profile
- Service and travel times
- Number and length of trains
- Number of load stations and intermediate wait blocks.

In addition, it can specify the type of output that is needed for each run.

Output Description

All outputs are at the option of the user. Depending on the options taken, the following can be output.

- Intermediate results
  - Status of each load station and train
  - Content of queues
  - Graphic map of the mine along with the present location of each train. (Shown in Figure 9)
- Final results
  - Station information
  - Production loss situations
  - Train movement information
  - Coal car status summary.

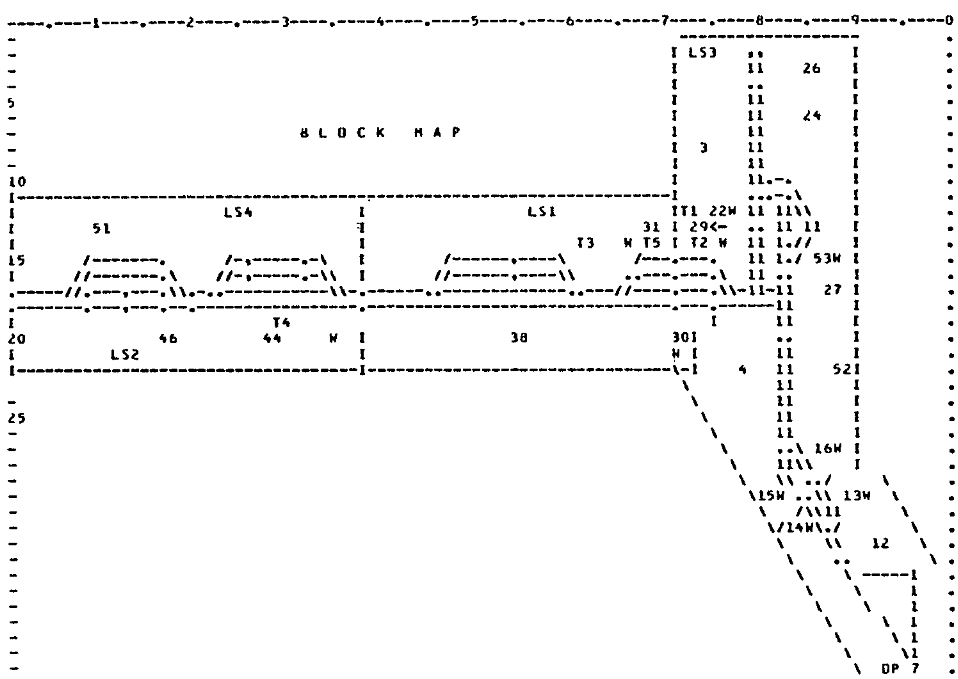
  (Shown in Figure 9)

4. SAMPLE RESULTS

Several test cases were simulated in order to evaluate the effects of various train configurations and strategies.

4.4 Various Strategies

In order to compare one strategy with the others, avoidable production loss and the number of coal cars delivered to the dump station were



LEGEND

: → Block Boundary
; → Load/Dump Station
T → Train
W → Wait Block
LS → Load Station
DP → Dump Station

Figure 9 Mine Map Output

used as the criteria. Using these criteria some strategies were found to be better than others.

INPUT				OUTPUT	
CASE #	DISPATCH STRATEGY	TRAINS	CARS/TRAIN	AVOIDABLE PRODUCTION LOSS	NUMBER OF CARS DELIVERED TO DUMP
1	BASIC	5	16	0.5%	304
2		4	16	4.4%	272
3		3	16	17.9%	240
4	MODIFIED LONGWALL DISPATCH	5	16	0%	304
5		4	16	1.1%	288
6		4	14	4.1%	266
7	ADEQUATE EMPTY CAR SPACE	5	16	0%	304
8		4	16	0%	304

Figure 10 Various Dispatching Strategies

As can be seen in Figure 10 there are three major dispatch strategies that were considered for simulation runs along with various numbers of trains and cars per train. The Figure 10 basic cases data was derived using a specific mine as a model for these case studies although other mines could have been used. The basic configuration is a limited version of a strategy known as the loads ready or LR strategy. The LR strategy provides that a loaded set of cars (called a consist) will be ready to be removed from the load station when a train arrives. This is accomplished by making the load station request for a train only after one of the consists is totally loaded. Case Number 1 has the most acceptable configuration for the basic strategy although there were some production losses. This can be seen in the Avoidable Loss and Number of Cars Delivered column of Figure 10.

The major characteristic of the LR strategy is that production stoppage is not due to the lack of trains but due to the traffic congestion and route reservation systems to forecast needs.

Modified Longwall Dispatch Cases

In the modified longwall dispatch strategy the longwall station can request a train before any of the consists is fully loaded. This permits earlier arrival of trains. There is a risk that the longwall production will abruptly stop and cause an arriving train to wait at the station until the consist is fully loaded. Since the longwall station accounts for over 50% of the production, however, other trains should be able to meet the need of other load stations.

The results of the modified strategy were better than the base cases. The five train case did not cause any avoidable shutdowns and the four train configuration caused 1.1% avoidable production loss -- considerably better than 4.4% from the comparable base case. The analysis of the four train case shows that the production shutdown occurred mostly in the non-longwall stations. The specific instances of the shutdown situations indicated that the shutdown occurred because the trains could not respond to the late request due to traffic congestion.

Even this strategy does not fully utilize available train resources. One indicator of train utilization is the average number of moving trains in a given time period. This traffic rate was plotted for an eight-hour shift as shown in Figure 11. The resulting profile shows that train movement closely follows production profile. After initial maneuvering, none of the trains move until after 20 minutes into production. The trains came to a complete standstill for 30 minutes due to a production shutdown for 52 minutes during lunch.

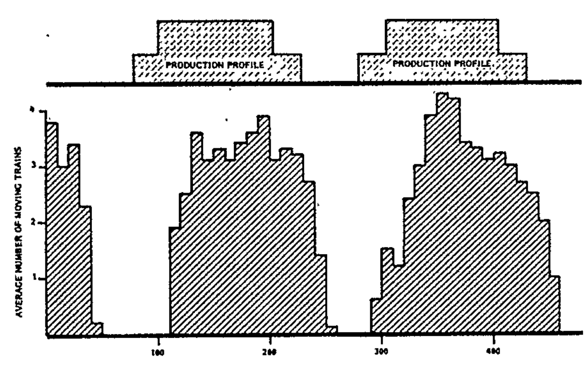


Figure 11 Train Utilization - Base Case 1

Adequate Empty Space Cases

An ideal LR strategy requires room for two trains in the empty car space and room for two trains in the loaded car space for each load station. The reduced empty car space was postponing early train requests in the earlier cases. In "adequate empty space" cases, the empty-car space was increased to a full 32 cars per station to allow complete flexibility of the LR strategy.

Under these cases, the five- and four-train configurations did not cause any avoidable production losses. These cases allowed better utilization of trains during the time when there was little or no production by filling early train requests.

4.2 Simulation Analysis

The analysis of Case 5 and Case 8 in Figure 12 indicates why Case 5 requires five trains versus four trains of Case 8. Case 8 strategy provides better utilization of trains by taking advantage of the slack time in the system during breaks and shift changes. This reduces the peak demand on trains due to increased car storage in the load stations. With less peak demand the number of trains can be reduced to decrease the overall traffic congestion. Thus, for the same coal production profile only four trains are needed in Case 8.

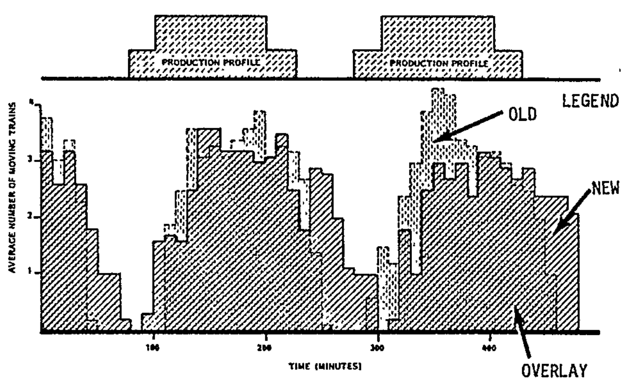


Figure 12 Train Utilization
Base Case vs. Adequate Empty Space Case

It is not obvious which case is the better strategy in the real mining environment. Although Case 8 requires one less train, it requires more expanded space in each load station. The cost of expanding the buffer space must be compared to the cost of acquiring and maintaining an extra train.

Other mines can be analyzed by changing the input portion of the simulator which defines the mine configuration to be modeled. As a result the simulator may be helpful in demonstrating to mine operators how different haulage strategies may work in their own mines.

5. SUMMARY

The operation of an underground coal mine haulage system has been simulated to test various train configurations and dispatching strategies. Dispatch decisions, such as timing and selection of train and destination, are modeled and can be varied by the user to simulate haulage system to sustain coal production with minimum resources. With the large number of variables, events, queues and decisions, simulation was an effective tool to analyze this system behavior.

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