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The Implementation of a Computerised Truck Dispatch System at Palabora

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Efficient modern-day mining operations are turning increasingly to technology to combat rising operating costs in an adverse economic climate for the industry. Computerised truck dispatching is one such technological advance that has enhanced the efficiency of the mining operation at Palabora. The economic incentives, basic operation and general system benefits of Palabora's computerised truck dispatching system are considered.

Introduction

Palabora Mine is situated in the lowveld plain of the north-eastern Transvaal, some 550 km to the north-east of Johannesburg. Immediately to the east of the mine lies the Kruger National Park and the border with Mozambique, whilst 175 km to the north lies the Limpopo river and the border with Zimbabwe.

The Palabora Igneous Complex is an elliptically shaped vertical pipe of volcanic origin, some 7 km by 3 km, with a younger alkaline pipe intruded centrally into the complex. This intrusion is the host rock for the copper sulphide and associated mineralisation.

Mining has taken place on the outcrop, Loolekop, for some 1 200 years but it was only in 1932 that modern-day mining commenced when the late Dr Hans Merensky started a small quarry for the winning of phosphate.

In those early years the grade of the copper ore body was considered too low to support an economically viable mining operation. It was not until 1956 that Palabora Mining Company was formed on the initiative of the Rio Tinto Zinc and the Newmont Mining Corporations to investigate the viability of mining. The first phase of the mining operation commenced in 1964 with the establishment of mining cuts on Loolekop. To date (Oct. 1986) over 1 453 million tons of material have been removed from the Palabora open pit.

The primary product is a high-quality refined copper in both rod and cathode form. Palabora produces sufficient copper to meet the requirements of the entire South African market, the balance going for export. Other significant products are anode slimes (containing gold, silver and platinum), uranium calcine (yellow cake), magnetite, baddeleyite (zirconium oxide), nickel sulphate and sulphuric acid. A large tonnage of phosphate bearing rock is also mined by Palabora on behalf of the Phosphate Development Corporation.

Background to the mining operation

The first phase of the mining operation at Palabora began in 1965 with the establishment of mining benches on Loolekop. The mining equipment in use at that time consisted of two P&H 1400 shovels ($3,1 m^3$) and a fleet of twenty-six 65 ton KW Dart trucks with an additional five P&H 1600 shovels ($4,6 m^3$) and one P&H 2100 shovel ($9,2 m^3$) being introduced in 1966 (Crosson[1]).

The initial open pit plans called for a mining rate of 75 000 tons of rock per day of which 40 000 tons was ore, the planned end-of-life of the mine being in 1992. No less than five mine expansions have taken place through the life of the mine, with production reaching a peak during 1980 when an average of 348 195 tons of material was mined per day. The effect of these expansions has been to increase the planned life of the open cast operation by seven years to 1999. Following a more favourable stripping ratio, production is currently planned at 307 000 tons per day of which 93 000 tons per day is ore at an average head and cut-off grade of 0,50% Cu and 0,15% Cu respectively.

The mining equipment in use at Palabora has increased in size and capacity, following the typical technological trends of many large-scale open cast operations throughout the world. By 1985 the shovel loading fleet had been rationalised to six P&H 2800 and three P&H 2100 shovels and the haul truck fleet to seventy-nine 154 ton Unit Rig MK36 trucks and four 154 ton Euclid R170 trucks, making a total of eighty-three haul units.

The pit is mined in 15,2 m high benches, the lowest working bench currently being bench 30 at a depth of 323 m below the average surface elevation. The pit is finally planned to reach bench 56 at a depth of 721 m below the average surface elevation and 325 m below sea level (see Figure 1). The overall slope angle is maintained at an average of 45° to 53° throughout most slopes and is achieved through a combination of controlled perimeter blasting and double benching.[2]

All drill holes are sampled in order to determine the precise mineralogical make-up of each blast. After blasting, each muckpile is subdivided by means of demarcation flags and identification boards into smaller mining blocks known as composites. Each composite is marked by means of a unique number and classified into one of thirteen different material types according to its mineralogical constituents and the mineral ownership area in which it occurs.

Under normal mining conditions shovels are planned to square face muckpiles with trucks in double backup. All major permanent ramp systems are installed at a grade of 8%, with the more heavily used ramps having trolley assist lines installed. The trolley assist system has many advantages over standard diesel powered haulage, the main ones being

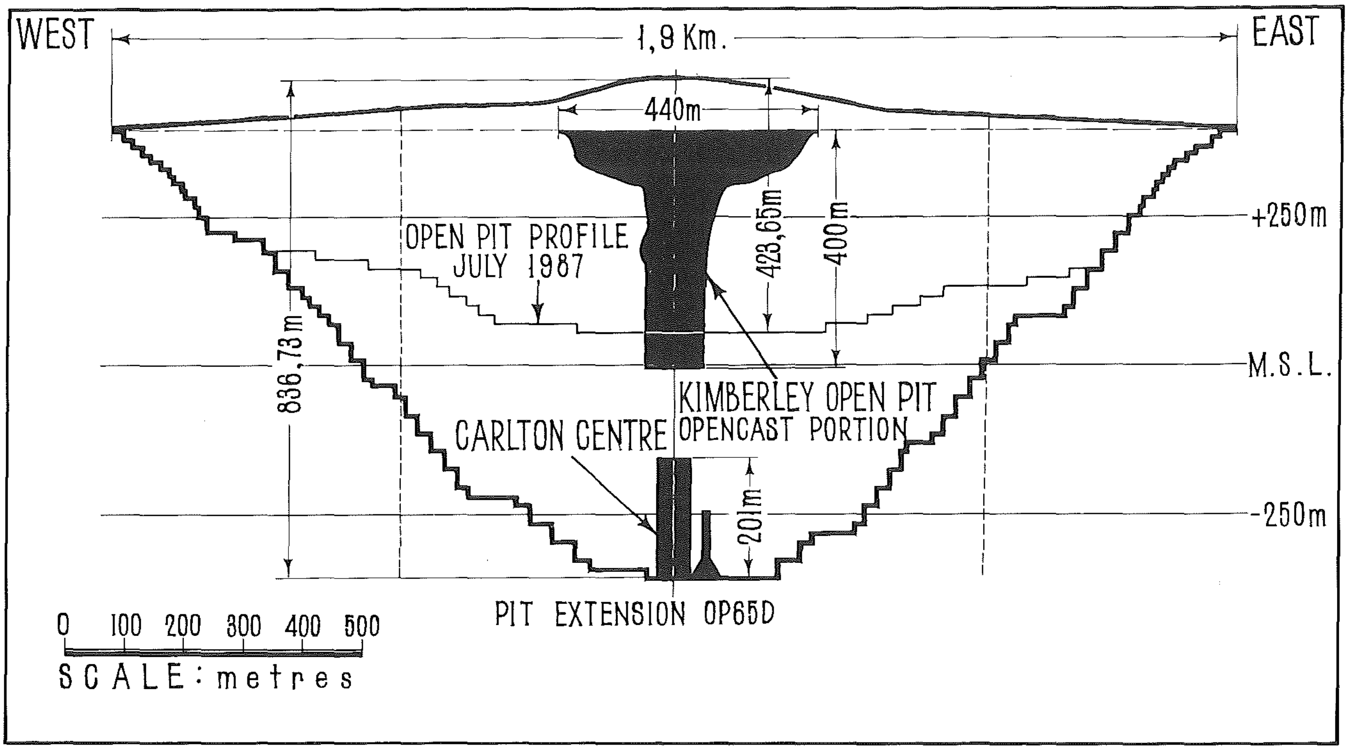

FIGURE 1. East-west cross-section through the Palabora Pit, showing the current and final pit walls. The World Trade Center buildings are superimposed to convey an impression of the depth

reduced fuel costs and greater haul truck productivity through increased speed.[3]

All of the ore is currently hauled to surface and delivered to one of three 54" Allis Chalmer gyratory cone crushers. All other material is delivered to one of twelve dumps according to the material classification and ownership.

Previous truck dispatching systems

The first method of truck dispatching was based on manual batch allocation, a system which suffered certain inherent inefficiencies. The principal problems were that shovels rarely required an exact number of trucks to satisfy their loading requirements and that shovel digging rates, crusher breakdowns and shovel delays and breakdowns could not be timeously compensated for.

The first automatic truck dispatching system [4] was commissioned in July 1972, with operation on a continuous basis being achieved in the early part of 1973. The haul truck fleet at that time consisted of nineteen 90 ton Unit Rig M100s and thirty 65 ton KW Darts. The basic concept of the system was to be able to detect a truck as it entered the pit and assign it to a shovel by means of a shovel priority rating system.

Subsequent to the installation of the system, studies indicated that the resultant increase in productivity varied from between 5% to 8%.

The major disadvantages of this system were that it was not possible to determine accurately shovel loading and crusher digestion rates: communication was restricted to one point within each haul cycle; and it was not possible to determine the exact location and state of each haul truck, thus limiting the decisions for truck allocation to the situation as perceived by operations personnel from the lookout tower.

Basic requirements of a fully computerised system

It was evident that in order to improve upon the previous truck dispatching system it would be necessary to exercise far greater and tighter control over the haul truck fleet. Accordingly, it would be necessary to identify each truck individually and be aware of its location and status at all times. Furthermore, it would be necessary to utilise this information as input to a process control system based on a high speed digital computer which would contain the necessary logic to make decisions on how best to allocate haul trucks in order to maximise production. A further requirement would be the ability to communicate with each loading and hauling unit in order that instructions may be given on a real-time basis. It was vital that changes in state (for example, equipment status, crusher rates, shovel digging rates) might be compensated for quickly and effectively and not just 'as and when possible'.

Less important requirements of the system were the provision of adequate production reporting; an interface with the current maintenance system; and the requirement for minimum input from both look-out personnel and equipment operators. The latter of these requirements could only be provided by a system which was self-monitoring and self-adjusting.

Investigations into various systems and their benefits

Investigations into the availability of a system capable of satisfying these requirements commenced in 1980. Broad concepts were drawn up in order to develop an initial and brief functional specification as a guideline for directing further engineering input.

In the latter half of 1983 a detailed simulation study was conducted by mining consultants to determine the potential increase in haul truck efficiency that could be anticipated from a more sophisticated dispatch system. The basis of the study was to compare the then current dispatching system with one such as that defined in Palabora's broad specification.

The results of this study showed conclusively that haul truck efficiency could be increased by between 4,7% to 8,6%.

The economic justification

The impact of high fuel costs since 1973 has placed great emphasis on the need to improve haul truck efficiency. Additionally, the low value of the Rand has increased dramatically the cost of new and replacement haul trucks. The overall mining and beneficiation costs for 1985 amounted to some R285,7 m, of which R141,2 m was attributable to the mining operation. Of this figure, R71,7 m was directly attributable to haulage costs, thus making it the highest single cost area.

Given these economic considerations, the potential payback on a system which offered even the bare minimum increase in truck utilisation of 4,7% was extremely favourable. The projected savings, including capital cost savings, amounted to R14,83 m in 1985 Rand figures.

System selection

Following project approval in August 1984, various suppliers were invited to tender, with the contract finally being awarded to Modular Mining Systems Incorporated of Tucson, Arizona.

Preparation of a highly detailed functional specification followed the award of the contract, and system installation commenced in June 1985. The name of the dispatching system installed by Modular Mining Systems is DISPATCH, and it will be referred to as such throughout the remaining sections of this paper.

Basic means of operation

The basic aim of DISPATCH is to optimise haulage patterns for a given configuration of shovels, dumps and crushers based upon measured shovel digging, truck hauling and crusher digestion rates. In order to determine the optimum haulage model, DISPATCH employs the Simplex method of linear programming. This optimum model is regenerated when significant events such as shovel breakdowns occur or by default once every twenty minutes. A steady state is assumed to exist and it is therefore necessary to apply secondary dynamic assignment logic to ensure that deviations from the steady state are accounted for.

DISPATCH is in direct radio contact with the onboard field equipment control units mounted in all shovels, trucks and crushers via two UHF FM digital radio channels. In order for DISPATCH to be able to make accurate decisions with respect to truck allocation it is necessary for it to have access to all relevant data, including the pit route network, equipment status and other information received from the field control units. All of this information is contained within a complex, purposely designed 'pit data base' which is continually modified and updated by manual data entry and self-adjustment from measured parameters.

DISPATCH keeps track of the location of trucks by means of both location beacons and information entered into the field control units by the truck drivers. Location beacons are placed at various key points in the pit, on shovels and on the surrounding dumps and haul roads. When a request is received for a shovel assignment, all alternative assignments for that truck are evaluated as well as for all other trucks expected to request an assignment within the next few minutes or so. An optimum assignment is then given to the truck. It is this feature in particular that dramatically enhances the efficiency of the dispatching operation as likely future events are always taken into consideration.

Once a truck has received an assignment and is progressing towards its destination, it will pass location beacons en route. Certain of these beacons can be designated to act as reassignment locations so that if the validity of that trucks original assignment has been re-evaluated, a new assignment can be given. This will usually occur if the shovel to which the truck was originally assigned has broken down, or if another shovel which was previously on breakdown has returned to service.

During normal operation there will always be circumstances which cannot be handled by DISPATCH itself, for instance a truck driver may go to the wrong shovel or a shovel operator may push an incorrect button on the operator interface panel. Should such a condition arise then DISPATCH will prompt the lookout operator to take corrective action.

Operators

There are five groups of personnel who form key links in the smooth and effective operation of the system. These groups comprise haul truck drivers, shovel operators, crusher operators, lookout operators and mine engineering. They will be considered in turn.

The truck driver

The basic actions required of the truck driver are to inform DISPATCH when the truck arrives at a shovel, when it is being loaded, when a dump assignment is required, to confirm arrival at the dump and to request an assignment back to a shovel. Other input required is that relating to the state of the haul truck, such as downs or delays being experienced, the quantity of fuel put in the truck, etc. Communication with the driver is via a 32 character digital display on the operator interface panel.

The shovel operator

The shovel operator has basically the same facilities as the truck driver, except that he is required to indicate to DISPATCH information pertaining to the composites being loaded, and when the loading of a truck has been completed.

The crusher operator

The primary function of the crusher operator is to indicate to DISPATCH which ore stockpile he is tipping on and when he commences and finishes crushing a load. The latter information is utilised by DISPATCH within its linear programming calculations to determine the correct feed rate of trucks to the crushers and hence the correct feed rate of trucks to the ore shovels.

The lookout operator

The nerve centre of the entire operation is the open pit lookout tower. Here there are four computer terminals in use (see Figure 2), each of which serves a different function in assisting the lookout operator to control the mining operation.

Mine engineering

Mine engineering personnel are responsible for the upkeep of the DISPATCH system, particularly with respect to the primary pit configuration data such as haul routes, composite data, production equipment information, etc. As with computer operating systems, DISPATCH has many configurable system parameters which

FIGURE 2. The open pit lookout tower, showing the DISPATCH control terminals

affect the efficiency with which it operates. It is the responsibility of mine engineering personnel to ensure that these parameters are set to optimise the efficiency of the dispatching operation at all times.

A full description of the principles and theory upon which DISPATCH assignment logic is based has been given by White and Olson.[6]

Dispatch hardware

A detailed description of the system hardware is beyond the scope of this paper. However, for further reference Baker, Coburn & White[7] have described fully the operation of the system and the functionality of the associated hardware.

Location beacons

Location beacons are small, low power VHF transmitters located at strategic points in the haul route system. They are compact and robust and are mounted in a stainless steel tube for maximum protection against the elements. As a result of their usually remote location they are normally powered by solar panels, as shown in Figure 3. The effective range of the transmission is approximately 50 m which enables DISPATCH to determine accurately the position of any truck which should detect a specific beacon.

Beacons serve various purposes and may be defined to DISPATCH in a number of ways. Each beacon has a unique identification code and can be defined as either a call point, crusher reassignment, shovel reassignment, auto arrive or trolley line beacon. Of particular note here are the shovel and crusher reassignment beacons which are located close to the shovels and crushers respectively in order to ensure that truck allocation is based upon the most up-to-date information and allow DISPATCH to make any last-minute changes if

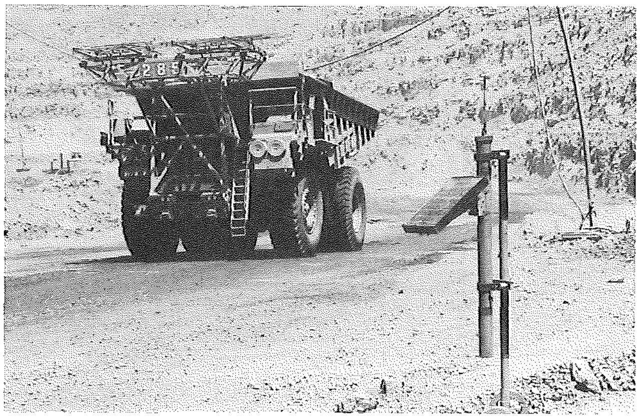

FIGURE 3. A haul truck approaching a location beacon

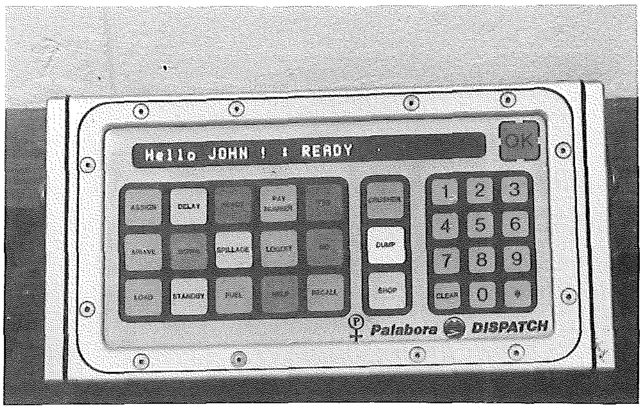

FIGURE 4. An operator interface panel for a haul truck

necessary, before the truck arrives at its final destination.

Field control units

Field control units are mounted in all trucks, shovels and crushers to enable equipment operators to communicate with DISPATCH and vice versa. The field control units consist of a vehicle interface panel, an operator interface panel, a radio and a power supply. The vehicle interface panel, often referred to as the 'black box' is of rugged construction and contains three cards to cater for communications, beacon receiving and vital signs monitoring.

The operator interface panel (see Figure 4) contains a microprocessor to control the 32 character display

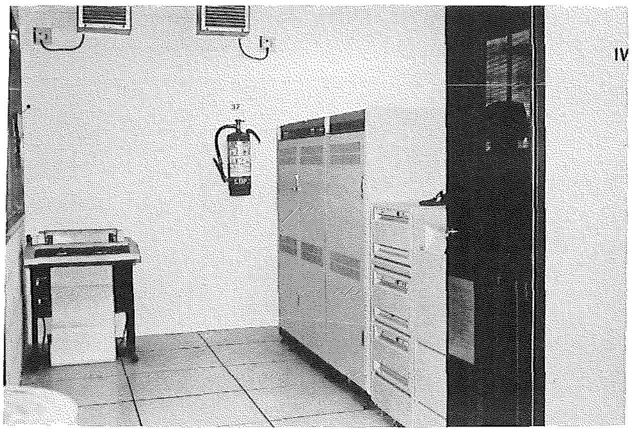

FIGURE 5. Central computer room, showing system console, VAX-11/780, disc drives and communication cabinet

and data entry via the keypad. The radio is a standard Motorola Mitrek voice radio.

Communications hardware

Communication is achieved with the use of a two channel UHF FM system. Two repeaters, both on a 100% duty cycle, are located at the lookout close to the edge of the pit in order to ensure good radio coverage.

Communication between the VAX and the field equipment is achieved by means of an interface panel supporting a communications protocol developed specifically for efficient error-free communication on a radio channel.

Central computer hardware

The central computer (see Figure 5) is a Digital Equipment Corporation VAX-11/780 with 8 MB of internal memory, floating point processor, 16 ports, three RA81 456 MB hard disc units and a TU80 Magnetic tape drive. The system was originally delivered with 4 MB of internal memory, but various operating system and application program upgrades necessitated a further 4 MB of memory and the sharing of swap and page files between two discs.

Dispatch software

All of the DISPATCH software installed on the VAX is written in 'C' for maximum system efficiency, but the majority of the software installed in the field hardware is written in Pascal and Assembler.

When the system was first installed much of the software distributed between the various mine sites around the world was generic. However, as more systems were sold the system suppliers experienced difficulty in maintaining a multitude of sites each with its own idiosyncrasies whilst still developing software for others. The Palabora software has therefore undergone many radical enhancements within the first two years of operation, many of them aimed at turning the system into a set package which can be configured to suit any specific open cast mining operation. This is particularly true of the system reporting which is now achieved by a forms management command language which can be easily developed and manipulated by mine personnel.

Palabora-specific features

Several aspects of the system originally delivered to Palabora required a certain degree of customisation, particularly the strategies pertaining to the crusher feed rate, shiftchange, truck wheel retorquing and training methods. These will be looked at in turn.

Crusher strategy

As a result of the variable nature of the ore delivered to the primary crushers, rapid variations in the crusher digestion rates occur. In order for DISPATCH to ensure a steady and balanced flow of trucks to the crushers, the crusher digestion rates need to be measured parameters. The digestion rate of individual loads is determined from the elapsed time between the ready signal for a truck to tip in the crusher and a signal received from the crusher operator's interface panel indicating that the load has been digested. In this way a rolling average digestion rate for each crusher may be maintained.

Shiftchange strategy

Prior to the installation of DISPATCH, shiftchange took place between approximately 10 minutes prior to the end of one shift and 10 minutes into the start of the next. Drivers would invariably pace themselves towards the end of the shift in order to arrive at the shiftchange in a timely fashion. The means by which DISPATCH assigns trucks to shift change is to determine if the truck could take another load and be back at the shiftchange area prior to the end of the shift; if not a shiftchange assignment would be given. Dependent upon specific cycle times, it was not uncommon for trucks to arrive at shiftchange 30 minutes prior to the end of the shift. As the shiftchange location was on a major haul route this caused disruption to the normal traffic flow. It therefore became necessary for all trucks which were scheduled to arrive early at the shiftchange to be assigned to a smaller holding location where they would not affect the normal traffic flow.

Truck retorquing

When haul truck wheels are refitted or replaced it is necessary that the haul truck return to the Tyre Bay after the first, third and sixth load in order to retorque the wheel nuts. This practice was previously controlled manually. However with the introduction of DISPATCH, the system was automated. DISPATCH simply keeps track of the loads hauled by the truck since it last had a tyre re-fitted and assigns the truck to the Tyre Bay at the appropriate time. This ensures that truck wheels are retorqued at the correct time, thus making for increased safety and also allowing DISPATCH to account for Tyre Bay downtime when looking ahead to future truck assignments.

Training methods

Training was identified as one of the single most important factors to be addressed if the project was to be a success. The area of most concern was the ability and willingness of the haul truck drivers to interact with the system correctly. In order to address this problem a small simulator (see Figure 6) was developed at Palabora's request and set up several weeks prior to the arrival on site of the majority of the hardware. This simulator consisted of a shovel and truck field panel unit driven by a small 16k microcomputer. In this way shovel operators and truck drivers could be trained in the correct use of their respective dispatching equipment several weeks prior to system start-up, and any problem areas could be addressed well in advance. The training of all other personnel such as lookout operators, instrumentation technicians, and so on, took place during system installation and start-up, with full coverage of all key aspects being under-

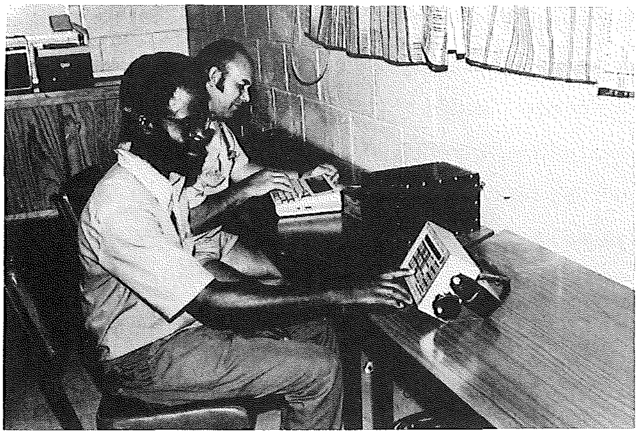

FIGURE 6. Training of haul truck drivers under simulated conditions

taken by Modular Mining personnel until there was sufficient in-house knowledge and ability. Acceptance of the system has been good, particularly amongst the haul truck drivers. This may in part arise from the fact that DISPATCH tends to enhance job interest.

System support

Supplier support for the DISPATCH software is achieved via a phone link to the United States over a 1200 baud phone modem. Assistance is available on a 24 hour per day basis for situations which affect the normal running of the dispatching operation. System updates are received on a regular basis via the telephone link. Updates are received in the form of source code difference files which are then incorporated into the source code resident on Palabora's VAX. Compilation of the source code is therefore carried out in Palabora. This method of sending difference files as opposed to entire updates significantly reduces telephone charges and provides for a more rapid response to the rectification of any system software bugs.

Determination of system benefits

The system was originally justified on a 4,7% increase in haul truck efficiency. Installation commenced in July 1985 and in November of that year this objective was achieved by the placing of four trucks on permanent standby. This represented a 4,8% reduction in the haul truck fleet size without any noticeable loss of production.

After 12 months of debugging and enhancement a detailed study was performed in order to determine the precise increase in truck efficiency. Two mining periods were examined in detail using historically accepted measures of performance. The first part of the study covered a three-month period just prior to the installation of DISPATCH, the second part a three-month period subsequent to the installation of DISPATCH. The 'truck time' calculated to give the same level of production as that achieved was compared to the 'truck time' actually available. The ratio of these two figures for each period showed that the truck utilisation factor subsequent to the installation of DISPATCH was 7,07% higher than the period prior to installation.

Analysis of mining operation

The efficiency of any mining operation is as good as the understanding that management and operations personnel have of the bottlenecks and restrictions within the production cycle. DISPATCH has various utilities which permit close examination of all aspects of the operation in order that any limiting factors may be investigated. Of particular note is a utility that was developed jointly at Palabora's request, known as the Performance Evaluation Procedure (PEP). This utility is designed specifically for mine operating personnel in order that they may determine exactly which facet of the operation is limiting production. The factors weighed against each other are haulage rates, shovel digging rates and crusher digestion rates. Historical data from previous production files is accumulated for comparison against currently measured values. The PEP report then determines which of these current factors are limiting production by evaluating the production levels which could be met if historical rates were achieved. This form of quantification of production is still in the development stage, yet good results are being obtained and are proving to be useful. The report is run automatically on an hourly basis in order that prompt action, such as a change in dumping location, may be taken if necessary.

Prior to the installation of DISPATCH it was very difficult to determine when there were excessive trucks in the field which were not being utilised effectively, especially during the period leading up to and just after blasting operations. The PEP utility now provides lookout personnel with the necessary information to decide when trucks may be parked without adversely affecting production.

Other more subjective benefits to have come about from the implementation of DISPATCH are improved material accountability, enhanced planning and operational control and the ability to simulate short-term mining scenarios.

Future developments

There are a multitude of applications that are scheduled for future development, three are worthy of particular note.

Truck refuelling

Haul trucks are refuelled once every 24 hours on a fixed rota system. On certain occasions trucks arrive at the fuel bay with an almost full tank of diesel, usually as a result of significant equipment downtime within the preceding 24 hours. In order to make the system more efficient DISPATCH will determine the amount of fuel used by each truck and automatically schedule trucks for refuelling when the fuel level is low. It is anticipated that this will increase the average interval between refuelling stops to approximately every 36 hours.

Tyre TKPH monitoring and control

The ton kilometre per hour level of each haul truck has a great impact on tyre life. By determining the amount of work done by a truck within a specific time frame it is possible to calculate the TKPH value attained and base future truck assignments upon the requirement for a less arduous haul cycle in order to reduce this TKPH value and hence the temperature of the tyres.

Vital signs monitoring

Damage to truck and shovel components can be significantly reduced if sufficient warning of abnormal running conditions is provided. Vital signs monitoring of equipment provides the necessary warning to prevent equipment damage in many cases. DISPATCH has the capability of monitoring up to 32 analogue and 32 digital alarms for each piece of equipment fitted with a field control unit. Any condition such as oil pressure, temperature or voltage can be monitored as long as it is possible to generate the necessary signal. All alarms are processed by the Vital Signs monitoring board in the field control unit.

Conclusion

Since the installation of DISPATCH the system has proven itself in terms of tighter and more efficient truck control. The information generated by DISPATCH permits the analysis of Palabora's mining operation to a level of detail not possible before. In financial terms the payback upon which the system was originally justified has been realised. However, the challenge for the future is how best to optimise this extremely powerful tool to take advantage of those more subjective and often not-thought-of aspects.

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