

1 *Advanced Technology in Mining*

Knowledge Discovery in Mining Truck Condition and Performance Databases

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ABSTRACT: Modern mining machinery is equipped with a large number of sensors that monitor its condition and performance. Data collected by these sensors is used to help with failure diagnostics, to warn the operators of impending failures, and to assess mine performance. Availability of large volumes of such data, gathered in real time and transmitted over wireless mine communication systems, together with availability of sophisticated data processing tools and the related hardware, provide a number of opportunities for further enhancement of mine performance. One such approach is application of data mining techniques for knowledge discovery in the databases containing condition and performance records of mining equipment. The paper describes the study undertaken to explore one such opportunity.

J INTRODUCTION

1.1 Background

Many newly developed technologies are being introduced to mining industry. Between these are the technologies that are capable of collecting variety of data on real time location, condition and performance of mining equipment. These technologies include Caterpillar's MineStar®, and in particular its part VIMS®, Modular Mining Intellimine®, and other. They were originally developed to facilitate development of a Total Mining System, a system that combines all mining related processes into one coherent and easy to control package, which allows optimizing the production and maximizing profit. Brief description of the selected technologies in question follows.

1.2 Caterpillar's MineStar

MineStar® is an integrated mining information system, developed by Caterpillar, Inc. and its alliance partners (Caterpillar, 2001). The system allows for tracking of machine health, productivity, machine and material movement, and drill management. It also includes Computer Aided Earth Moving System, CAES®, and an advanced truck assignment program. MineStar® has the capability of linking machines in the field to MineStar® office systems, as well as to other mine information systems. Caterpillar's alliance partners, Mincom and Trimble Navigation, have provided office software,

and radio infrastructure software and GPS technology, respectively.

1.3 Modular's Intellimine

IntelliMine® is being developed by Modular Mining Systems, a subsidiary of Komatsu Mining Systems (Modular Mining, 2001). Applied in surface mines, IntelliMine® is to allow to maximize mine productivity by integrating optimized haulage fleet assignments, high precision GPS applications, Web reporting, and the latest spread spectrum radio communications network, IntelliCom®.

In underground mines IntelliMine® will maximize production and minimize equipment downtime by optimally allocating equipment, managing and monitoring the mining cycles, and improving equipment utilization

1.4 Other Systems

In addition to the two integrated, multi-module systems described above, a number of other, single purpose systems are available. These can collect, store and transmit a variety of data related to mining operations. Typical systems in this category include Komatsu's KOWA® (Komatsu Oil Wear Analysis), Cummins' CENSE®, Contronic Monitoring System® used by Volvo Construction Equipment Group and Euclid-Hitachi Heavy Equipment Ltd., and TRIPS® system used by Terex Mining.

1.5 Mining Systems Innovations

Introduction of innovative technologies to mining is a precondition to development of more efficient, computerized, total mining systems. At present the bulk of development is related to surface mines, the result of simpler communication set-ups and availability of GPS (Global Positioning Systems). For the time being underground mining lags behind these developments. It lacks cost-efficient and effective communication systems, and required reliability of data collection / transmission technology is lacking.

Total Mining Systems, when developed, are expected to comprise of (Golosinski and Ataman, 1999):

- Accurate and reliable data acquisition / transmission systems able to collect, transmit and process data in real time
- All computerized planning and scheduling systems that interact with mine machinery to optimize the productivity and minimize human related delays and errors
- Vital signs monitoring systems that will track health and performance of every piece of equipment and facilitate timely predictive maintenance, which in turn will provide optimum availability and minimize operating cost of each piece of mine machinery
- High-speed, broadband communication systems that can download megabytes of data and transfer it bi-directional without delay. This will allow the whole system to function in real time.

With introduction of systems like MineStar® and Intellimine® this dream is about to be achieved. However, several problems still persist. One of them is lack of reliable predictive capability related to equipment condition and performance.

2 DATA COLLECTION AND STORAGE IN MINING

2.1 Background

The capability to both generate and collect data has been increasing rapidly in all industries. Today, countless databases are serving the needs of business management, government administration, scientific and engineering organizations, and many other applications. Resulting rapid growth in volume of data and database sizes has generated an urgent need for new technologies and tools that can intelligently and automatically analyze gathered data and transform it into useful information as well as extract knowledge contained therein. One such technology is data mining, discussed below. Data mining is becoming a research area of increasing importance.

Data mining, also referred to as knowledge discovery in databases, describes a process of non-trivial extraction of implicit, previously unknown, and potentially useful information from data in a database. There is a number of algorithms that can efficiently mine wide variety of data. These include Decision Trees, Associations, Neural Networks, Clustering, Genetic Algorithms and Rule Induction (Berson and Smith, 1997). Based on these algorithms a number of software packages were developed, which by now are user friendly and allow to efficiently mine the databases. Some of the packages use just one algorithm and found applications in a specific areas, whereas others use integrated data mining architectures with multi-strategy approach and can be used in a multitude of applications. The latter include Clementine®, Darwin®, and Intelligent Miner® (Freitas and Lavington, 1998) between others.

2.2 Knowledge discovery in mining

With extensive number of various databases the mining industry is in a unique position to take advantage of the advances in information technology. In particular data related to equipment condition and performance, available in abundance and easily transmitted via the Internet, offers the huge potential for application of modern data processing tools. Research presented in this paper is the world's first attempt to use data mining of these databases for knowledge discovery (Golosinski, 2001).

Subject of the investigations were databases containing mining truck performance and condition data collected in De Beer's Jwaneng Mine in Botswana. The data was collected throughout the year 2000 from several CAT 789B off-highway trucks using Caterpillar's VIMS® system. IBM's Intelligent Miner® V6.1 software package was used to do data mining. The purpose of investigations was to confirm the possibility of finding useful information in the subject databases by applying representative statistical and other data mining techniques. Brief description of the tools used in the investigations follows.

2.3 VIMS® (Vital Information Management System) of Caterpillar, Inc.

Caterpillar's Vital Information Management System (VIMS) is a tool for machine management that provides operators, service personnel and managers with information on a wide range of vital machine functions (Caterpillar, 2001). It collects the data generated by numerous sensors that are integrated into the vehicle design, and processes this data into a

set of equipment performance indicators. If VTMS detects an impending abnormal condition in any of the machine's subsystems, it alerts the operator and instructs him/her to take an appropriate action. This may be modifying machine operation, notifying the shop of needed maintenance or performing a safe shutdown of the machine. Use of VTMS improves availability, component life and production while reducing both repair cost and the risk of a catastrophic failures. A standard feature on large Caterpillar's mining trucks and wheel loaders, VTMS also provides production and performance information. Caterpillar's VIMSwireless® is a next generation technology that allows to transfer VTMS data through a wireless link between the truck and the office, and analyzes that data on an individual truck or a fleet-wide basis

VTMS System collects and records data in several files, namely: Event List, Snapshot, Data Logger Data, Trend Data, Cumulative Data, Histogram Data and Payload Data.

2.4 Intelligent Miner of IBM

IBM Intelligent Miner for Data (International Business Machines, 2001) helps to identify and extract high-value business intelligence from data, including high-volume transaction data generated by a point-of-sale, ATM, credit card, call center, or an e-commerce, to name just a few applications. This software package empowers its users to discover patterns, which might otherwise be unobserved, across volumes of data they would not be able to penetrate with other analytical tools. Intelligent Miner offers the opportunity to provide support to the mining process, as well as application services that enable development of customized software applications.

Intelligent Miner utilizes following statistical and data mining methods for knowledge discovery.

- Mining Functions: Associations, Clustering, Sequential Patterns, Similar Sequences, Classification, and Neural and Radial Basis Function Prediction.
- Statistical Functions: Bivariate Statistics, Linear Regression, Principle Component Analysis, Univariate Curve Fitting and Factor Analysis.

3 APPROACH

3.1 Data Source

As noted above, De Beer's Jwaneng Mine in Botswana provided all the VIMS data used in this research. The data was available as a number of sets, each set containing a complete record of 30 minutes of single track operation. The mine does not use

VIMS Wireless, thus the limit on the length of data records.

Each 30-minute set was downloaded from individual trucks into a notebook computer and subsequently converted into the database format (MS Access) using VIMS office software VTMSpc®

3.2 Data Cleaning and Preparation

To prepare data for data mining it needs to be reviewed and cleaned to minimize the "noise", which could have detrimental effect on evaluation of the results. Typical problems that need to be addressed at this stage include missing values, empty columns, mismatch of various records, and the like. The data sets that covered full truck cycle, usually around 25 minutes for the investigated mine, were selected for further evaluation. Sets with less than 25 minutes of data are automatically rejected.

Selected data sets were cleaned and care was taken to make sure that identical parameters were included in identical columns and that all the cells contained numeric values. MS Excel was used as data cleaning platform. In addition the column headers were matched with related columns using the MS Access Database.

The cleaned sets of data were then transferred to IBM's Intelligent Miner (IM) for statistical analysis and data mining. Sets of data can either be transferred to IM as flat files (MS Excel) or as database files (MS Access). IM also allows users to preprocess the data before using any data mining functions.

4 INVESTIGATIONS

4.1 Correlation Coefficients

The first step of the investigations involved search for correlation between various parameters. Knowledge of the correlation is a prerequisite for building a predictive model able to describe future performance and condition of the piece of equipment in question. Representative results of this work are shown in Figure 1 below.



Figure 1 Sample Correlation Coefficients of Parameters.

Rather than seeking correlations between all parameters, the clusters of related parameters were defined based on the understanding of how the piece of equipment operates, and analyzed. The clusters of related parameters are more representative of equipment condition and performance that is a complete set of parameters, many of which are not related through common features of design or operation of the equipment.

The investigations concentrated on analysis of data related to performance and condition of truck engine, transmission and differential, which together constitute the most important components of the mechanical truck. Only those VIMS parameters that represent recording of sensor outputs were evaluated. The other, calculated VIMS parameters, derived by combining output of various sensors were excluded from further evaluations.

5 RESULTS

5.1 Parameter Relations

The data sets contained records of 85 truck parameters recorded at 1-second intervals. Several of the parameters were recorded in a binary form, and not all parameters were recorded in all data sets. From all these only the data, which was thought to be indicative of truck engine, transmission and differential condition was selected for data mining.

The longest data set that contained four 30-minute data sets for a specific truck, total of 2 hours of data, was then data mined. Unfortunately, not enough complete data sets were available for all trucks for which the VIMS data was provided. The incomplete sets were later used for confirmation and validation of the results of data mining.

Two parameters: engine speed and fuel flow were selected to describe and define engine condition (dependent variables). Both depend on and are related to a number of other parameters (independent variables), including several parameters calculated internally by VIMS. The latter were not included in the analysis for die reasons justified above.

Engine Speed and Fuel Flow parameters are the related to the highest number of other parameters (Fig. 2). The results also indicate existence of a relation between "Engine Oil Pressure" and "Engine Speed", as suggested by the VIMS developer. In addition, a strong relation was discovered between "Engine Coolant Temperature" and "After Cooler Temperature".

The other VIMS parameters do not show statistically significant relations with the two main parameters: Engine Speed and Fuel Flow Rate.

The results presented above were obtained by mining of data collected at one mine site only and using limited data sets (2 hours of data at most, with

no more than 30 minutes of continuous data). It is, therefore, difficult to draw general conclusions applicable to the mining industry as a whole. However, the findings do apply to the operation in question.

		Correlation Coefficients	
Eng Speed	Related Para.	Cor. Coeff. x 100	
	Eng Oil Pres	66.82	
	Trn Out Spd	81.69	
	Ground Spd	81.79	
	Gear Code	82.55	
	Gear Seiet	78.74	
	Actual Gear	75.2	
	Diff Lube Pres	67.43	
I Fuel Flow	Related Para.		
	Eng Load	96.05	
	Trb Out Pres	95.3	
	Boost Pres	95.26	
	ThrtPres	89.65	
	Rl Exh Temp	78.61	
	Lt Exh Temp	85.32	

Figure 2 Correlation coefficients between Engine Speed and Fuel Flow versus related parameters.

Larger data sets are being acquired at present. It is hoped that their analysis may confirm relevance of the relations defined in this study to the industry as a whole. As this data is collected at several different mine sites, it will also allow to define site-specific relations between various VIMS parameters, if such exist.

5.2 Effects of truck Payload on VIMS Parameters

The next stage of the data mining was intended to analyze the relation between the payload carried by a truck and values of various parameters recorded by VIMS. For this purpose, a number of VIMS data sets were selected, each containing at least 25 minutes or continuous data. Out of 105 VIMS data sets that were available 35 fitted this criterion and were used in analysis. For all the selected data sets the data recorded for empty truck were combined with those for loaded one in order to define the relations between truck load and other VIMS parameters.

Since all data was recorded on the same model trucks, and since focus of investigations was on qualitative relations rather than quantitative ones, the external factors that may influence VIMS parameter values were not given consideration. These may include weather, road condition, type of hauled material, operator behavior and the like.

Overall the total length of the recorded data used in this analysis was 14,000 seconds (3.8 hours) with each of the 85 VTMS parameter values recorded once a second. The data was collected between January and October 2000.

The factor analysis module of Intelligent Miner was used to data mine these records. For compatibility with previous investigations the same parameters as before were selected as dependent and independent variables.

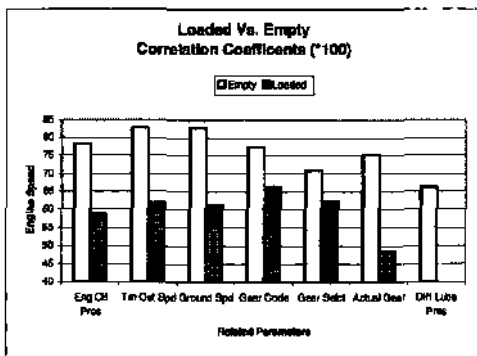


Figure 3. Loaded vs. Empty Truck - Engine Speed vs. Related Parameters.

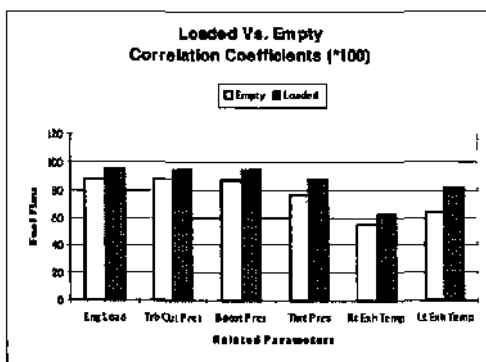


Figure 4. Loaded vs. Empty Truck - Fuel Flow vs. Related Parameters.

The representative, selected results of data mining reported in this paper can be summarized as follows:

- If the truck is empty, Engine Oil Pressure and other listed parameters are more strongly related to Engine Speed than when the truck is loaded. This relation is shown in Figure 3.
- e When the truck is loaded Fuel Flow parameter is more strongly related to the listed parameters (in

the referred figure) then when it is empty. This relation is shown in Figure 4.

Other results and relations are not discussed here for the sake of brevity.

5 CONCLUSIONS

Results of the investigations confirm that the data mining in general and IBM's Intelligent Miner in particular can be used to discover knowledge in the databases that contain data related to performance and condition of mining equipment.

The VTMS data is suitable for data mining with Intelligent Miner, providing that it is pre-processed to a format that is acceptable to Intelligent Miner. However, conventional VIMS System has a 30-minute on board data storage limit that prevents continuous data collection. Thus continuous analysis of data is not possible with this system. VIMS wireless needs to be used in future work to carry the analysis on a continuous basis in Intelligent Miner platform.

Intelligent Miner was not originally developed to data mine mining related databases. As a result communication problems exist between data acquisition systems commonly used on mining equipment and the Intelligent Miner.

The character of data collected by various mining data acquisition systems varies. As a result the specific data mining algorithm that is best able to handle the data may vary. Matching the algorithms to the data types is the subject of the research that follows.

REFERENCES

- Berson, A, Smith, S. J., 1997, Data Warehousing, Data Mining and OLAP, McGraw-Hill
- Caterpillar Inc 2001, www.cat.com.
- Chen, M, Han J., Yu, P S , December 1996, Data Mining- An Overview From a Database Perspective, IEEE Transactions on Knowledge and Data Engineering, vol 8, no 6, pp 866-883.
- Freitas, A A, Lavington, S. H., 1998, Mining Very Large Databases with Parallel Processing, Khrwer Academic Publishers.
- Golosmski, TS 2001 Data mining for information Proceedings, 29th APCOM, Beijing.
- Golosmski, T. S, 1999, Mining System Selection and Application Continuous vs Cyclical mining, Braunkohle - Surface Mining, vol 51, no 1,33-38, January
- Golosmski T. S., Ataman I K., 1999, Total Open Pit Mining Systems: A Dream or a Reality?, Proceedings, 16th Mining Congress Of Turkey, pp. 89-92
- IBM- International Business Machines 2001, www.ibm.com
- Modular Mining Systems 2001, www.mmsi.com

Performance of the Bigger, Faster and Smarter New Generation Electric Mining Shovels

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ABSTRACT: The world Mining Industry is seeing a continued movement to larger loading and hauling units in classic truck and shovel applications. The "Bigger, Faster, Smarter" equipment has provided a great opportunity to lower miner's cost per ton. However, in some cases, due to specific production requirements, established pit development or restrictions on capital, there are other available options in lowering the cost per ton. Better shovel/truck matching, and optimizing the loading activity are some considerations. This paper takes a look at the performance of the new larger loading equipment and explores the available options to keep abreast in a competitive market.

1 INTRODUCTION

"Higher productivity at a lower cost per ton", that's the common mantra we hear from the Mining Industry today. In the face of ever increasing operating costs and unpredictable commodity costs, as well as the increase in competition in an ever-shrinking Global market, many mining operations are under immense pressure to lower costs.

Many mine operators are faced with difficult decisions regarding equipment - "repair or replace?" in older operations, "what size is optimal?" in greenfield operations and "how do I become more efficient and cost effective with the equipment I already have?" The answers to these questions are further complicated by the volatile market in which we operate with a resultant myriad of choices for operators to consider.

In addition, we have seen a considerable increase in size of equipment in operation at mines with a theme of "Bigger, Faster, Smarter" for the latest offering from P&H Mining Equipment. As the equipment gets larger, some operators of existing mines with smaller and older equipment are considering "upgrading" to larger machines. Are the larger machines indeed as cost effective as the manufacturers claim them to be? And is the price tag justified?

So, the answer lies in the requirements of the operation and the prevailing economic constraints in that region.

Using examples from the P&H range, namely the 2300XPB, 2800XPB, 4100A and 4100XPB, this paper will demonstrate the effect on cost per ton of

different elements of the loading operation. Using an exclusively developed Interactive Production Costing Model, we have run countless scenarios to present the comparisons in this paper. All calculations have been done utilising the equipment to the maximum production with nominal truck presentation and typical mining conditions, and keeping them the same for all exercises. In reality, the results will vary from mine to mine and analysis should be conducted for specific applications. What is important in the numbers that follow are their comparisons relative to each other, not the absolute value.

2 SHOVEL SIZE

It's probably most common that shovels are referred to in terms of their nominal capacity in cubic units of capacity. This is calculated using nominal material densities; nominal weights of a general-purpose dipper, and nominal fill factor. Note the excessive use of the word "nominal", dipper sizing will change according to the conditions and constraints prevailing at a specific mine. So any shovel model will ultimately be sold with a dipper size "tailored" to the operation.

"Nominal" dipper sizes for the P&H range of equipment as follows:

2300XPB - 25 m³
2800XPB - 35 m³
4100A - 45 m³
4100XPB - 56 m³

Do we size a dipper for the "Rated Suspended Load" of the shovel, or do we consider truck size?

3 TRUCK MATCHING

The best match is one where the shovel, loading its maximum payload is able to fill a truck to its maximum payload in 3 or 4 even passes.

Typically the P&H shovel will be able to load a range of trucks. There is no absolute match, as mentioned before; the dipper will be tailored to give the right match. Figure 1 below illustrates the flexibility of the range; please note that truck payloads are indicated in METRIC tons:

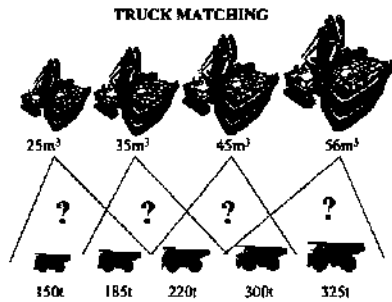


Figure 1 Truck-shovel matching

Figure 2 shows typical production levels for the shovels loading the selected range of trucks from 90t to 400t.

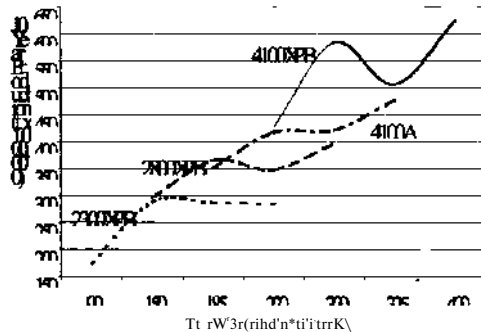


Figure 2. Typical production level for each type of shovels

This exercise does include some numbers that are not really a true match. Firstly there is currently no 400t truck, but the graph depicts what a 4100XPB would do with a truck that size. Secondly, it is geometrically not a good match for a 2800XPB to

load a 300t truck, but the numbers have been included to show the trend, production would actually be lower than depicted due to the geometrical constraints. Lastly, a 90t truck has also been included for the 2300XPB, again this is a match outside of the design of the shovel, but the curve trend is more apparent with it's inclusion.

What does this graph tell us? Firstly that the larger the shovel, the chances are you will get better production from the unit. Secondly, matching trucks is far more critical in the larger range of shovels than with smaller shovels.

The assumption also stands for this exercise that trucks should ALWAYS be filled to maximum payload. In a shovel/truck operation, the costs of loading are in the region of 30% of the total system costs. With the trucks therefore the more expensive portion, it stands to reason that if any under utilization of capacity is to be incurred it should be with the shovel. As the utilization of the shovel capacity approaches 100%, there may be merit in accepting slightly underloaded trucks, but this exercise would site be site specific and a separate exercise would have to be conducted.

One further assumption is that the number of passes to load a truck is 3 or more. To "drop" half of the payload of a truck into the bowl for the first pass is considered detrimental to the truck operator, as well as to the truck from the perspective of its structural longevity.

Figure 3 shows the impact on loading cost/t for matching different truck sizes.

From Figure 3, you see that the cost per ton also fluctuates for each shovel type, which highlights the need for truck matching. The overall trend across the product lines is that the cost per ton produced diminishes as we move towards the "Bigger, Faster and Smarter" shovels with correctly matched trucks.

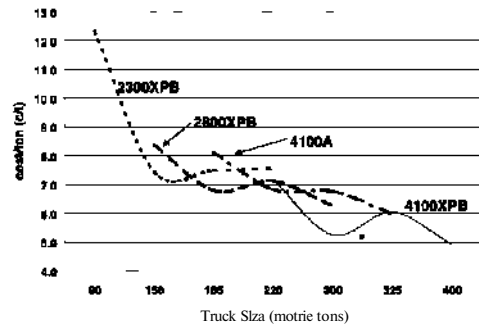


Figure 3. Unit production cost for each type of shovels.

An important element to consider is that you may not get the "ideal" match, with a resultant say, 2.8 passes required to load a truck. Some operators are

of the belief that they are able to judge 0.8 of a load, but much time is spent "getting it right" with the majority resultant that it is not. Overloaded or underloaded trucks are both detrimental to the operation. Overloading accelerates fatigue and induces premature failure, while underloading tends to be uneconomical. Figure 4 shows the effect of over or underloading trucks.

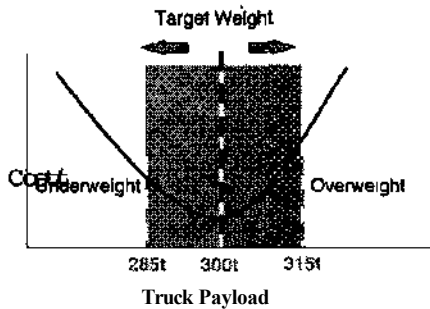


Figure 4. Typical truck cost curve.

The solution is to match the dipper to the truck and not the shovel. This ensures the best environment for the operator who then has to concentrate on efficient loading techniques, rather than exercising continuous judgement on truck fill. The next item that therefore raises a concern is the issue of productivity. All too often we as miners discuss the productivity of our equipment and use them as a basis of comparison. Unless both operations being compared are exactly the same the productivity comparison is meaningless.

4 PRODUCTIVITY

Productivity is a function of a number of factors, the major influences being:

- Truck size selection
- Blasting proficiency
- Average swing angle
- Truck presentation
- Truck Spotting time
- Operator efficiency

• Truck Size Selection

We have already demonstrated the effect of overall production on truck size selection. As we are becoming more proficient in understanding the conditions under which we are mining and the behavior of the material in the operation, we are able to tailor equipment for the mining operation. We

have alluded to dipper sizing, and matching it to the truck. There is now a trend to tailoring the truck to the mining operation. Much work has been done in the area of truck body design and there is a shift away from a "generic" truck body. This enables operations to be optimised and to ensure that payloads are maximised for that all-important 70% of the costs of the load and haul cycle - the haul.

In order to demonstrate the effect of truck payload selection, we have run the 4100XPB model with truck selection changes. Figure 5 graphically depicts the effect on productivity.

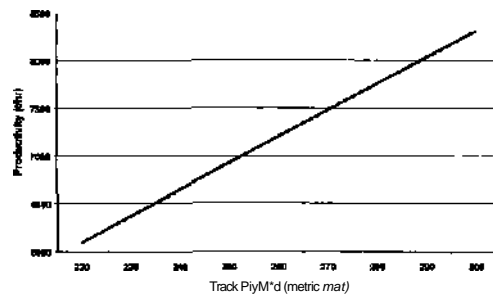


Figure 5 Effect of truck payload selection on productivity.

• Blasting Proficiency

Inefficiencies in drilling and blasting can cause substandard digging conditions resulting in either longer cycle times to fill a dipper or sub-standard dipper fills, and in some cases both of these conditions. To ensure that the truck is full the operator is forced to move from an optimal situation say, three-passes, to four or even five passes.

Figure 6 depicts the effect of sub-standard blasting conditions, where the operator is forced to deviate from optimal three-pass loading to a four or even a five-pass situation.

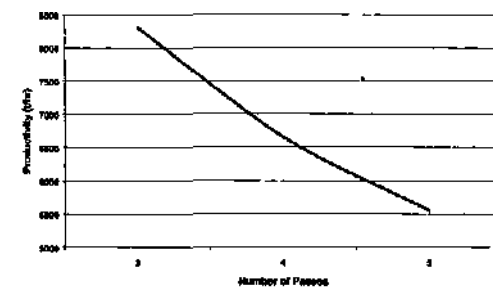


Figure 6 Effect of 3,4 or 5 pass loading on shovel productivity.

- Average Swing Angle

All the studies thus far have been conducted using an average swing angle of 70°. Choice of loading practice and face loading management on the part of the operator can cause the average swing angle to vary considerably. Figure 7 shows the effect of different average swing angles.

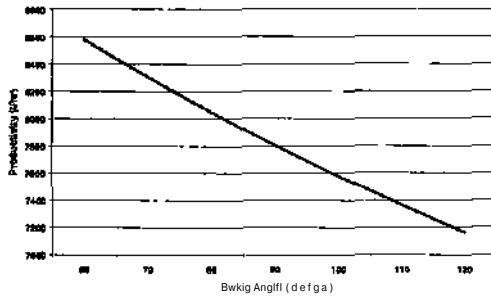


Figure 7. Effect of swing angle on shovel productivity.

- Truck Presentation

It could be debated that truck presentation does not affect productivity, since the time spent "waiting on trucks" is booked separately and not included in the calculations. This may well be the case for operations that are extremely "under trucked" and the operator *has* the time to book the waiting time. However, if the truck is in sight of the operator, the waiting time may not be booked and somehow gets included in the loading time and therefore used in productivity calculations.

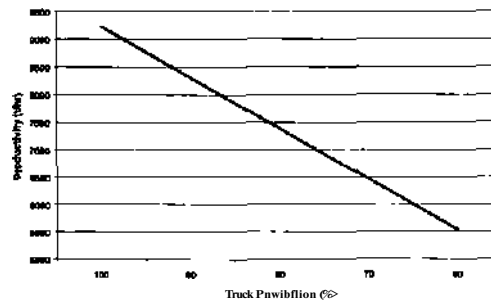


Figure 8. Effect of truck presentation on shovel productivity

These errors may also be eliminated if there is electronic monitoring of the truck fleet. For the purposes of this exercise let us assume that the

operator does not differentiate this waiting time from loading time. Figure 8 looks at the effect of truck presentation. The truck presentation is presented as a percentage, i.e. 80% Truck Presentation means that the shovel will have a truck to load 80% of it's available time.

- Truck Spotting Time

Much time is lost in the truck loading cycle due to maneuvering the truck into the loading position. The use of the double back-up loading method does bring this to a minimum. Some applications utilize a modified drive-by method of loading with a resultant spotting time of less than 10 seconds. Poor practices could result in Truck Spotting times of more than a minute.

Figure 9 demonstrates the effect of Truck Spotting Time on Productivity. One thing to remember is that truck spotting time is also affected by floor conditions (severe undulations) or floor cleanliness ("housekeeping" around the shovel).

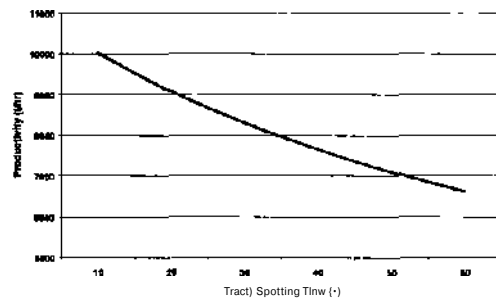


Figure 9. Effect of truck spotting time on shovel productivity

- Operator Efficiency

The operator spends 8 hours a day on the shovel and is probably the single biggest contributor to shovel efficiency. The control of digging and loading practices falls directly under the control of the operator. In essence, the shovel operator is the manager of the loading operation.

The method the operator tackles the digging face influences swing angle, time in the bank and truck positioning.

The net effect of an inefficient operator is increased shovel cycle time. Figure 10 shows the effect of increased cycle time on the loading operation.

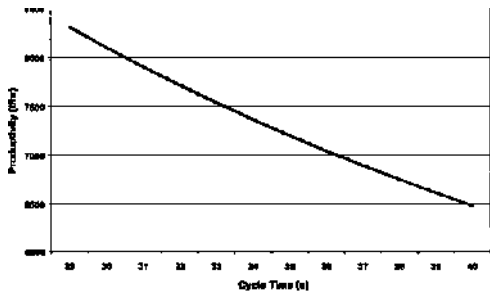


Figure 10. Effect of increase in cycle time on shovel productivity.

5 TECHNOLOGY

A large portion of this paper has concentrated on productivity - and technology is a huge contributor to the high productivities we now enjoy.

Digital controls, OptiDig, Diagnostics, Remote Communication and LoadWeigh capabilities all contribute to these productivities.

- Digital Controls

The older analog control curve has a single point where peak power, the product of bail pull and bail speed, is delivered. From Figure 11 one can see the digital peak power is delivered over a much wider range of operating points.

This capability, plus more bail pull at the slow end of the curve reduces time in the bank. The higher speed at light loads reduces time lowering an empty dipper.

Lower cycle times mean higher productivity.

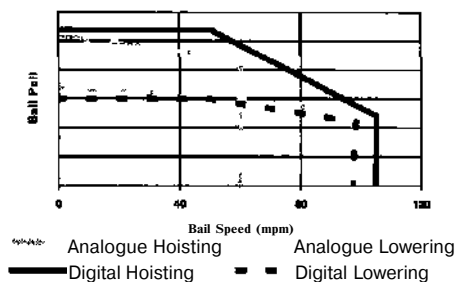


Figure 11. Bail pull vs bail speed in analog and digital control

- Diagnostics and Remote Communications

Although probably more related to "uptime" and therefore overall production, this is an important feature that mine operators can pursue in achieving

overall shovel efficiency, and ultimately higher annual production.

A program of regular diagnostics can identify trends and highlight problems before they occur. In addition, the newer technology, associated with a network of relay stations can bring vital sign monitoring right into the maintenance offices.

Operators can also be monitored from remote locations and potentially expensive practices can be halted before their continuance can result in unnecessary downtime. Cycle time analysis can also be carried out from a distance and an education program set in place to rectify any bad habits from manifesting themselves in the operation.

- OptiDig

The digital technology also enables the new equipment to be fitted with productivity enhancing tools such as OptiDig which senses digging motion feedback and balances hoist and crowd motions to optimize power usage, regardless of material density or operator experience.

- LoadWeigh

The ability to tell with any CERTAINTY what's in each dipper load is an extremely valuable tool for the operator. This provides a "dipper by dipper" account of the payloads loaded by the operator. From this feedback the operator is able to accurately determine what's on each truck and the system informs the operator the remaining tonnage required to make up the truck payload. So the primary use of this tool is to tighten up load variance (see Figure 12). Of course, the operator is not entirely responsible for the efficiency of the dipper fill, blasting plays an important role in this and LoadWeigh is another tool to determine blasting effectiveness.

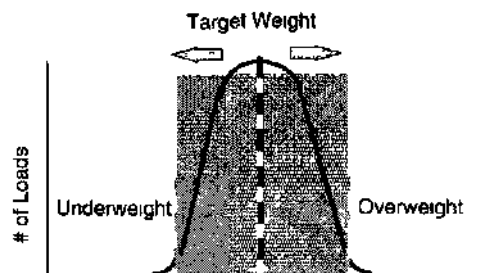


Figure 12 Tighten up load variance.

There are many other features inherent in the shovel of today that enhance productive capability and minimize downtime. That's what makes them "Smarter".

6 WHAT ABOUT THE OLDER EQUIPMENT?

Does this mean that in order to "enjoy" the benefits of new technology that new equipment should be purchased? Absolutely not! In an ongoing effort to meet the needs of the Industry, we recognise that not all equipment has reached the end of its useful life, and that not every operation has the available capital for full machine replacements.

Every development project is conducted not only with the newer equipment in mind. Our engineers make every effort to provide the newer technology in the form of an upgrade for our older models still working in the field. This presents an economical alternative to operations to become more cost effective at the loading face, and which does have an effect on associated operations as well.

We have seen dramatic improvements in productive capability in operations that have opted for the digital upgrade. Of course, the introduction

of the digital technology opens the door for the application of other upgrades such as OptiDig and LoadWeigh.

So being an owner of older equipment does not necessarily preclude one from applying the new technology.

7 SUMMARY

In this paper we have highlighted the benefits and cost effectiveness of the new "Bigger, Faster, Smarter" shovels. We understand that not every operation is suited for the larger equipment and there is definitely a benefit in going smaller, especially when one is limited regarding quantity of final product. We are sure there is still sufficient food for thought for existing operations that are just looking for improvements in efficiency, not only from an applications standpoint, but consideration of training and upgrades.

Finally, we extend our thanks to P&H for giving us the opportunity to share some ideas on improvement of the shovel/truck operation.

Together we can move forward to produce at the lowest cost per ton.

Assessing Spontaneous Combustion Risk in South African Coal Mines Using a GIS Tool

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ABSTRACT: The mapping of areas that are prone to spontaneous combustion can be achieved by using a Geographic Information System (GIS) as a database. This database can be considered as a collection of spatially referenced data that acts as a model of reality. The main spontaneous combustion risk factors are: coal factors, geological factors, environmental factors, and mining factors. The calculation of the coal factor will be explained in detail. For each factor that contributes to the spontaneous combustion problem a raster map is created. These maps are then assigned ratings according to pre-determined ranges of values and each are assigned a weighting. A risk map is obtained by combining the weighted maps.

I INTRODUCTION

The Witbank Coalfield in Mpumalanga Province of South Africa extends over a distance of approximately 180 km from the Brakpan/Springs area in the west to Belfast in the east and about 40 km in a north-south direction. It is known that the Witbank Coalfield (Figure 1) has a recurring spontaneous combustion problem.

There are over 50 collieries operating throughout the coalfield. In order to study the spontaneous combustion problem various data had to be collected by visiting the collieries and through a literature survey.

A searchable database for existing literature has been created for easy access to the information. It reviews current practice in detecting, monitoring, preventing and controlling spontaneous combustion at all stages of coal production. Problem areas include underground, surface and abandoned mines, spoil piles, dumps, storage, transport and pillars. The number of papers and reports collected so far exceeds 400.

Tests have been performed on coal samples from various collieries to determine the Wits-Ehac Index, which measures self-heating liability by using differential thermal analysis (DTA). The test apparatus used was developed at the School of Mining Engineering, University of the Witwatersrand (Gouws et al., 1987). DTA has historically been considered a good predictor of self-heating liability.

Following a large experimental study, a new index was developed by Gouws (1987). This Wits-Ehac index makes use of the crossing-point temperature and the slope of the differential temperature time curve, as follows:

$$\text{Wits - Ehac Index} = 0.5 * \frac{\text{slope of stage II}}{\text{crossing - point}} * 1000$$

A coal with a high Wits-Ehac index is more prone to spontaneous combustion than a coal with a lower index value (Gouws, 1987).

Because of the known incidents of spontaneous combustion, there was a need to locate problem areas within the Witbank Coalfield. It was found through the literature survey that a relationship exists between the coal properties and spontaneous combustion risk.

This relationship could either be studied by statistical methods or visualization of the coal properties on the map. The visualization technique developed to map the high-risk areas using a GIS tool is the subject of this paper.

2 RELEVANT FACTORS

Chakravorthy and Kolada (1988) grouped the critical factors contributing to spontaneous combustion into intrinsic (coal properties and geological features), and extrinsic, i.e. those that can be controlled (mining practices). These are listed in Table 1.

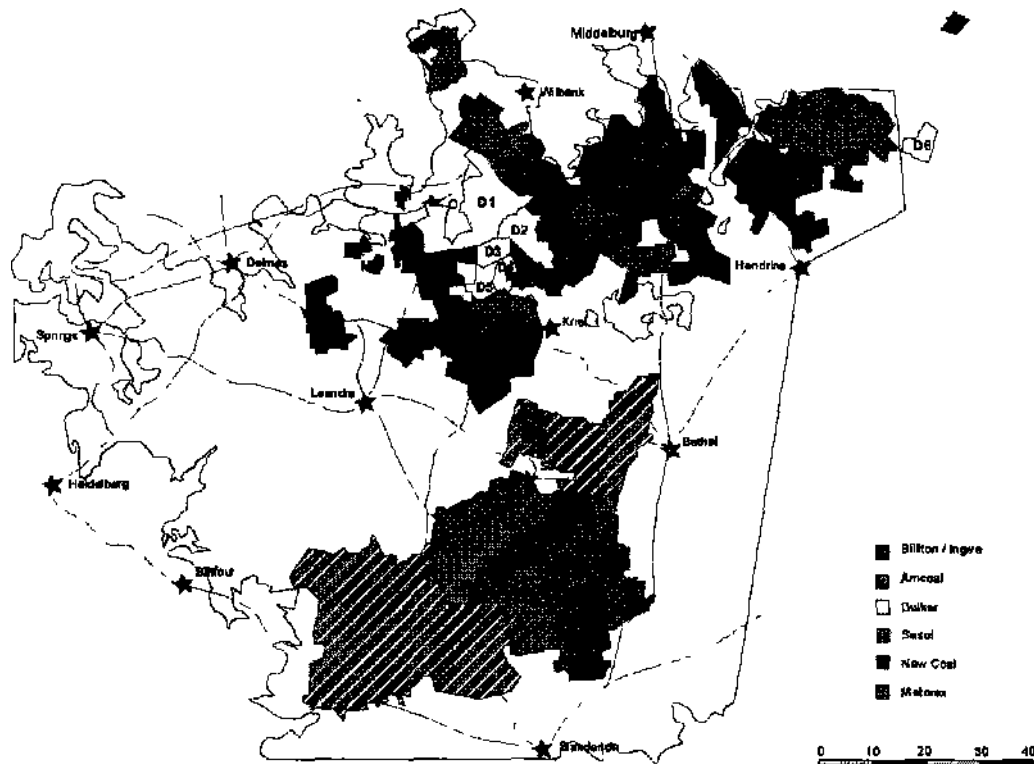


Figure 1. Locality map of Witbank Coalfield Collieries.

Table I Critical factors contributing to spontaneous combustion

Coal Properties	Geological Features	Mining Practices
High volatiles	Thick seams	Coal left at roof and floor
High Moisture	Pynte bands and carbonaceous shale	Poor maintenance of roadways
High Pyrites	Presence of faults	Air leakage through air crossings, doors, pillars
Presence of exinite, vitrinite, inertinite	Weak and disturbed strata	Caving to surface under shallow overburden
High friability	High strata temperature	Close proximity to multi-seam working Poor ventilation management

3 DATABASE BUILDING

Management of spontaneous combustion depends largely on how information is handled in order to define and monitor problem areas. By studying the

Witbank Coalfield a methodology has been developed to locate and define problem areas.

Data handling should be approached in a systematic manner by using databases and computer programs that are capable of handling various kinds of input.

There are a few expert systems and/or fire risk indices developed by various organizations in different countries. Many of these expert systems were developed for unique circumstances such as opencast mining or mine dumps only. These expert systems were not found suitable for the coalfield concerned.

The Witbank coalfield is currently worked by many collieries with varying mining methods and environmental factors. This means that the whole coalfield cannot be assessed by a single formula containing all the risk factors. Nevertheless, a coal risk factor map can be produced irrespective of the mining methods employed at the individual mines.

A different approach was used to assess the potential risk of spontaneous combustion for the Witbank coalfield. Various maps (contour maps, polygon maps, segment maps, point maps, raster maps and topographical maps) are generated as tools for the database. A GIS software package (ILWIS)

capable of integrating land and water information was chosen for generating these maps.

In this knowledge database the Wits-Ehac liability index is included together with coal properties.

3.1 Wits-Ehac Liability Index and the Test Apparatus

Differential Thermal Analysis (DTA) and crossing point temperature tests have been carried out to find the Wits-Ehac index value of the coal samples from the Witbank area collieries.

The apparatus consists of an oil bath, coal and inert material cell assembly, oil circulator, heater, flow meters for airflow monitoring, air supply, compressor and a microcomputer. The temperatures are recorded every 15 seconds by the microcomputer during an average of a 3-4 hour testing time. The coal is heated from 30 °C to 200 °C. The kick-point and the crossing point temperatures are determined. The kick-point can be defined as the temperature at which the coal starts burning. Crossing point temperature is the temperature at which the coal temperature is higher than the inert material (Calcined Alumina) used.

Three sets of differentials (the difference between the temperature of inert material and that of coal) are obtained. These are used to form DTA curves. There are three slopes on these curves. *Slope I* starts at minimum differential to crossing-point temperature where the differential is zero. *Slope II* starts from crossing point temperature to the kick-point. *Slope III* is where the coal starts burning after the kick-point temperature. Stage II slope is one of the best indicators of spontaneous combustion. The steeper the Stage II slope the more liable the coal is to spontaneously combust.

The calculated Wits-Ehac values may range from as low as 2 to as high as 7. Through experience it was found that coals with values up to 3 are considered low risk, 3-5 are considered medium risk and 5 and upwards are considered high risk coal.

In order to determine the Wits-Ehac index for Witbank collieries several laboratory tests have been performed on samples taken from various collieries.

3.2 Coal Properties

Previous researchers have established a link between the coal rank, coal petrography, moisture, presence of pyrites and spontaneous combustibility.

In particular, there is said to be an inverse correlation between the rank of the coal and spontaneous combustion propensity. It is reported that lignite and sub bituminous coals are more liable than anthracite. Bituminous coals with high volatile matter result in relatively higher self-heating rates than those with low volatiles. The Witbank coalfield is bituminous throughout and therefore rank is not included in the calculations.

There are four lithotypes in banded coal, which are: vitrain, clarain, durain, and fusain. Recent work generally concluded that vitrain, clarain and durain, in that order, are more susceptible to oxidation than fusain. Therefore, it was decided that vitrinite, exinite and mertinite (they exist in the composition of vitrain, clarain, and durain) should be used as contributing factors in the risk calculations.

Another important factor in determining the self-heating liability is the change in moisture content with time. The significance of this factor is itself dependent on the environmental conditions in the coal seam. If the temperature difference is very high after rain then there is a good chance that it will increase risk. However, in normal conditions in-situ moisture would decrease the risk of spontaneous combustion. Based on this fact, in-situ coal seam moisture is used as a factor, where the less the moisture content the higher is the risk. In order to consider the effect of weather conditions the climate variations can be mapped and added to the risk calculation.

In addition to the factors mentioned above, the factors listed in Table 2 should also be used in generating risk maps and in the calculations.

To date the research has not used all of the factors mentioned here but most of the coal factors and depth of coal seams have been used.

Table 2. Contributing risk factors for each category

Coal Factors	Geological Factor	Environmental Factors	Mining factors
Coal reactivity, Calorific value.	Presence of dykes and sills, Presence of faults.	Mean annual temperature and rain fall distribution	Method of working (opencast or underground, retreat or advancing, etc),
Density, Ash content, Volatile matter, Inherent moisture, Pyrite content.	Depth of the seams. Floor rolls, Parting, Overlying strata, Seams in proximity,	Water table variations, Subsidence, Shallow abandoned workings.	Coal left at roof and floors Rock bumps, Scope of accumulation of fines.
Total sulfur, Vitrite, Exinite, Inertinite, Friability, Porosity		Sinkholes, Source of hot spots, springs, adjoining fires	Rate of face advance, Nature of extraction (one lift, multiple lifts)

4 GENERATING MAPS

There are two important components of geography dependent data; its geographic position and its attributes or properties. In other words, spatial data (where is it?) and attribute data (what is it?) are distinguished. In the Geographical Information Systems spatial and attribute data are linked to get real information.

Attribute data in this case will be factors that affect spontaneous combustion.

The process undertaken has followed a particular sequence. Firstly, maps of the Witbank Coalfield collieries were digitized by using 15 sheets

(1:50000). The topography of the Witbank Coalfield is shown in Figure 2. Another map is digitized showing the boundaries of major collieries and overlaid onto the topography map.

The digitized maps are of three types: point maps (showing collieries or sample points), polygon maps (boundaries of the collieries) and segment maps (topography and main reference points such as major towns, railways, main roads, etc.). These maps can be overlaid on each other, or mathematical and statistical calculations can be performed. In order to simplify comparisons between them, each map was created with the same resolution.

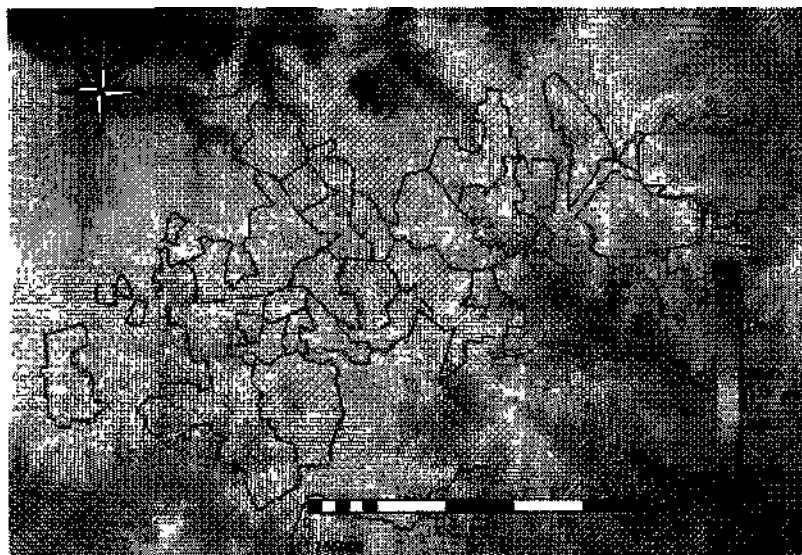


Figure 2 DEM of Witbank Coalfield created from topography map; colliery boundaries overlaid on it.

Most of the analysis is based on raster maps. In a raster model, spatial data are organized in grid cells or pixels (a term derived from "picture element"). Pixels are the basic units for which information is explicitly recorded. A resolution of 200mx200m per pixel was chosen, since this allows the smallest items within the coalfield, such as panel length to be seen.

A map was created for each contributing factor. The pixel values of each map can be combined according to a formula, e.g. $MapA + MapB = MapC$. The IL WIS GIS software can calculate each pixel with the same coordinates according to the defined formula and records the results in another map.

One may ask why the use of maps instead of spreadsheets in order to calculate risk or define problem areas. To be able to add, for example, the risk factor of the Wits-Ehac Index and subsidence,

point form cannot be used, as the data types are different. Risk of subsidence can only be expressed in an area map. Therefore all the point maps with coal properties information have to be converted into two-dimensional maps.

A point map of collieries (sample points) is digitized and linked to an attribute table in which there are separate columns for each coal property such as percent of volatiles, percent of ash, pyrites, vitrinite, etc. For each attribute column a point map is created with a value domain. These point maps are rasterized in order to be able to make mathematical calculations.

The rasterized point maps can be analyzed by using spatial autocorrelation of point data. The statistical analysis referred to as spatial autocorrelation examines the correlation of a random process with itself in space. A point interpolation

performs an interpolation on randomly distributed point values and returns regularly distributed point values. Filling in the spaces between the points depends on the chosen resolution and the type of interpolation method. For coal factors a resolution of 200 m is chosen. For the total Witbank Coalfield the size of the map is 564 x 599 pixels, each pixel being 200 x 200 m². Various interpolation methods can be used: Voronoi tessellation, moving average, moving surface and trend surface. However, the best

interpolation method for most geological features is moving average (ILWIS2.1 Applications Guide, 1997) and so it was used to obtain the coal factor maps. Inverse distance is selected as the weighting function. The resultant map is a raster map with equally distributed values in space, e.g. the ash percentage distributed throughout the coalfield has been mapped using the moving average method and can be seen in Figure 3.

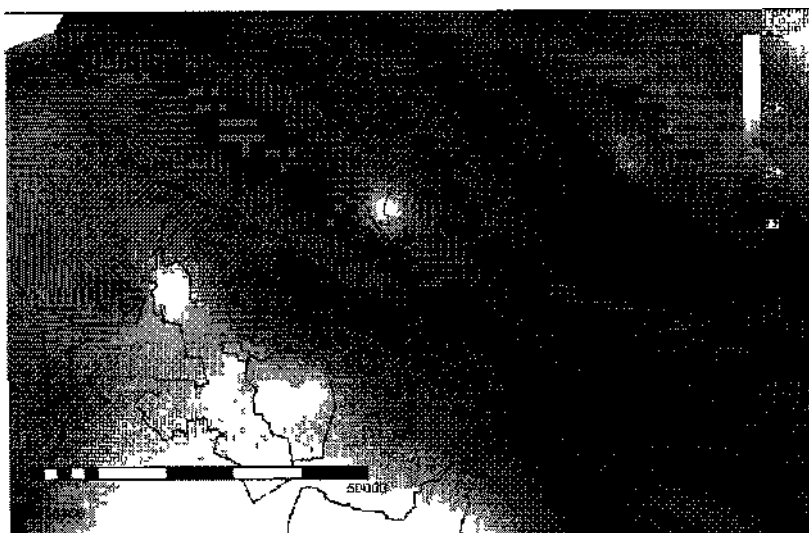


Figure 3. A rasterized map of ash content obtained by moving average from a point map.

5 MAPPING PROBLEM AREAS

Each of the maps created using the moving average method has also been assigned weighting values depending on the range of data. In order to assign weights the value range within a map has to be divided into regions of high to low risk.

The map in Figure 4 shows the depth of seam factor, which is obtained by inserting the ranges of values from high to low risk. According to local mining experience, where the depth of seam is less than 40 m risk is high while between 40 and 300 m below surface spontaneous combustion risk is considered low. Therefore a weighing of 2 is assigned for depths less than 40 m and 0 for deeper seams.

Other maps of different coal factors are created similarly. The risk ratings for each contributing factor have been determined by examining the literature and are also based on practice. Singh and Demirbilek (1984) classified the risks and determined factor ratings; the rates from their paper and from other literature were the main basis of determining the weightings used in this research.

The weighted maps are then created from the raster maps of coal properties. They are then simply added to obtain the risk map (Figure 5). The resultant map can be "sliced" to highlight areas with high risk.

As an example of comparing research results with practice, it can be seen in Figure 5 that part of a colliery shown by the arrow is in the high-risk area and it is known that this colliery is currently experiencing serious spontaneous combustion problems. However for this risk map only the coal factors and the depth of the seam have been used. Other factors such as mining, geology and environmental conditions have not been included. In this colliery opencast mining of old pillars left from previous underground operations is practiced. This is a mining factor that contributes heavily to the spontaneous combustion problem.

It is accepted that the weightings used are still not perfect. This is merely a technique developed for application of GIS for environmental risk assessment.

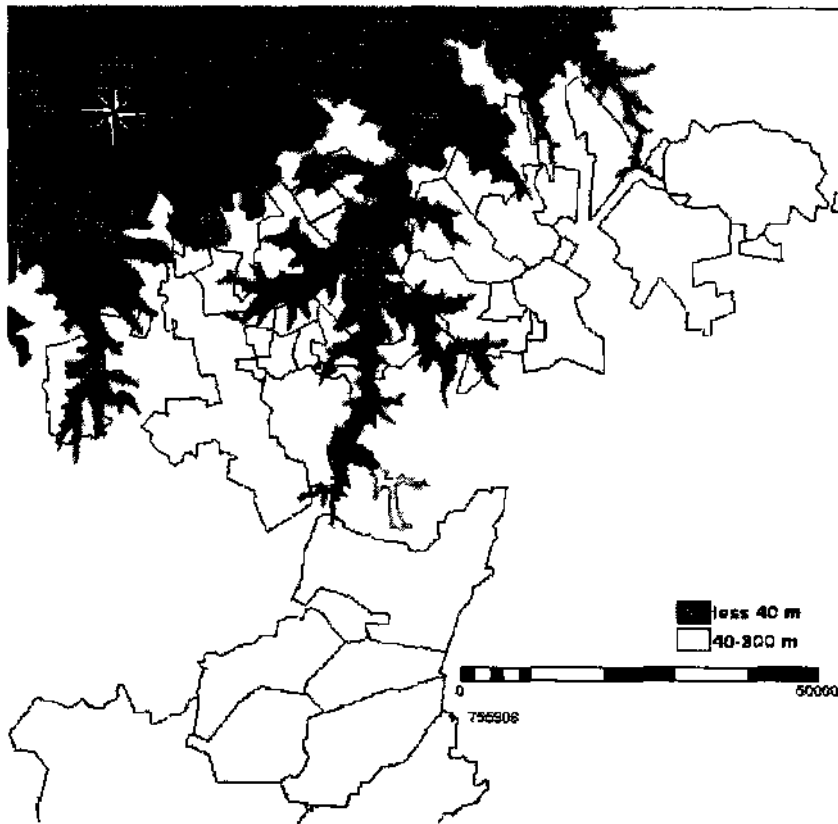


Figure 4 Sliced map of depth factor.

A comparison of actual incidents and this theoretical information - depending on future incidents of spontaneous combustion - can be used to perfect this technique.

The way to determine the range should be based on local experience, supplemented by an iterative process of comparing results with observed conditions on the mines. The maps are applied the slicing operation after defining the range and determining the rating limits (Figure 4).

6 CONCLUSIONS

The above techniques for risk calculation and mapping of the nsk areas is a simple approach as far as the mapping of spontaneous combustion propensity is concerned. In the literature nsk factor calculation is usually in the form of formulas and tables. This research has shown it is possible to bring together all kinds of information by using GIS techniques. It is also suggested that the monitoring

of existing coal fires can be undertaken by using the same software.

Coal fire monitoring by aerospace remote sensing and GIS techniques is an advanced approach, which has been implemented in the Rujigou coalfield, Northwest China. There they have developed a PC-based information system with the aim of monitoring spontaneous combustion and managing information such as remote sensing and geological surveys (Wang et al, 1999).

One advantage of computerized risk analysis is that the database that is needed to analyze the coalfields can be updated as information becomes available. Updating risk maps is fairly quick and easy. The software allows update of the risk maps as new data is entered without having to recreate all the maps.

In the future we can find out the effect, changing environment and mining conditions has on the overall risk map. This can be done by comparing the old risk maps to the new by keeping the database alive.



Figure S Combined nsk map (lighter colors showing high nsk areas)

ACKNOWLEDGMENTS

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REFERENCES

- Chakravorty, R.N., Kolada, R.J., 1988, Prevention and Control of Spontaneous Combustion in Coal Mines, *Mining Engineering* October
- Gouws, M.J., 1987, Crossing point characteristics and Differential Thermal Analysis of South African Coals. *M.Sc. Dissertation Johannesburg* 14
- Gouws, M.J., Wade, L., Phillips, H.R., 1987, An Apparatus to Establish the Spontaneous Combustion Propensity of South African Coals, *Symposium on Safety in Coal Mines CSIR Pretoria*, p 71-72
- ILWIS 2.1 for Windows, 1997, Applications Guide. *ILWIS Department, International Institute for Aerospace Survey & Earth Sciences Enschede, The Netherlands*
- Singh, R.N., Demirbilek, S., Turney, M., 1994, Application of Spontaneous Combustion Risk Index to Mine Planning,

Safe Storage and Shipment of Coal, *Journal of Mines Metals and Fuels* July

- Wang F., Vekerdy Z., and van Genderen J. L., 1999, Database management and implementation for coal fire detection and monitoring in the Rujigou Coalfield, Northwest China. *2nd International Symposium of Remote Sensing Enschede The Netherlands* 16-20 August

A New Approach to Monitoring in the Advanced Dispatching System for Coal Mines

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ABSTRACT: Monitoring and supervision systems based on binary signals (machine operation/standstill), which are currently in common use in Polish coal mines, are insufficient for management needs. Machine diagnostics and facility management require continuous checking of the load parameters of longwall complexes, mining machines, haulage lines and the power supply conditions of machines. The visualization of the state of an object as complex as a mine must be uniform, fast and synchronized, forming the basis for selective, easy data access. For almost 30 years, the EMAG Centre has been developing and supplying dispatching systems to coal mines. This paper deals with how the development of computer-based systems proceed. The function and features of the new dispatching system SD2000 are described. Coal mine monitoring levels and applied web, Internet and intranet technology are presented.

1 INTRODUCTION

Efforts in the Polish coal industry to withstand competition from foreign coal are focusing on the areas of safety, reliability, profitability and environmental protection of mines (Mironowicz & Wasilewski, 2000). This means that mines must be provided with modern techno-organizational solutions in order to enable improvements in output.

This can be achieved by:

- extending the effective operating time of machines and equipment,
- increasing time between overhauls,
- minimizing production stoppages resulting from safety hazards.

However, this situation requires a new approach to supervision problems at mines. The demands of operations management in the control area of a modern coal mine can be met only by sophisticated equipment and control systems. The range of duties of the main dispatcher of the mine extends from human safety through high availability and long service life of machines to high efficiency and rapid deployment of reserve capacity. Comprehensive monitoring of the mining complexes and haulage lines together with diagnostics and early warning of pre-failure states are essential.

2 DEVELOPMENT OF DISPATCHING SYSTEMS AT EMAG CENTRE

The early 1970s marked the beginning of computer-aided dispatching systems in Polish mines. Based on original constructions - the minicomputer MKJ-25 (Gacek & Wojciechowski, 1976) - the first dispatching systems were implemented at two mines. Processing limits made it necessary to replace the MKJ-25 with proven hardware and system software. In the late seventies, a clone of the minicomputer series HP2100 was created, application software was developed, and mines were provided with a system called SMC-3. Operational experience, developed software and access to domestic medium-scale integrated elements at the beginning of the eighties resulted in the production of the industrial minicomputer PRS-4 by the EMAG Centre (Mokrosz et al., 1982). Successful construction (up to 1988, 150 sets were produced - the majority installed at mines in Poland, Romania and China) became the hardware base for modular dispatching systems offered by the EMAG Centre to mines.

The basic modules of this system were:

- HADES - monitoring of process run and output balance.
- SAK - evaluation of bounce hazards by seismoacoustic methods.
- SYLOK - location of tremors and estimation of their energy.

- CMC 1/2 - digital methane monitoring outstation.

The next stage in the evolution of dispatching systems at the EMAO Centre was the development of the MICROHADES and DTS modules. The DTS module made it possible to present technological data on semi-graphical color television screens, creating a Dynamic Synoptic Table. The DTS software was introduced to the PC platform by a group of former workers of EMAG, and the ZEFIR system (Dec & Gajoch, 1999) was implemented in mines starting from 1992.

3 PROJECT GUIDELINES FOR SD2000

Although the ZEFIR system was at first accepted by users, soon there was a need for further development. However, the decision to retain compatibility with preceding versions (SMC-3 -> PRS-4 -> PC; DOS -> Windows; flat binary, file data structures) prevented effective technological changes. In Poland in the nineties, coal mines became part of the economy where the notion of efficiency and profit became a normal economic term. Dispatching systems had to become instruments contributing to cost reduction in coal mining and machine operation. The concentration of mining and considerable reduction in employment required the development of system functionality on the mine surface as well as underground. The system had to become open, a component module of the future system type MRP, ERP or SAP for mines. This was a new approach to the problem of dispatching systems at the EMAG Centre. The first attempt to replace the DTS function by large-format projection took place in 1998 (PTS-1, Poppe & Zymelka, 1998). In 1999, EMAG proceeded to develop a completely new dispatching system, named SD2000 (Wojciechowski, 1999). The supervision of processes and the mine safety state requires systems of continuous operation based on developed structures of analog data acquisition which provide information about the parameters of equipment operation and processes. Decision making on the basis of a huge data stream is beyond the capacity of a mine dispatcher. Thus, it was necessary to create a hierarchical supervision structure at particular levels, with the separation and suitable assignment of control functions to a special mine division.

A modern monitoring, control and management system for mines cannot consider the problems of individual machines, devices and processes separately, but must put them together in complex, correlated structures presented on the mine spacing chart. This concerns not only the ventilation system but also the structures of transport, power supply,

power shutdown, advance rate and the location of the cutter-loader at the longwall, etc. This was the starting point of the project.

In the project, the following assumptions were accepted:

- to make diagnostics of longwall complexes as thorough as possible,
- to relieve the chief dispatcher of the observation of process parameters by transferring part of his duty to a suitable division of the mine,
- to offer the chief dispatcher concentrated, easily comprehensible information,
- to assist the chief dispatcher in critical situations and in the control of miners working underground,
- to provide the accounting, planning and quality inspection departments with tools for analysis and simulation,
- to provide high-level supervision staff with tools for quality inspection,
- to eliminate duplication of work connected with updating maps, plans and diagrams in paper and electronic forms by including a planning department to direct the service of the system,
- to reduce the service and maintenance costs of the system,
- to use the latest computer technology,
- to present the monitoring results according to a hierarchical scenario.

For the computer part of the SD2000, the following assumptions were accepted:

- an open, distributed system,
- PC and Windows platform,
- standard communication protocols,
- modern, effective database,
- intrinsically safe system for digital field transmission,
- dedicated industrial network (Ethernet) on the surface, operating in conjunction with the LAN in the mine.

4 IMPLEMENTATION ISSUES

A hard coal mine, as an object of monitoring, presents a complex spacing structure. In the conventional systems of control and supervision, monitoring is applied at two levels - local and global. At the mine, this corresponds to the level of technological centre supervision and the dispatcher's level observing all processes according to the accepted scenario. To date, dispatcher system support has used two scenarios - territorial and technological. The first includes monitoring of all equipment and sensors in one place, e.g., getting region; in the other, monitoring comprises a group of devices combined in technological line, e.g., main haulage with surge tanks. So far, no hierarchical

scenario has been realized. On the one hand, it features a highly concentrated information overview of the state and run of all-mine processes in one compact area at the same time; on the other hand, It presents, in a remarkably simple way, detailed information on the operation, standstill and failure of all equipment. The realization of such a scenario required the development of technology and price reduction in an efficient engineering process within the hardware, software and database mechanisms.

The idea of presenting the mine structure and technological and safety state with the use of the methods applied in the programs of the geographical information system and management facility GIS/CAD FM lay in:

- the use of real maps and schemes used every day by a mine to create images of mine spatial structure on monitors or large-screen displays,
- the assignment of graphical schemes of particular technologies to successive image layers, e.g.:
 - alarm broadcasting communication line,
 - telephone line,
 - power network,
 - degassing pipelines,
 - air pipelines,
 - fire-fighting pipelines,
 - fresh and used air current path (ventilation system),
 - escape routes,
 - location of technological lines,
 - location of fans,
 - location of air-stopping,
 - location of signaling-telephone sets,
- animation of change in the color/shape/size of a graphical object, representing a sensor change of the measured parameter,
- signaling of fire/gas/bounce/water hazards in the region by change of color in the area background,
- connection of the sensors on the map with a database containing current and archival measuring values and description.

All these, accomplished by intelligent software of the MMI environment, made the dispatcher's work easier, enabling:

- the manipulation of layers in any combination of overlapped images of beds and process maps,
- the selection, zoom and storing of maps and installation fragments selected in a very easy way by using the favorite option,
- fast search and location of objects on maps through knowledge of their exact or approximate names,
- personalizing of MMI (Man Machines Interface).

The benefits of such an approach are:

- the use of only a single set of technical documentation (digital) by all mine divisions,

- simultaneous mapping of changes in surveying geological and technological description at all mine workstations,
- updating of documents at specialist divisions (communication, electrical engineering, ventilation, methane monitoring, etc.) with the background of an up-to-date mine plan,
- forecasting of hazards by the chief dispatcher on the basis of the association of mining run effects on changes in safety parameters in remote mine regions,
- direction of the service specialists nearest to the damaged machine or device to repair it according to the optimal route,
- safe withdrawal of miners from dangerous areas.

In the SD2000 system, a series of new solutions within the domains of organization, technology and structure was applied. In this system, a new idea was used, different from the present philosophy of mine management. By departing from a central dispatching system, the distributed structure of dedicated subsystems to particular mine services was applied. The system has a hierarchical structure (Fig. 1) within the range of monitoring, presentation and visualization methods.

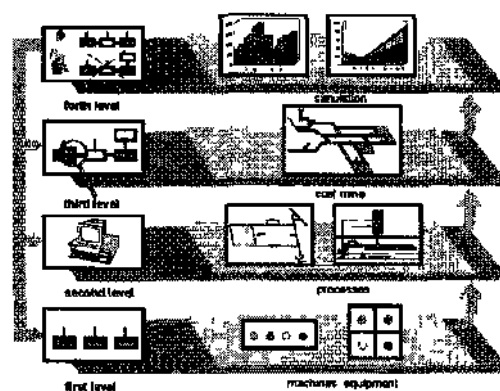


Figure 1 Monitoring structure

The operators and service personnel control the operating status of the equipment and machines on LCD graphic panels of local substations directly at the mine workings (level I). The subsystems (level II) of the mine divisions (power, machinery, communication, methane monitoring and ventilation) collect the detailed data. The specialists in these divisions become the active users of the supervising system and not only the consumers of processed information. At the chief dispatcher's stand (level III), necessary concentrated, easily comprehensible information is offered by all the subsystems. The dispatcher makes use of integrated

data in a synoptic table and supervises the technological parameters and safety state of the mine. Fast, reliable decision making is ensured in all operating situations. Operating on the WINDOWS NT platform, the SD2000 system distinguishes itself by intelligent graphic access to information. Internet technology enables remote diagnostics of machines, service and updating of the software components even from outside the mine site (level IV).

The SD2000 software is based on three-layer architecture, which is characterized by a vertical applications partition into logical useful layers. Each makes up an integrated part, which can communicate with elements on the next levels by network mechanisms. The first layer (of presentation) is used to communicate with a user. For the users (i.e., high-level supervising staff, planning departments, remote users) who make use of the informative function of the system, a WEB viewer, e.g., Internet Explorer, constitutes the program of this layer. This layer cooperates with the application server. The function of this server is to process all data according to defined rules, i.e., with application logic. Here, the data analysis and the creation of report contents and trend diagrams is performed. The database server is at the lowest layer and it receives data from the measuring systems. The three-layer architecture improves the safety of the system because both the application server and database are placed in a separate safe segment of the network. This architecture also reduces installation costs as it does not require a lot of licenses (which are not cheap) for the users of database servers. One license per application server is enough. The customers using common data can only obtain a connection with the last one.

The SD2000 database has a compound structure. Local process databases at network nodes depict a monitored process in real time and over a longer period depending on the process type. The database of one node constitutes a source of data for others. The global relational database uses structured query language used by the applications programs to collect and analyze the data. Using its advanced mechanisms, this database ensures adequate efficiency, safety and access to information. It also enables access to data through the Internet or intranet. Data are collected from all the nodes, i.e., local dispatching substations, in a homogeneous base. The database performs the role of a data warehouse, separating the executive information sphere from that of decision information.

In the SD2000 system, the Internet is widely used for:

- building a centre for remote diagnostics, maintenance and conservation of dispatching systems at mines by EMAG,
- providing the management staff of the coal mine

with dispatching information in indoor, delegation, holiday or operating conditions (Fig. 2),

- making information from the dispatching system available to supervising staff working in the mine LAN.

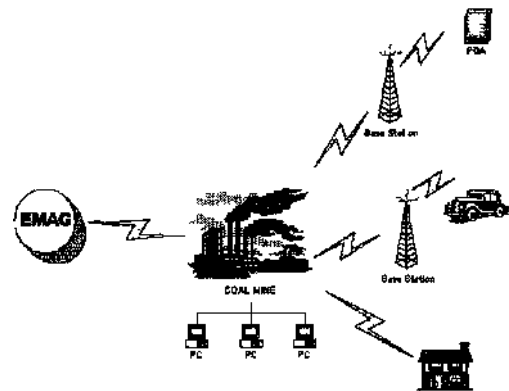


Figure 2. A coal mine as a WEB vertical portal.

An advantage of using standard HTML/XML for the presentation of data from the database server is that the data are available on any computer connected to the network and equipped with a WWW viewer. The use of server-client architecture (in this case, a WWW viewer) dramatically reduces the costs of installation and maintenance of many stands where production data should be accessible. Only the computer, which operates as a server, must be a real computing power unit. The "customer" computers can be common all-purpose stations without special hardware requirements.

5 FEATURES OF SD2000

The SD2000 system has network architecture and it is composed of intelligent nodes distributed all over the mine. The nodes are connected by an industrial network at the process level, and by the LAN at the dispatcher's and management levels. The nodes can operate autonomously, which makes development and configuration easier in accordance with mine requirements.

Acquisition and access to information from the nodes are obtained in a form of network variables.

The features of the man-machine interface MMI in the SD2000 system are:

- user-friendly action, based on a cursor manipulator and standard keyboard and right profiles,
- simple and easy action for familiarization of service, based on readable icons, virtual keys,

contextual menus and an on-line assistance system,

- assistance in work by additional windows warning of alarms and a system of profiles varying the form of presentation depending on requirements,
- clarity of information directed to operation of the mining-haulage process and analysis of disturbances on the multi-monitor dispatcher's control desk.

By placing the cursor on a graphical object representing a selected sensor and pushing the right mouse button, the user gains access to a wide range of data (Fig. 3), such as the type, serial number and producer of equipment, information about overhauls carried out and the appointed times of periodical surveys, and current measuring data in graphical and numerical form where the breaks of criteria are signaling.

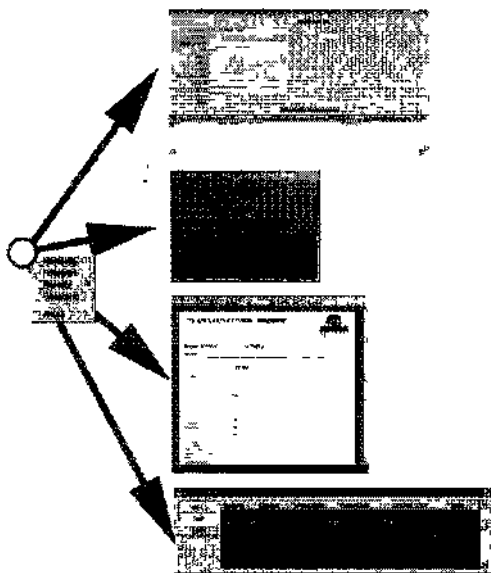


Figure 3 Sensor as information carrier

The multi-screening technique enables the service of all connected operator monitors by one keyboard/mouse (Fig. 4). A graphic video wall presents an image of the whole mine state, as well as scaled-up fragments, allowing the dispatcher to analyze particular technological lines, haulage elements and dangerous areas with full measuring-monitoring information just as on the dispatch office monitors, but with a considerably larger active surface of visualization. This makes it possible to include a great number of graphic and measuring-monitoring data without affecting the clarity and

readability of the image, thanks to the high resolution of the optical system (1600*1200). The graphic video wall, built from easy-to-configure projection modules placed one next to the other, creates a one-piece screen with the size depending on the needs of the mine and its financial resources.

Visualization of the mining and haulage processes as well as the safety state is based on several categories of images:

- those showing the arrangement of machines, equipment and sensors in the background of a real spatial picture of the mine by means of digital maps of beds and levels,
- simplified diagrams of installations, technology or networks,
- look-up images, presenting several sizes in a compact simple form on screen simultaneously,
- group images, presenting comprehensively die conditions of selected technologies, processes and safety,
- trends, presenting runs on a time basis,
- images previewing reports sent to the printer
- those showing message lines of failure, hazards, commands and event histories with sorting of information on events under different criteria, e.g., priorities, technological areas, types of events.

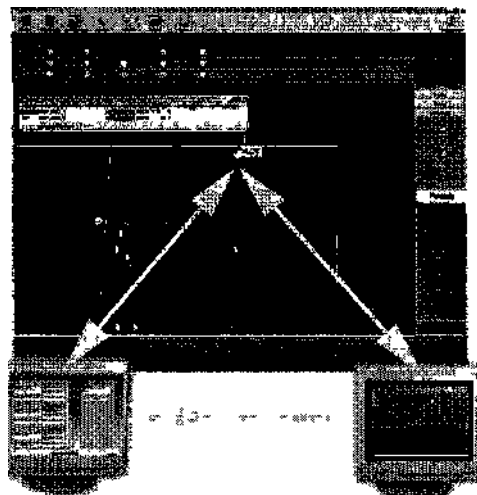


Figure 4 Multi-screening technique in the SD2000 system

6 COMPUTER PART OF THE SYSTEM

From the IT point of view, the SD2000 system forms the farm of servers working in their own network domain. Data from the technological server, alarm and communication server, haulage server and hazard monitoring and ventilation control server are

transferred to the database server of a central system by use of ADO technology. The central system consists of a set of servers, workstations and supporting equipment.

The software of the central system has a modular structure. Of the many modules, there are modules of data collection and for building the base of real-time data, the protection module responsible for the archive, replication and recovery functions, modules generating diagrams and reports, and the editing module.

Each change in the value of any measured variable is marked with a time stamp and according to the value, it is sent to tables for the needs of corresponding modules. On the image displayed on the graphic video wall (Fig. 5), the module of technology and safety presentation animates, on the basis of measured values, the graphical objects which represent machines and equipment in the background of mine maps. These values fill the alarm and measurement tables and produce messages for the dispatcher. Diagram modules take care of the proper graphical presentation of these values. The report module generates a list of events in the system at a certain time. The layer structure of the displayed images makes it possible to assign groups of layers comprising a given subject area to particular technologies, systems and networks. The appropriate rights of access to particular layers allow the distribution of the editing module between mine departments that update their sphere of duty, without the possibility of them changing elements in which they should not interfere.

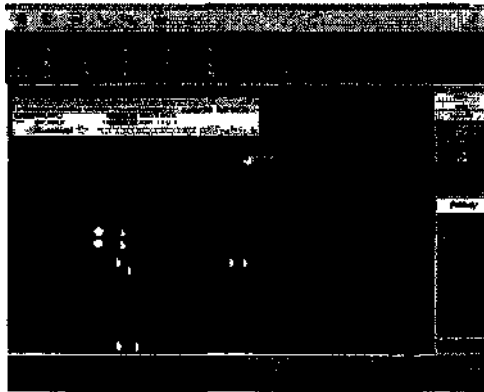


Figure 5. Synoptic module.

The editing module enables the updating in a remarkably simple way of maps, diagrams and objects. In editing, it is possible to make use of a library of graphic elements representing the mine equipment.

The SP2000 system ensures connection and data exchange with other databases. Due to genuine technological solutions, the extremely fast connections, stores and access to the relational database are achieved.

By application of the ODBC protocol, the SD2000 system can cooperate with well-known databases such as Sybase, Oracle or Informix. Integration with the mine computer network, by using an intranet vertical portal for information coming from the database server, is very important. Data generated in the form of diagrams, tables and reports can be seen by any Internet viewer - without additional software at the customer's side. Active X controls built in to the portal allow graphic presentation of various diagrams on a WWW page.

The histograms and linear diagrams are accessible in current or historical mode. In addition to diagrams showing the state of operation of machines and equipment, alarms are displayed with their history of occurrence.

The application software works only on the server, so there is no need to install programs in individual computers in the network or manage it at the place where these data are received. The changes in application are refreshed on workstations immediately after connection to the server. The distributed system maintains its remote outstations by itself. This is the "zero administration" feature of the SD2000.

7 CONCLUSIONS

The aim of the development work which has been carried out by the EMAG Centre over the last 25 years has been effective and efficient control of the production process run and continuous monitoring of safety conditions. This work has resulted in a series of solutions within the range of communication, alarm signaling, control and supervision of machines and equipment and mine safety control.

As one of these solutions, the SD2000 dispatching system enables the integration of the spheres mentioned above, providing advanced monitoring and dispatcher support, data presentation and visualization and use of modem software technologies. Thus, it has emerged as a new reference point for a new generation of dispatching systems for mines in the new millennium.

REFERENCES

- Dec B., & Gajoch, A. 1999. The Zefir dispatching system, 1" *School of Mining Aerology .2SJ-292 (in Polish)*

- Gacek A., & Wojciechowski, J. 1976. Computer System MKJ-25, *Proc. of the Science-Technique Conference SEP..25-39* (in Polish).
- Mironowicz, W. & Wasilewski, S. 2000. Monitoring and control systems to minimize the influence of mining plants on environment. *IFAC Workshop. Future Trends in Automation in Mineral and Metal Processing.*: 340-346, Finland.
- Mironowicz, W. & Wojciechowski, J. 2000. Monitoring and visualization of mining processes and safety condition in the dispatching system SD2000, *Proc. of the 28th Int. Conference on Automation and Telecommunication in Mines and Processing Plants – Coal and Minerals.*: 124-128.
- Mokrosz, M., Suchy, J., & Zymelka, K. 1982. Programmable Controller PRS-4 - basis of automatic solution in coal mine, *Informatyka*. 8 (in Polish).
- Poppe, L., & Zymelka, K. 1998. Modern monitoring system for production and safety in "Wesola" coal mine - a new possibility, *Mechanizacja i Automatyzacja Gornictwa*. 8-9:48-52 (in Polish).
- Wojciechowski, J. 1999. The year 2000 dispatching system for mines, *Mechanizacja i Automatyzacja Gornictwa*. 4-5: 21-27 (in Polish).

Devices for Breaking and Haulage of Rocks on the Basis of Electromagnetic Motors

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ABSTRACT: In this paper, tractive motors of the electromagnetic type are described for the creation of vehicles and equipment for rock breaking. The technical performances of a conveyor train (CT) and impact machine with electromagnetic motors are presented. The parameters calculated are given for the motors, allowing the design of a conveyor train transport system for wide-ranging exploitation and planning of exploitation at open casts.

1 INTRODUCTION

Recent development in the mining industry in the Republic of Kazakhstan has tended towards the mining of useful minerals by the surface mining method. At the same time, with the increase in the number of open casts, there has been an increase in the output of useful minerals by ore mining at deep levels.

Today, about 70% of the rock mass volume at open casts is transported by road. This kind of transport is mostly used when for the mining of deposits with hard bedding conditions. However, the atmosphere around open casts is polluted by truck exhaust gases, which are emitted when trucks operate at grade, and this substantially worsens the ecological conditions at open casts.

The modern form of mining useful minerals by the surface mining method is unthinkable without drilling-and-blasting operations. Powerful ejections of gas and dust when these operations are carried out have a substantial negative effect on the ecological situation not only at open casts, but also on the environment as a whole.

In addition, damage to the environment as a result of dust-gas ejection leads to potentially dangerous gassing situations, and this causes temporary stoppages of operations.

The constant increase in the labour intensity of mining-transport operations, which is caused by increases in open cast depth and complications in mining and geological conditions, have made the creation of new vehicles necessary and rock-breaking devices with new motors which are not sources of gas-dust ejection, but ensure the output of the mining enterprise.

2 DEVICES FOR HAULAGE AND BREAKING OF ROCKS

Such motors were developed at the Kunaev Institute of Mining on the basis of electromagnets with internal magnetic conductors (Yedygenov et al., 1993. Patent No. 2573; Yedygenov, 1993. Patent No. 1981) and solenoids (Yedygenov & Sagimbayev, 1988).

In electromagnetic motors, the physical mechanism used is interaction of the magnetic field forming in the electromagnet when voltage is applied to its winding with a ferromagnetic armature.

Depending on the location of the armature and electromagnet relative to each other, tractive motors are subdivided into electromagnetic motors of the solenoid type and electromagnetic motors with internal magnetic conductors.

In tractive motors of the solenoid type, the working zone, that is, the zone of interaction of the magnetic field with the armature, is the internal area of the electromagnet. In such a motor armature, which is the freight-carrying unit in transport devices, the electromagnet is drawn in and moves internally. In this case, the armature containers are determined with regard to dimensions and type of transporting freight and also the geometrical dimensions of the motor

The working zone of the electromagnetic motor with the internal magnetic conductor is the external surface of the electromagnet. In this motor armature an S-type section is made, which passes over the electromagnet and moves along it.

Electromagnetic motors those have drooping characteristics, are easily self-synchronized,

ensuring non-contact, non-impact interaction with motion tracks, and this increases their reliability and operating longevity.

In addition, achievements in recent years in the creation of high-temperature superconductors on the basis of yttrium-barium ceramics have opened up great potential for motors of the electromagnetic type. The use of superconductor winding will allow increases in the coefficient of efficiency of electromagnetic motors of up to 90-95% due to decreases in losses from heating.

3 TRANSPORT DEVICES

At the Kunaev Institute, electromagnetic container transport (ECT) for inter-section transportation was developed with electromagnetic motors of the solenoid type. In this transport, tractive motors are located along the line of transportation at a distance S from each other and by means of a commuting device act in turn on a ferromagnetic container. When this interacts with a motor, it accumulates kinetic energy, and uses it to move from one motor to another.

The technical performance of the experimental-industrial ECT device is presented in Table 1.

A container train was also developed, the mover of which is a tractive motor of the electromagnetic type with a magnetic conductor.

The conveyor train (CT) is a vehicle consisting of a flexible system of running trucks, with a freight-carrying belt for moving large-sized rock mass, which continuously move between points of load and discharge. Tractive motors are located at stationary points along the train way and the distance between them is equal to or slightly shorter than the train length, ensuring semi-steep transportation of rock mass, as the magnetic field of the motor acts on the conveyor train as the haulage rope of a winder. Testing of the train showed that

electromagnets with internal magnetic conductors are more effective than linear asynchronous electric motors (LAEM), which are now used when carrying out design work for conveyor trains. The effectiveness of the electromagnetic motor increases due to the absence of the "final effect", which is typical for LAEM. This tractive motor has no current collection devices and this simplifies its design and allows it to be used in dangerous conditions when explosions can occur.

Conveyor trains with electromagnetic motors can transport rock mass over long distances and they have a small radius of curvature in the horizontal and vertical planes.

In comparison with regular railway transport systems, the conveyor train leads to decreases in the haulage distance of 3-5 times and decreases in the duration of one transport cycle of 2-4 times.

In addition to electromagnetic motors in a conveyor train system, the use of electric energy and creation of the magnetic field at the same time act on the motion trucks with no contact, and this ensures non-impact interaction, increased reliability and operating longevity, with the potential for high speed of movement.

The substantial advantage of CT is its relatively simple design. Conveyor trains have a modular design. The CT module consists of the tractive motor, motion trucks, guides, and a system of control by motors. By varying the number of modules, it is possible to change the production capacity of the transport system and the distance of transportation. It is possible to replace failed motors or motion trucks quickly and easily with new motors or motion trucks. Such repair operations have practically no effect on the continuity of the transport process. The advantages of this vehicle also include the possibility of control by productivity depending on demand by way of additional trains or the removal of trains from transport communications, and the fact that the CT route can be located in areas with any relief and by pit walls

Table I. Technical performance of the electromagnetic container transport device.

Parameters	Unit of measurement	Value of parameter
Production capacity	t/h	2.0
Distance of transportation	m	45.0
Dimensions of electromagnetic motor-		
length	m	0.71
width	m	0.42
height	m	0.32
Motor capacity	kV	50.0
Container load-carrying capacity	t	0.2
Container dimensions		
length	m	0.81
width	m	0.4
height	m	1.5
Type of transporting freight		Finished products lo lathes

with angles of inclination up to 30-40°. CT is ecologically clean because as a motor of functional aggregates, it uses electromagnetic motors.

At the Kunaev Institute of Mining, the technical design of a conveyor train with electromagnetic motors (CT with EMM) was developed. Details of its performance are presented in Table 2.

On the basis of the theory of similarity with experimental data by testing the experimental design of the electromagnetic tractive motor, parameters of the tractive motors were obtained for a range of carrying capacity values of the conveyor trains, as presented in Table 3. In the table, the parameters of a motor operating at the horizontal part of the route are presented in the numerator, while the parameters of a motor operating at an inclined part of the route when $\alpha = 30^\circ$ are presented in the denominator.

Table 2. Technical performance of CT with EMM

Parameters	Value of Parameters
Production capacity, m ³ /h.	500-1000
Distance of transportation, km	10
Speed of movement, m/s	
by main line	6-8
at loading-discharging site	1-2
Angle of inclination, degrees	up to 40
Granularity of material, mm	0-1500
Train length	250-300
Capacity of tram, m ³	126
Number of tractive stations	30-40
Number of motors in tractive station	5-7
Power of motor, kw	230

Table 3. Parameters and type dimensions of tractive motors.

Motor parameters	Carrying capacity of conveyor train, tons			
	30.0	60.0	120.0	160.0
1	2	3	4	5
Force of traction, kN	3.5/5.0	6.0/5.0	12/10.0	16/20.0
Current, A	300/620	450/620	690/1240.0	900/2400
Voltage, V	200/600	300/600	300/600	300/600
Number of turns	600/1020	680/1020	700/1100	800/1200
Dimensions, m	0.6x0.25x0.1	0.6x0.7x0.1	1.2x0.15x0.1	1.2x0.8x0.1
	1.2x0.7x0.2	1.2x0.7x0.2	1.5x0.8x0.3	1.5x0.8x0.3
Number of tractive motors coming into operation simultaneously at tractive station	1/3	1/6	1/6	1/4

The parameters of the motors obtained by calculation allow the design of a conveyor train transport system for wide-ranging exploitation and planning of exploitation in open casts.

4 IMPACT DEVICE

Electromagnetic motors with internal magnetic conductors may be used in the design of impact devices (Yedygenov et al., 1993. Patent No.2136).

An electromagnetic device of impact operation (EMTD) includes (Fig. 1) a mobile installed in guiding pipe 1 armature 2 and fixed in it by means of top 3 and bottom 4 brackets power electromagnets 5, connecting with commutating device 6. Power electromagnets 5 are located with clearance in longitudinal openings 7, which are made by perimeter of armature 2 symmetrical its longitudinal axis. Armature 2 interacts with its working tool 8, and power magnets are installed on brackets 3 and 4 with the possibility of longitudinal movement.

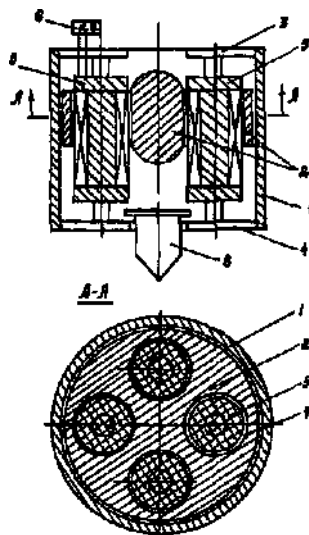


Figure 1 Scheme of electromagnetic device of impact operation

Depending on the energy necessary when impacting, the voltage, by means of commutating device 6, is applied to one, two or all, for example four, power magnets 5, and in each of them a magnetic field appears. At the same time, the magnetic fields of all acting power electromagnets 5 act simultaneously on armature 2, and as a result it is brought up to speed along guiding pipe 1 and power electromagnets 5 from top bracket to working tool 8. Armature 2, when interacting with working tool 8, transmits its kinetic energy to the working tool.

After energy transmission by armature 2 to working tool 8 by means of commutating device 6, for example, by way of polarity of magnetic field changing in one or some power electromagnets 5, forces, directing on opposite side of the working tool, begin to act on armature 2. By the action of these forces, armature 2 moves along, aligning its movement guiding pipe 1 and power magnets 5 from impact tool 8 to top bracket 3, that is, to the initial position at the beginning of operation. When the armature reaches top bracket 3, commutating device 6 again changes the polarity of magnetic fields in power electromagnets 5, running for return of armature 2 to initial position, and then the cycle is repeated.

Use of the electromagnetic device of impact operation makes it possible to control the energy of unit impact due to the varying number of operating power electromagnets. In addition, it is possible to reduce energy cost due to control of the number of electromagnets used for return of the armature to the initial position.

The technical design of the electromagnetic impact device (EMID) was developed at the Kunaev Institute of Mining. Details of its technical performance are presented in Table 4.

Table 4. Technical performance of EMID.

Parameters of impact device	Value of parameters
Energy of impact, J.	2000-2500
Frequency of impacts, 1/min.	150-200
Mass, kg	98
Overall dimensions, mm:	
height without tool	1320
diameter of body	730
Capacity by the hour (number of broken quarry stones per hour) when breaking of rocks with coefficient of hardness ρ according to Protodyakonov and volume of quarry-stone V :	
$\rho \geq 10, V = 2.0-2.5 \text{ m}^3$	15-20
$\rho \geq 15, V = 1.0-1.5 \text{ m}^3$	10-15

5 CONCLUSIONS

The electromagnetic motor with internal magnetic conductor that was developed at the Kunaev Institute of Mining may be used for a variety of purposes when producing different types of mining and transport equipment.

REFERENCES

- Yedygenov, Ye.K., Sagimbayev, D.T., Yedygenova, Z.V. 1993. Linear electric motor. Patent No. 2573. Republic of Kazakhstan.
- Yedygenov, Ye.K. 1993. Linear electric motor. Patent No. 1981. Republic of Kazakhstan.
- Yedygenov, Ye.K., Sagimbayev, D.T. 1988. Perspectives of conveyor trains using when useful minerals mining by surface mining method. Alma Ata: KazNHNTI, 45 p.
- Yedygenov, Ye. K., Dzhanugurov, S. I., Yedygenova, Z.V. 1993. Electromagnetic machine of impact type of operation. Patent No. 2136. Republic of Kazakhstan.