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IMPLEMENTING MAINTENANCE MANAGEMENT SOFTWARE IN MINING: A HUMAN FACTORS ANALYSIS

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This report outlines characteristics and problems of implementing maintenance management information system (MMIS) software, and reviews several human factors principles which can guide the successful implementation of these programs.

INTRODUCTION

The tasks and knowledge required to maintain sophisticated modern mining equipment are by nature more complex and diverse than that of most other mining work. Therefore, the provision of information on proper procedures and safety precautions to maintenance workers, and the provision of accurate and timely technical and cost data to maintenance managers is critical to the safe and cost-efficient performance of mine maintenance work.

U.S. mine operators agree that controlling equipment maintenance costs is a key to the future competitiveness and safety of their operations. Complex modern machine designs and controls are placing many new and different demands on maintenance workers at U.S. mines and plants and the costs and staffing for maintenance are increasing faster than most other functions, averaging 96 pct of new capital investment value at some U.S. plants (Nolden, 1987).

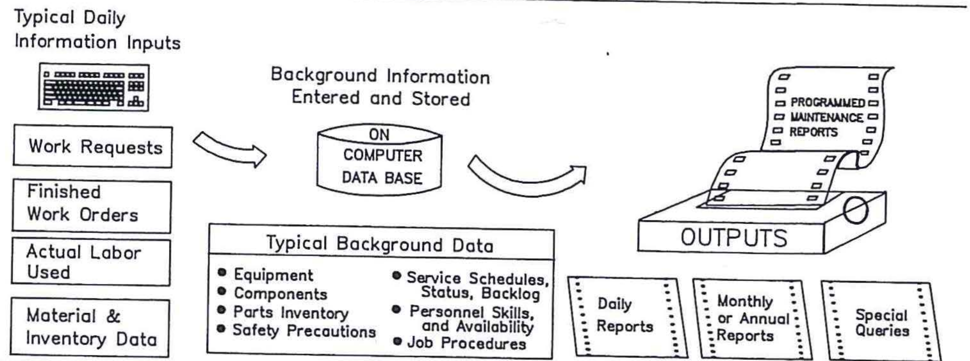
MAINTENANCE MANAGEMENT SOFTWARE: CHARACTERISTICS, CHALLENGES

Recent articles testify that new desktop computer software, for tracking and managing maintenance information, offers great potential to lower costs and improve the efficiency of mining equipment maintenance (i.e. up to 30 pct), (Robelesky, 1988; Dean, 1988; Timmons and Jensen, 1989; Chironis, 1990; Britton, 1990; Stewart, 1990). However, similar programs were written and introduced for mainframe computers over 20 years ago with marginal results in many cases (Wallis and Ketteringham, 1987). Likewise, many mining organizations have experienced frustration or even made costly mistakes while attempting to implement maintenance information management programs into their operations (Robelesky, 1988; Dean, 1988; Chironis, 1990).

Keys to Efficient Maintenance Management

Modern industrial maintenance organizations need to track and manage large amounts of complex and detailed information (see Figure 1). Managers must be able to quickly access and coordinate all of this data in a very precise and mistake-free manner to come up with the optimum schedule for repairs or other maintenance related activity. Likewise, many maintenance decisions and assignments require careful and accurate consideration of these related data to avoid serious and costly mistakes or injuries. In a maintenance department of any size at all, manual recording or memorization of maintenance information quickly becomes a difficult if not impossible task. Trends toward

FIGURE 1. Typical 1st order maintenance management information system (MMIS): information storage and reporting only



Typical Maintenance Reports

Daily Reports

- Morning Status (All equip. out of service)
- Backlog on Active Work Orders (hrs left to finish)
- Deferred Maint. Summary (Including PM work due)
- Inventory Order Pt List (All parts at or below order pt.)

Monthly or Annual Reports

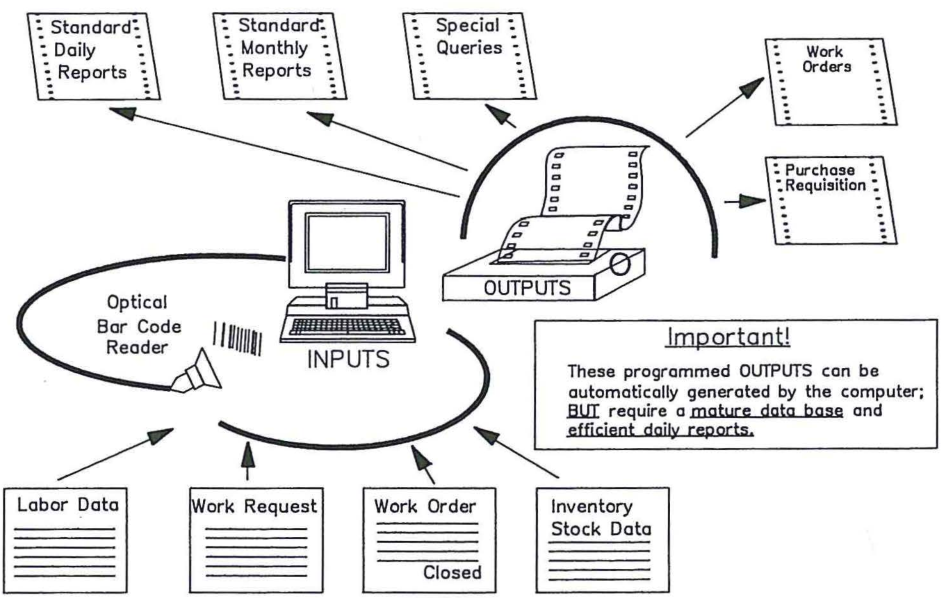
- Equipment Available Summary
- Labor Summary; by Craft and Regular vs. Overtime hrs
- Work Orders Completed by Type (Emergency, Breakdown, PM)
- Equip. Maintenance Frequency and Cost vs. Budgeted Amounts

The reports are only as current as the data base and the daily information inputs

Special Queries

- Repair Histories by machine or component
- Material Used by Machine or Dept.
- Workload Forecast by craft
- Supplier History
- Inactive Inventory (not used in last 12 months)

FIGURE 2. — A second order MMIS: with optical bar code reader and automatic generation of PM work orders and purchase requisitions



preventive maintenance programs and just-in-time scheduling and inventory orders have made the coordination of this data an attractive target to apply computers.

Benefits of Maintenance Management Software

Most maintenance managers and plant engineers are easily convinced that computer management of maintenance information offers distinct advantages. A detailed list of benefits promised by companies marketing new maintenance management software include:

(1) Improved scheduling and compliance with preventive maintenance (PM) plans through aided or automatic PM work order generation and tracking.
(2) Reduced equipment breakdowns, emergencies, downtime, and therefore less "rushed maintenance".
(3) Decreased safety hazards for both operators and maintenance workers.
(4) Increased equipment availability and utilization.
(5) Decreased energy costs.
(6) Reduced inventory and procurement costs through aided or automatic tracking and reordering of inventory with just- in-time coordination to the PM and other work orders.
(7) Increased component service life.
(8) Reduced material costs.
(9) More accurate and timely data for planning, budgeting, contracting or bidding, and purchase decisions.
(10) Improved accuracy and currentness of cost and performance data, and reporting capabilities to base personnel accountability, promotions, and problem solving.
(11) A structured approach and more "control" of costs by management.
(12) Better tracking of warrantee paybacks.
(13) Improved maintenance worker utilization, productivity, quality, and less overtime pay.
(14) Improved communications and relationships with other departments.
(15) Increased feeling of professionalism by workers.
(16) Retention of maintenance information that an employee who leaves the organization would take with them if this information were stored only in their mind.

Characteristics of Maintenance Management Software

The benefits listed above are significant and impressive, and some are even confirmed by a few industrial companies who have successfully implemented such programs. Today, nearly 150 vendors can be found in the business of marketing maintenance management software (Greene, 1988). In addition, many companies have developed homegrown systems for their equipment maintenance, or use spreadsheet programs to store and manipulate maintenance data and costs. Still, a fair number of large maintenance organizations (with more than 50 craftsmen) are using a manually-tracked-paper-copy preventive maintenance management system, which suggests that the majority of medium- and small-size firms also rely on manual systems (Greene, 1988). The ratio of manual to computerized maintenance management systems is estimated to be at least 4:1 (Greene, 1988), which suggests the need and/or the opportunity to expand the use of this technology today.

Some of this software is tailored to one specific equipment maintenance application and one specific computer system. Other packages are designed to be applicable to maintenance operations generally and run on a variety of different computer systems. Most of the newer software is geared for desktop computers because of their lower cost, growing familiarity, and ease of use.

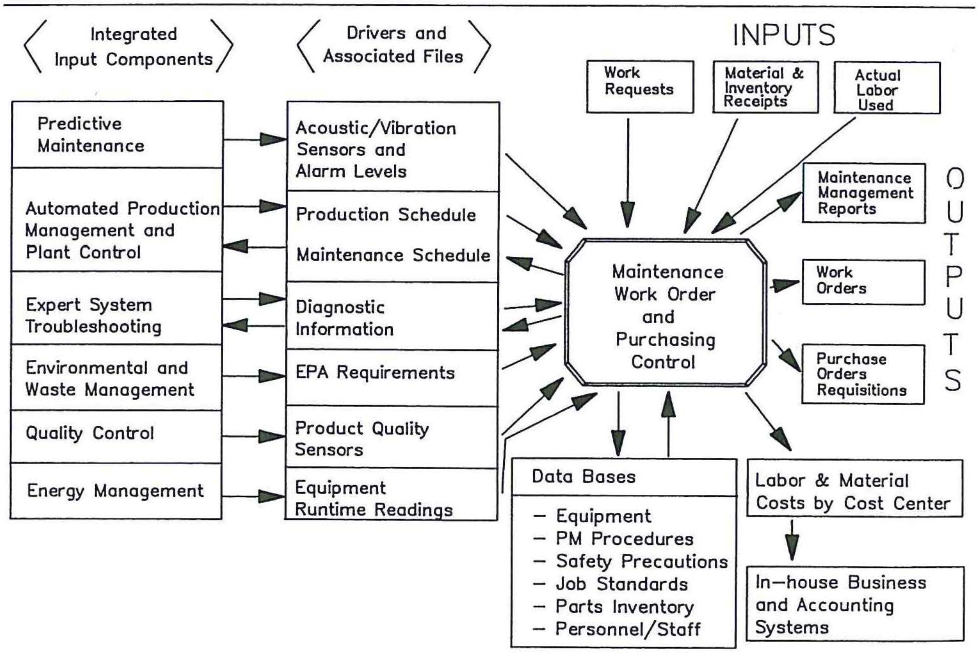
New technology has begun to be included and interfaced with this software such as; optical bar code readers, electronic sensors, and expert systems. These new developments offer improvements to maintenance management systems, but may make them even more complex and more difficult to successfully implement. Therefore, maintenance management software should be characterized by the categories of functioning that are available; e.g. (1) First Order Systems that provide storage and reporting of various levels of equipment maintenance and inventory information (Figure 1); (2) Second Order Systems which automatically track and generate PM schedules, work orders, and inventory reordering (Figure 2); and (3) Third Order Systems tied to automatic production management, accounting databases, plant control, electronic sensing for predictive maintenance inputs, and even artificial intelligence/expert systems to guide maintenance diagnostics and troubleshooting of maintenance problems (Figure 3). The distinctions between these categories are important because they are often unclear to initial observers; yet they can significantly affect the level of difficulty and potential for frustration, mistakes, or wasted time during implementation of the software (i.e. first order systems can function to some extent even when the data base isn't up-to-date, second order systems can't).

Most maintenance management software vendors offer training to assist implementation. Some training is often offered as standard with the purchase, but many vendors recommend that a buyer purchase more than the standard training. However, they purposely leave this decision up to the customer. Customers logically desire to minimize training costs and tend to underestimate the time and amount of training and practice they will need to implement these systems, which obviously causes some of the difficulty experienced in implementing these systems.

COMMON MISTAKES WITH MAINTENANCE MANAGEMENT SOFTWARE

In the minerals industry today, the overall utilization of maintenance management software is quite low compared to their estimated potential, and the efficacy for daily maintenance management with many of the systems that have been installed is often quite low (Dean, 1988). Ten mistakes or difficulties documented in reports (Robelesky, 1988; Dean, 1988; Chironis, 1990) of mining operations who have implemented MMIS are:

FIGURE 3. — A third order MMIS:
with state-of-the-art integrated inputs and outputs



1. Too few people in the organization understand the vast amount of information involved in coordinating equipment maintenance; or they miscalculate the human logistics of entering all pertinent background data into the computer, or maintaining records from day to day.
2. Some people in the organization do not understand the need or the benefit for computerized management of this information.
3. Those managers, who can make productive use of these data for day to day decisions, don't understand what specific questions can be answered within the system; don't understand how to access such an answer from the on-line computer; or don't have the time or the technical confidence to explore it.
4. Some systems, especially the mainframe systems, have been quite inflexible, or very difficult to access in a flexible way, making learning even harder.
5. Workers assigned to interface with the system do not feel comfortable or confident with the computer operation, the disk operating system, or the database command language.
6. Users assigned to interface with the system do not feel comfortable with the large data entry requirements, especially during the beginning phase when the system has to be loaded with large amounts of background information to get started.
7. The organization underestimates the need for training and practice with the system and tries to get by with less training and support than was suggested or needed, as a means to save money.
8. Day to day data entry is not kept current, and/or the system is used only as a routine monthly or quarterly report generator, which takes away many of the advantages of storing the data on an on-line computer (i.e. if the information isn't current, it is useless for guiding day to day decisions or generating daily work orders or inventory reorders).
9. The system is run in isolation from the production people, thereby losing their commitment to the program which is vital for a tightly scheduled program like this to work. Input from production people can also provide observations of the operating conditions and machine response which are essential to tracking the underlying causes to any machine maintenance needs, especially in a rugged mine environment.
10. The system is abandoned to some degree before it is fully implemented or fully realized.

HUMAN FACTORS ANALYSIS OF MAINTENANCE SOFTWARE DIFFICULTIES

The foregoing mistakes and difficulties can be understood as stemming from human factors deficiencies in the way these programs are designed and implemented. These deficiencies are not unlike those encountered during the massive movement to automate office work and office systems with computers (Smith and Smith, 1988). Office automation has taken much more time and attention to human factors details and training than was originally thought necessary, when the technology was first being developed and offered for sale. Millions of dollars were wasted before the importance or control of the human factors important to the design and implementation of office automation were recognized. The human factors difficulties of introducing computer based information systems (MMIS) among industrial and heavy equipment maintenance organizations have the potential to be more severe than with office workers, because the technologic unfamiliarity and skill discrepancies are in most cases greater. On the other hand, the experience and knowledge gained in the design and implementation of office automation system hardware and software will undoubtedly benefit maintenance management systems design and implementation.

Relevant Human Factors Studies and Principles

Previous studies of human-computer interaction have revealed principles that provide valuable guidelines and solutions when evaluating the difficulties to implementing maintenance management systems. Gould and Lewis (1983) surveyed 447 designers and developers of computer office systems and found four neglected principles for designing more usable computer systems and support materials. Most designers agreed that these principles were helpful and important; however, most of them also agreed that they often neglected using these principles. Briefly stated they are: (1) early focus on users; (2) integrated design with users on the design team; (3) early and continual user testing; and (4) iterative design and modifications based on the repeated user testing. Notice the emphasis on users in each of these principles or steps. Reasons cited for neglect of user input are: (1) user diversity is underestimated; (2) belief that technology and the power of reason are the keys to good design and that user interaction only helps for fine tuning; (3) belief that users usually don't know or can't tell what they need; (4) belief that user interaction is too time consuming and difficult to be practical.

Some other studies on human-computer interaction give helpful clues to why user diversity is largely underestimated by those designing and implementing computer systems. Egan (1988) surveyed 12 studies which measured the individual differences during human-computer interaction and found that individual performance differences are large compared to those found in most work settings; i.e. performance differences for information search tasks had a range of approximately 9:1, and text editing and programming had ranges of approximately 5:1 and 22:1 respectively, whereas a performance range of 2:1 encompasses 95 pct of the working population (Salvendy and Knight, 1982).

Individual differences in human-computer interaction thus account for much greater variability in performance than current system design or training procedures can overcome or accommodate in many cases. However, Egan (1988) relates four successful recent approaches to user differences which mix specialized interface design and specialized user training in different proportions. These are:

Robust interfaces; which have been altered based on user testing to improve performance on those features where performance differences were greatest. Some of these interface improvements have merely reduced or simplified some of the commands, while others have developed into very novel improvements to interface design such as: menu driven interfaces; natural language interfaces; on-line aiding <HELP> interfaces; input devices (i.e. joysticks, mice, light pens, touch screens); graphic-oriented interfaces; windowing systems; and speech output and recognition systems.

User prototypes; which are specifically programmed to interface with selected user groups; and have proven helpful for use with strongly defined user groups (e.g. Spanish speaking users, or users with a particular job, background, or educational level).

Adaptive training systems; which deal with errors during practice by: blocking certain errors; prompting correct responses; and/or giving feedback following errors. These helps can be provided in a separate training system for practice only, but have also achieved success when incorporated into the working system and made appropriate to aid even the skilled user.

Mastery learning approaches; which allow each student as much time and instruction as needed to master a program by separating the procedure or skill into small units and objectives and providing testing and followup until each part is mastered.

Carroll and Olson (1988) showed that modeling or giving a flow diagram of complex computer-software interaction can help users understand a system, especially novice users.

Studies of the organizational side effects of introducing computer systems are also important. Walton (1982) shows that past studies of the implementation of computer systems within organizations have often focused on ways to overcome resistance to the new system. He argues that this focus should be extended to system design and training to avoid resistance whenever possible rather than trying to overcome it. Sheridan (1988) showed that for systems that take over some of the previous human supervisory tasks and control, making the system "human trustable" is as important as making it "human usable". Crowston and Malone (1988) state that information systems tend to coordinate groups into larger functional departments. This makes analysis of the organization, to identify the roots of any resistance to change or any vested interests for or against the system, critical to the design of training and implementation plans for maximum understanding and commitment.

RECOMMENDATIONS FOR IMPLEMENTING MINE MAINTENANCE SOFTWARE

Undoubtedly, any mining organization attempting to design or implement a maintenance management information system can benefit by considering the human factors studies and principles reviewed earlier. The following discussion recommends eleven key steps to implement a MMIS. These recommendations are based on past mistakes experienced while implementing MMIS and on relevant research findings (see sections above).

(STEP 1) Conduct an accurate economic evaluation or audit of current maintenance costs, including any waste and inefficiency known or suspected. If possible, roughly estimate the benefits to be gained at the operation by implementing a MMIS.

(STEP 2) Analyze the organization to determine any vested interests for or against making improvements in any of these maintenance functions, or any possible resistance to change or resistance to computer maintenance management systems.

(STEP 3) Provide orientation training and background about the audit (STEP 1) and benefits expected from such a system for important managers and representatives from the eventual users and any resistance group identified in (STEP 2) (e.g. proposed users, union representatives, finance, maintenance, data processing, production executives).

(STEP 4) Convince all parties that to achieve the proper coordination to allow success with such a system, the organization of responsibility for the maintenance function must be shared with production/operations. In many organizations this requires the creation of a larger functional department and changes the lines of responsibility, but the information system can provide the coordinating link that allows this to work.

(STEP 5) Early involvement, by the managers and representatives mentioned earlier, in all of the decisions about priority goals and objectives for the proposed system, clear criteria to measure performance against, and how the system will be implemented and maintained.

(STEP 6) Select a system, software, and implementation and training plan based on all costs and other factors such as special training needs and preferred computer systems and interfaces. Include evaluation of several alternatives and vendors in this decision and involve all those parties mentioned earlier. When selecting a system and a plan expect some users to need 5 to 10 times longer than others. Remember that information systems come in differing orders of complexity (Figures 1-3), and that lower order systems are more forgiving in terms of the required currentness of data input and output, and thus less frustrating during initial implementation.

(STEP 7) Purposely overestimate training and practice time to avoid unrealistic expectations. Also, give special consideration to advantages possible with various robust interfaces such as; barcode readers, menu driven and graphic-oriented interfaces.

(STEP 8) Establish and communicate clear lines of responsibility and involvement for implementing and maintaining the system throughout the organization (STEP 4).

(STEP 9) Procure extensive training for one or more individuals in the organization who will be assigned to serve as resident facilitators or technical experts during the critical implementation phase. Any previous experience and skills with the computer operating system and hardware to be used by the system will help.

(STEP 10) Begin the training plan. Remember to expect wide ranging individual differences in the speed and proficiency with which each user acquires skill and confidence in these tasks, and explain this to each user. Provide a flow diagram or a model of the computer-software interaction which can help novice users visualize and understand how the system works better. Training should be heavily geared to hands-on practice with the system or a training prototype. Incorporate mastery learning approaches which give each student as much time and instruction as needed to master a program by separating the training into small units and objectives and providing testing and followup until each part is mastered.

(STEP 11) Carry out the rest of the implementation plan. Expect mistakes and frustration in the beginning phases, so maintain your previous record keeping system at first, using the new system as a backup until the bugs are worked out and the needed proficiency is proven.

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