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**An Investigation of Benefits
Associated with
Computerized Preventive Maintenance Systems**

**by
Peter-John Vaillancourt
B.Comm (Honors)**

**A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfillment of the requirements
for the degree of Master of Management Studies**

**SCHOOL OF BUSINESS
CARLETON UNIVERSITY
Ottawa, Ontario**

DECEMBER 20, 1992

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PREVENTIVE MAINTENANCE SYSTEMS**

submitted by Peter-John Vaillancourt, B.Comm (Honors)
in partial fulfillment of the requirements for
the degree of Master of Management Studies

Thesis Supervisor(s)

Director, School of Business

Carleton University

January 11, 1993

ABSTRACT

Preventive maintenance can provide a number of benefits to an organization, and the use of computers to assist in the task is a relatively new concept. However, like other information system applications, CPMS also face resistance. Among the major reasons is a lack of a framework by which these systems can be justified. Another reason is managers' attitudes toward maintenance in general and preventive maintenance in particular. This thesis is a step toward building a framework by identifying and justifying the benefits of CPMS. To ease the application of the framework a computerized job-aid has been developed to assist in the CPMS justification. It is aimed at assisting in the philosophical and attitude change required towards maintenance operations.

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Chapter 1

Introduction to PM and CPMS

Although maintenance expenditure in many firms is sizeable it often receives little attention as many managers feel helpless in controlling the expenses. Expenditure increases when maintenance activities are viewed as predominantly non-routine and can not be pre-scheduled.

Typically non-routine maintenance refers to corrective and emergency maintenance. Corrective maintenance through diagnostics is the identification of malfunctioning equipment and the correction of such deficiencies before a major breakdown. Emergency maintenance is necessitated by unforeseen breakdowns or damage and is intended only to get equipment up and running. Routine maintenance, on the other hand, can be scheduled and planned. It aims to prevent equipment failure; hence, it is also known as "preventive maintenance" (PM).

Preventive maintenance increases equipment availability and reduces maintenance costs, it offers an alternative to the "wait

until it breaks down" approach¹. Through scheduling, problems are targeted at their source while they are still minor and quickly remedied, thus avoiding a major crisis. Such a program can shift the focus of the maintenance department from random failures to an orderly maintenance scheduling system.

Preventive maintenance can play a significant role in the success of a company's production processes. An organization's reluctance to invest in the upkeep of its plant and equipment typically leads to greater costs in the long run. There are several reasons for this. Firstly, most equipment today requires substantial investment; and if a satisfactory return is to be received on such investments, equipment must be maintained in peak operating condition. Equipment not run at top condition, may need to be retired prematurely. For firms with a large number of equipment such premature retirements can add up to a significant figure. Preventive maintenance can actually increase the life expectancy of equipment by ensuring all servicing requirements are met. This increase in equipment life can result in a dramatic reduction in capital investments by reducing the need for purchasing and maintaining a large inventory of parts and standby equipment, as well as new purchase acquisitions.

¹ The underlying feature of this approach is to wait until the equipment fails, then only do what is necessary to get the equipment running again. Little or no time is allotted to properly maintain the equipment, and minor or non-critical problems are usually ignored until the problem compounds and results in a very costly and lengthy repair. This method leads to "fire fighting".

Secondly, preventive maintenance reduces the number of unforeseen breakdowns of equipment and the consequent loss of productivity. As a corollary, overtime hours are also reduced as off hour hour breakdowns are less frequent.

One of the primary features of preventive maintenance is to ensure that regularly scheduled maintenance servicing is not overlooked. To accomplish this such details as what equipment is to be serviced, where it is located, the parts and supplies needed, and the type and number of personnel required to complete the task must be readily available. Also, communication amongst the various maintenance disciplines must take place. For example, electricity and water may have to be cut off for a period of time while a production line is shut down and serviced. This task would require the services of the electrical, plumbing, and mechanical maintenance crew. Scheduling is very important for establishing maintenance schedules with other departments as it allows all parties concerned to set and agree upon a suitable maintenance period for larger jobs.

As all the above activities imply, to succeed at preventive maintenance, most companies find that a great deal of paper work must be done by the maintenance supervisors. Planning for supervisors can take on a variety of forms in order to accomplish the scheduled work. For example, supervisors must assess time requirements along with parts and manpower availability before delegating work to crews.

However, the paper work for a maintenance supervisor is not completed once the work is assigned. They must constantly

record and report on work accomplished. Such recordings are: actual man hours used, material charges, equipment identification, downtime, equipment specifications or idiosyncrasies, work performed, and any other pertinent information. This is seen as an essential paper work task as such information is often needed for reference. Also, from such data maintenance supervisors have to distribute such reports as backlogs, equipment data, expenditures, and production performance that are valuable for management decision making processes. Supervisors also have to account for costs which may involve paper transactions with such departments as payroll, accounting, warehouse, and plant supervision.

Quite often maintenance supervisors find that their paper work duties overwhelm them. They soon begin to get frustrated with their clerical duties as they have little opportunity to practice the true trades of their profession. To solve this dilemma, supervisors frequently reduce the effort needed to adequately maintain paper work requirements. Unfortunately in the long run inadequate data can be quite costly.

A computerized preventive maintenance system (CPMS) can aid maintenance planners in the many clerical duties required to successfully operate a preventive maintenance system. A CPMS's role is to act as an information and storage retrieval system, enhancing the effectiveness of preventive maintenance. A CPMS records all the relevant data related to the preventive maintenance of equipment. They included actual man hours used, material charges, equipment identification, work performed and

time per job. These data can be used for a variety of tasks. For example, historical data on equipment maintainability, and maintenance costs can assist in decisions for purchasing new equipment. Data generated from the system can enhance interdepartmental communication with payroll, accounting, warehouse, and plant supervision.

Given the importance of CPMS to the maintenance department, one would think that its introduction into an organization would be an easy task. However, due to issues presented in the literature review, CPMS has been difficult to adopt.

To address these issues, a comprehensive as possible list of CPMS benefits was compiled in order to verify how many of the systems' literature proclaimed benefits would materialize in an single study. As no adequate model was available to assist in the justification process of CPMS a computerized job-aid was developed from the benefits verified.

The main application of the software is to take the verified benefit list and form it into a knowledge base to be utilized as a job-aid tool for the task of justifying a CPMS. As a job-aid the software can be used as a learning tool for those considering or assigned the task of evaluating the benefits of CPMS. It prompts the user to recognize and consider those benefits having recorded a gain in an actual setting. The software created is named "Computerized Preventive Maintenance System Justification Assistance Software". The purpose of the software is to support the decision process rather than to

automate it.

In the following chapter, two major obstacles which have impeded the adoption of CPMS are presented. These are managements' antiquated views towards maintenance practices and the absence of suitable software justification models. The methodology used in the study is explained in chapter three. The results of the study along with limitations are presented in chapter four.

Chapter 2

LITERATURE REVIEW

Two themes dominate the literature on the difficulties of adopting a CPMS in an organization. The first theme suggests that acquisition of computerized information systems, in general, has been difficult due to the inadequacy of the models for justification of software. The second one suggests that introduction of a CPMS is difficult due to old-fashioned management views towards maintenance practices. In the following sections these two themes are elaborated.

At this point a note regarding the nature of the literature on this topic is in order. Most of the literature on maintenance appears in trade publications and magazines. In these publications the conclusions and results are seldom supported to the extent that is acceptable by the academic community. Much too often the authors are biased toward systems they are associated with and as a result, impartial criticisms of CPMS are almost non-existent. Nevertheless, many authors have articulated their experience and arguments well enough to form a basis on which academic work can be built.

2.1 PROBLEMS WITH SOFTWARE INTRODUCTION

Computers have become invaluable for obtaining accurate, relevant and timely information, and are well recognized for their valuable contribution to information processing. Yet, the

introduction of computer based information systems remains difficult (Roblesky, 1988). A CPMS is no exception. Here also the use of traditional justification methods seems to be the primary problem. Traditional methods, such as Return On Investment (ROI), Discounted Cash Flow, and Internal Rate of Return (IRR) are best suited for proposals with easily quantifiable objectives, such as increased capacity, decreased labor costs, and reduced overhead.

All objectives sought through the adoption of software, however, are not easily quantifiable and are more qualitative in nature (Kleen, 1981; Gellman, 1989). An example of qualitative benefits are improved forecasting abilities, parts scheduling, as well as improved replace/repair decisions. Unfortunately such benefits almost always show up after the system is in place and are extremely difficult to trace back to their source(i.e. software). Willmont (1989) found that less than half of the companies, he studied used computers for maintenance. He attributed this situation to the low priority given to maintenance in most companies, and a difficulty with quantifying benefits of computer based systems.

Calls for new justification models to address these concerns fail to generate adequate response and thus, software advocates have problems justifying systems to the skeptics (Keen, 1981). The problems only worsen when out of the ordinary approaches are used to convince management as technical data and jargon only confuse management (Bodart, 1982).

Robertson and Gatignon (1986), also found that as information software was not viewed as an immediate improvement to an organization being well hidden within the internal mechanisms of the company and not visible by the customer, management inhibited its adoption.

As can be seen from the literature presented, when intangible benefits are hard to quantify, the justification processes can become difficult. Unfortunately CPMS has proven equally difficult to introduce, especially in a department not recognized for a strong use of software systems and the focus of concerns are mechanical in nature and where traditional justification method are well suited.

2.2 CPMS INTRODUCTION PROBLEMS DUE TO MANAGER'S VIEWS TOWARDS MAINTENANCE

One of the major barriers to introduction of CPMS has been the upper management's skewed view towards maintenance. Since preventive maintenance is an integral part of CPMS, misperception of maintenance operations adversely affects CPMS adoption.

Thus far, it seems that managers have been applying several age-old practices to decisions regarding maintenance. Some of these have been referred to as the "percentage approach," the "efficiency illusion," the "overhead classification," and "utilization of slack resources."

The "percentage approach" is followed by some managers to decide on maintenance expenditure. This rule of thumb allocates maintenance based on a percentage of total sales. As long as the

expenditure remains small or unchanged from previous years, managers tend not to notice the maintenance operations. Without management support the maintenance operations are neglected and equipment starts to deteriorate. Consequently maintenance expenditures start to grow. By the time management notices the problem it is often too big and overwhelming (Simpson, 1990).

Some managers are under the "efficiency illusion." They believe that the maintenance activities are efficient as long as the production quotas are met. Although production efficiency can be severely lessened by poor maintenance, this illusion prevents managers from addressing the right problems when they happen (Simpson, 1990).

Management's treatment of maintenance as a "function of overhead" is yet another common problem, rooted in bad accounting practices (Sourwine, 1989; Sharman, 1990). Since maintenance is not seen as a "value adding" activity and not contributing to profit margins, expenditures are often lumped in with other overhead costs and allocated to products produced (Johnson, 1987; Thomas, 1989; Sharman, 1990). That is, maintenance expenditures are lumped into one cost pool and then allocated on the basis of direct labor dollar figures. In factories with a small inventory of equipment this is an innocuous procedure. However, the method is not effective where automation has reduced direct labor so much that costs are distributed unrealistically to labor intensive products or operations. For illustration, consider a factory which produces two products in parallel. One production process is fully automated, and the other is labor

intensive. Through this method of cost allocation, the majority of maintenance costs would be allocated towards the labor intensive product. Even if the bulk of the costs were directly attributable to the automated process, the end result is that a profitable manual process could be considered too costly.

Historically, management has also undermined the importance of maintenance by compensating for equipment problems through "slack resources" (Willmott, 1990). Slack resources come in many forms such as excess stock, overtime, spare capacity, additional equipment, and budgeting for unscheduled sub-contract work (Willmott, 1989). None of these, however, addresses the actual problems, they only mask them and contribute to higher costs.

Managers also tend to overlook maintenance as it is only one of many sub-systems within an organization. Maintenance has complex relations with payroll, purchasing, accounting, and production departments (Kelly, 1984). An example of the complexity is the constant communication that must take place between the maintenance and purchasing departments when purchasing large costly mechanical components. Quite often exact specifications and tolerances must be properly communicated for a suitable component to be obtained in time for installation. However, since maintenance is considered an indirect cost by most businesses, it is often relegated to a secondary role; it tends to be driven by the logic of the related departments (Spratling, 1986). For example, a purchasing department may choose items of inferior quality in order to reduce purchasing cost. As cost reduction is always viewed as favorable, the maintenance department faces the

continual task of justifying purchase requests to staff without appropriate background to evaluate the requests. It is this secondary role that shadows the importance of maintenance activities.

A significant problem that encourages managers to behave in ways described above is that it is extremely difficult to measure the output of maintenance operations. Determining the benefits gained by cutting down costs of downtime, poor delivery, rejected products, etc. is a difficult task (Kelly, 1984; Schiff, 1984; Eade, 1989). McNair (1987) thinks that too much attention on financial factors has made the difficult task of quantifying the qualitative benefits of maintenance seem essential.

Willmott (1989) found that maintenance was rarely discussed in the board room due to the absence of quantitative data. He found that quick payback, increased uptime, and increased technological change were of such concern to management they often overlooked traditional methods and procedures for preventive maintenance. Only 32 of the 62 companies he studied had monitored costs of individual machines. Of these companies, in many cases, direct and indirect costs requested were not available.

Thus, one clear message that comes from the literature is that management's traditional views of maintenance is a significant barrier for most maintenance departments to contribute more than they now do towards their companies' long term profits. The upshot of this is that it is difficult to persuade the

management to allocate more resources toward preventive maintenance. Despite its advantages CPMS does not receive its share of respect not due to it being viewed as a poor tool, but through what it does. Thus, CPMS adoption through its association with maintenance is unjustly inhibited.

To summarize, although literature has identified benefits of CPMS, managements antiquated views towards maintenance practices in general and the absence of suitable software justification models continue to impede CPMS adoption. In order to contribute to the knowledge available on CPMS and to address the obstacles confronting it, a comprehensive list of CPMS benefits has been assembled. The examination and verification of the comprehensive list has provided information to assist in the justification process of CPMS through the development of a computerized job-aid. The methodology cumulating to the computerized job-aid is presented in the following chapter.

Chapter 3

RESEARCH METHODOLOGY

The objectives of this thesis are to make a list of benefits that have been associated with CPMS in the literature and to verify, in a real setting, the extents to which these were realized. An abundance of knowledge exists on the tangible costs involved with the introduction of software such as CPMS, and a great deal must still be learned about intangible costs. However, this thesis does not address the costs in these issues. A proper justification framework would have to include this dimension.

Another objective is to develop a computerized job-aid for a typical CPMS justification process. The purpose of this job-aid is twofold. One, to make it easy for the decision maker to consider each factor of benefit associated with CPMS. Second, to allow the decision maker the opportunity to weigh each factor against the data regarding the extent of realization.

An extensive search of literature was undertaken to assemble as comprehensive a list as possible of benefits associated with CPMS. A number of authors had contributed to list, but not all of their benefits were mutually exclusive. As such, the benefits referred to in appendix "A" is an amalgamation of the benefits found throughout the literature. This list is comprised of those benefits that can be directly attributed to the introduction of

CPMS, and preventive maintenance benefits that through CPMS are achieved or improved. For verification of the benefits data were collected through the use of historical analyses, interviews, and a questionnaire. All three forms of data collection were designed to include the benefits identified from the literature. An expert system shell was used to develop a decision-aid from those benefits which were supported.

3.1 SITE SELECTION

The firm selected for the study was a mine located in Northern, Ontario. The company included both surface and underground operations and are devoted to the extraction and production of gold.

I worked for this company as a student both full time and part time for 10 years since 1979. The site was selected because it afforded me several advantages. As a result I was very familiar with the company's operations and employees. Little time was lost orienting myself with the company procedures, and past relationships with employees assured maximum cooperation. Secondly, the last four years of my employment at the case site were spent working with the company's CPMS. Thus the time spent for familiarity with their CPMS was negligible. Thirdly, as the firm is located in my home town savings in travel expenses were realized.

Another factor in the decision to select this case site was that its CPMS was developed internally. This was important to the study as it avoided problems that sometimes exist when

off-the-shelf programs are installed. As the system was developed internally all programming took into consideration existing hardware facility thus ensuring that CPMS features would not be lost due to hardware incompatibilities. This ensured all features could be examined in the study. Secondly, internal design ensured that the CPMS was compatible with existing systems such as payroll, accounting, and inventory. Thus no CPMS features were lost due to departmental software incompatibility. Finally, and most importantly, the presence of the system programmers would prove invaluable during data retrieval and in fully understanding the mechanics of the CPMS.

For a researcher to have worked at the research site would generally be regarded as contributing to predisposition towards the object of investigation. In recognition of this as a potential problem, every effort has been made to maintain objectivity in interpreting the data. Credibility may be added to these results by replication of this study at another site by another researcher.

The company agreed to participate in the study as an evaluation of its CPMS was deemed helpful. For example, management was interested in knowing the extent of material and labor savings since the introduction of the CPMS. Further, the management was not satisfied with the justification method applied to the CPMS project. It hoped a better method of justification for non-traditional capital projects such as software development would emerge from this study. They were also happy to contribute to other firms in the industrial

community considering the introduction of a CPMS.

The firm agreed that the researcher's independence and objectivity should not be compromised. Thus the top management took steps to prevent managerial interference in the reviews of the historical data, in interviews and in administration of the questionnaire. Cooperation from management personnel was solicited; access to all records, properties, and personnel relevant to the audit was provided.

3.2 EQUIPMENT SAMPLED

Eighty one pieces of machinery from a group of 265 were considered for the study. The CPMS had records on these machines for at least 30 of the 40 month time frame of this study. Records of 51 machines included in the study were kept throughout the 40 month study period.

The 184 machines that were not considered were either transferred or moved around from various properties, used as spares only, or acquired during the study period, and thus could not be used for the study.

3.3 Data Collection

INTERVIEWS

Fifteen staff members were interviewed. They were asked for their opinions on the CPMS benefits, and assistance in identifying CPMS features. All respondents were involved with the implementation of the CPMS and continued to use, supervise and maintain the CPMS after implementation. Of these, six were in plant supervisory positions, four were site supervisors, three

were from the accounting department, and two from the data processing department. Interviews about the software prototype were conducted with three people. They were all in plant supervisory positions.

QUESTIONNAIRE

A questionnaire was designed to measure the benefits which could not be examined from the documents. Fifteen respondents were asked to rank on a 5-point scale their opinions about realization of all the benefits.

A score of 1 would indicate strong disagreement with the suggestion that gains were made, and a score of 5 would indicate a strong agreement with the same. In all, thirty one benefits were examined through the questionnaire which is presented in appendix "F".

When interpreting the mean scores, the following classifications were made: 1 - 2.25 disagreed, 2.25 - 3.75 neutral, 3.75 - 5 agreed. It is understood that a mean score of less than 2.25 does not indicate deterioration of a given situation. It merely points to the fact that the respondents on an average did not agree that a benefit had been realized after the CPMS introduction.

HISTORICAL ANALYSIS

The historical analysis was similar to an independent appraisal². As such, the analysis could be regarded as an internal auditing which an evaluation³ of the firm's ongoing activities with regards to the CPMS took place. During this analysis a number of internal auditing techniques and tools were employed. Participative auditing used employees to gather information and contributed to the audit.

JOB-AID TEST

The results obtained from the historical analysis, interviews, and questionnaire were utilized in the creation of the computerized job-aid. The computerized job-aid was developed from the expert system shell PC-Easy. (Appendix "K" describes PC Easy.) The software developed for this study was also tested on site. It simulated the evaluation process which would take place with the job-aid. The test allowed for the job-aid to be tested in a real setting in which effectiveness in assisting the decision process was evaluated through interviews and direct observation.

² Sawyer (1988) defines an internal audit as "an independent appraisal function established within an organization to examine and evaluate its activities as a service to the organization." This definition is appropriate for this study, as one of the objectives was to evaluate and examine the benefits of an established CPMS.

³ Evaluation: "ascertaining the value of something by comparing accomplishment with a standard or goal."

The software was tested by three members in the organization who were involved in the implementation process. Each of them tested the job-aid software three times. The first test was conducted individually. This allowed me to determine the suitability of the program at the individual level, and investigate the flexibility of the program to individual user needs. The second test was conducted in a group setting to determine the software's use as an organizational tool. Finally, the third test was once again conducted by the individuals once they have had consultation with others during the second test. The results of this test allowed me to examine the changes in preference of the user after he has had consultation with other group members.

The results of each test were evaluated to determine the adaptability and sensitivity of the program, the consistency of the results, and the effectiveness of the job-aid software.

FEATURES OF THE CPMS STUDIED

The CPMS studied had 47 of the 50 features that have been associated with successful CPMSs in the literature. These features are outlined in appendix "B" and their verification in appendix "C". The high percentage of feature verified supports the selection of the case-site.

The three missing features are "indicate expected component changes", "indicate average component life", and "identify value added and non-value added costs". (The first two features, however were being implemented at the time of this study.)

Finally, as none of these missing features had any direct bearing on the benefits studied, their absence was unlikely to have affected this study significantly.

GENERALIZABILITY

As mining is a mature industry, and the firm studied has been in operation since 1933 it is expected that operations are similar to other mining companies. Thus, the results of the study may be generalized within the mining industry. Also as many of the machines examined in the study are similar to equipment used in other industries, the study results may be of value to other companies.

Chapter 4

RESULTS

The results are presented in two sections. The first discusses the results of the historical analysis, the interviews, and the questionnaire. As will be seen, the results support a number of CPMS benefits, especially those relating towards information processing. Also, the study does not support, for example, some claims assured by literature such as reduced paperwork. The second presents the results of the job-aid software trials. The software trials followed by discussions with the participants led to the confirmation that job-aid software would be a beneficial tool in the justification of CPMS.

4.1 RESULTS OF HISTORICAL ANALYSIS

For convenience, the benefits are divided into five categories. These are benefits related to; 1)handling of maintenance data, 2) decisions, 3) cost savings, 4) maintenance service, and 5) inventories and spare parts.

4.1.1 Benefits Related to Processing of Maintenance Data

Ease in identification of costs	4.47
Access to data	4.33
Timeliness of data	4.27
Confidence over data	4.27
Accuracy of data	4.20
Reduction of paper work	2.73

It appears that significant gains have been made with some data related benefits. In particular, the respondents agree that

access to data as well as accuracy, and timeliness of data have improved greatly with the CPMS. The information tracking and retrieval features of the CPMS were also found to be an improvement over previous manual record keeping systems. For example, material and labor costs for each piece of machinery are recorded and stored by the CPMS, where as with the previous system cost evaluations had to be limited to all machinery grouped within a cost center.

The increase in data confidence brought about through the introduction of the CPMS coupled with the increased ease of identification of costs has lead to improvements in decisions. The findings above are hardly surprising as data processing is at the heart of the CPMS which is a specialized information processing system.

4.1.2 Benefits Related to Decisions

Purchasing decisions	4.20
Forecasting personnel needs	4.20
Budget accuracy	4.00
Improvement in replace/repair decisions	3.87
Forecasting subcontract needs	3.87

The respondents thought that the CPMS permits the use of valuable data, much of which was restricted by the previous manual clerical procedures. For example, with the CPMSs' improved data tracking and retrieval capabilities now permit the user to examine costs related to individual jobs for individual pieces of machinery where as the previous system only permitted

period costs for all related work per cost center.

The respondents agreed that the purchasing decisions, as well as personnel and sub-contracting decisions improved through the implementation of the CPMS as the history or part usage and personnel requirements could be considered during decision making processes. Similarly repair/replace decisions also improved as the history of each machine could be examined. As all these decisions improve, budget accuracy was expected to improve as well.

Finally, although CPMS has improved data handling and therefore has improved decisions, respondents did not agree that paper work had improved. This increase can be attributed to the amount of information now available through the use of the system. One can speculate that the paper work may actually be reduced as system users learn how to effectively retrieve data from the CPMS.

4.1.3 Cost Savings

Equipment life extended	3.93
Reduction in financial outlays	3.67
Deferred capital investment for maintaining plant	3.53
Reduction in production bottlenecks	3.40
Increase in capital investment for new projects	3.33

One of the well recognized benefits of CPMS is extension of equipment life. The CPMS seemed to have passed that test as the respondents agreed that equipment life had increased. As reported above, it was found that financial outlays for upkeep of equipment had decreased, this in turn freed capital for more

favorable investment opportunities. Also, the historical cost analysis showed that on average, material and labor costs had decreased by 18% and 10% respectively. The management at the site thought that these cost reductions signify benefits gained through reductions in size and scale of repairs, equipment downtime, and unit operating costs. These savings alone, many managers confirmed, could justify the cost of a CPMS installation and operation.

4.1.4 Benefits Related to Inventory of Maintenance Supplies

Reduction in inventory	3.93
Reduction in non-critical equipment	3.80
Better use of lead times	3.73
Reduction in parts stockouts	3.73
Reduction in spare parts inventory	3.67
Ease in locating critical equipment	3.53
Ease in monitoring warranties	3.47
Reduction in critical equipment	2.47

An examination of benefits related to maintenance supplies show that cost savings have resulted through a reduction in inventory. Many felt that CPMS's ability to make better use of lead times had reduced the number of maintenance parts stock-outs. This benefit was realized as the CPMS system would link with the warehouse systems and determine if the necessary parts required for an upcoming job were available. If the parts were available, a hold would be activated on the inventories system thus removing the parts from availability. If the parts were not available, the CPMS based on its requirements would activate the warehouse systems automatic reorder programs

to ensure the necessary parts were available for the upcoming job. Subsequently, if the warehouse system was notified that the parts would not be available for the upcoming job, the CPMS operator would be notified automatically, that the upcoming job would have to be rescheduled.

Interestingly, the respondents did not agree that the CPMS had reduced the number of critical equipment on site. The reason cited most often is that as the key backup parts were never stocked in abundance in this plant. The respondents did however, credited the CPMS for assisting in monitoring the inventory of critical equipment and identifying components that were not in stock.

When examining the benefits the reader should keep in mind that much of the gains were due to improved communication between the maintenance, inventory and purchasing departments. The CPMS permits the maintenance department to effectively track what material it has used and communicate which items are needed to inventory and purchasing departments.

Prior to the CPMS implementation, large inventory of components and supplies were maintained. The ordering was done primarily on an ad hoc basis by the maintenance staff and often through standard procedures of the purchasing department. Many of these procedures were incompatible with the true needs of the maintenance department. Thus with regards to inventory, the CPMS was a success.

4.1.5 Benefits Related to Delivery of Maintenance Service

Identification of maintenance activity trends	3.93
Job sequence planning	3.80
Improvement in plant safety	3.73
Coordination between departments	3.67
Reduced pollution through reduced breakdowns	3.60
Improvement in work order instructions	3.40
Improvement in trend analysis	3.33
Improvement in work preparedness	3.13
Increase in productivity of maintenance personnel	3.13
Reduced pollution through routine maintenance	2.80
Improvement in responsiveness to work orders	2.87
Improved morale of maintenance department	2.40

Respondents agreed that the CPMS contributed to improvements in identification of maintenance activities, job sequence planning, departmental coordination and work order instructions. The improved information processing had a direct impact on maintenance activities as seen through improved trend analysis, work order instructions and work preparedness.

Some agreement was also found regarding improved plant safety and reduced pollution through a reduction in breakdowns. The diversity of the respondents to the questionnaire reflects upon the moderate scores registered for these benefits. However, to those in the plant, the significance of plant safety and reduced pollution was great; yet to others such as the respondents from accounting and data processing, these benefits were hardly noticeable.

Respondents to the questionnaire found that the CPMS had not significantly improved upon trend analysis, work preparedness and the productivity of maintenance personnel. Although information processing had improved, respondents had trouble assimilating the

abundance of information, and felt with time trend analysis would improve. With regards to work preparedness and productivity of maintenance personnel, respondents believed the CPMS had not resulted in a change as trades personnel were already performing exemplary work. Yet analysis of documents indicated change. For example, work backlog hours have decreased 65%, and work completed hours has increased on average 13%. The respondents had not noticed this change as work performance audits had not been done. The researcher speculates this contradiction has occurred due to the respondents perceptions of their abilities. In short, they feel they have been doing all that could possible be done with regards to preparedness and work productivity.

There were other CPMS benefits with which the respondents did not agree. For example, two highly touted benefits in the literature were reductions in paper work and improved morale. Neither of these benefits were recognized in this plant. In fact, the respondents believed the opposite to be true. They felt that the paper work had increased, and morale had decreased. Some interviews indicated that morale did not improve due to the introduction of computers in a traditional environment. This is ironic as the views of trade personnel support those in management who oppose CPMS implementation which only further complicates justification. These management views have been elaborated on in the literature review.

4.2 JOB-AID TEST

From the above results a computerized job-aid was designed to assist in CPMS adoption decisions. The job-aid is a program which expands the users knowledge on the benefits associated with CPMS. The job-aid is intended for use by those seeking to

After a brief introduction to the program, the users through a series of questions are prompted to express their degree of concern in a number of issues. These issues are all features which have been identified as CPMS benefits. Based upon the users response and the case site results, those benefits which are more likely to provide a gain for the user are identified both on screen and in print if desired.

During the first of the two individual tests, the respondents were asked to familiarize themselves with the program and comment on its operation. At the start up of the program, they found it easy: the introduction screens provided adequate information regarding the purpose of the program and its operation. As the program prompted the users through the CPMS benefits, help screens were useful in clarifying ambiguous terms. The format of asking the user to respond to each benefit individually was realized as a useful means of ensuring that the user considered all the benefits presented to them. One area of concern, however, was that the summary on the screen did not allow for the user to return to a screen once it was changed. All agreed that the print out was a better medium for the summary review.

Overall, the participants were pleased with the job-aid and agreed that it would have been useful at the justification stage of their CPMS. They believed that the job-aid could have provided them with tips in justifying the CPMS, and insights towards their justification approach. For example, it was suggested that due to the significant rewards from data and decision related benefits that a focus on these benefits would have been a more appropriate justification approach.

During the group test, the users were asked about the usefulness of the job-aid as an organizational tool. The result was clear. The software was a success as the respondents entered a lengthy debate regarding the importance of the benefits included in it. The job-aid had succeeded to remind the respondents to consider the importance of a CPMS and its usefulness to the organization from a variety of perspectives. The users agreed in retrospect that the job-aid would have certainly swayed some opponents of the CPMS. During this session the respondents' arguments focused on the inventory and cost saving related benefits. This focus is likely due to the tangibility of these benefits. Once again it is educational to see that the traditional justification models constrain the thought processes by channelling them toward tangible costs and benefits only.

Finally, in the second of the individual studies, the participants were asked to comment on the job-aid after having had a chance to discuss it with colleagues. In general, the respondents agreed that the job-aid would be valuable in helping

an organization determine which benefits would be attractive for them and the extent to which they can be used in justifying a CPMS in its specific context.

As this research is a case study, its results may not be applicable to other organizations. Every aspect of the firms management style, or production process may not be the standard for the industry, although it is expected that a significant portion would be.

Finally, there may be other errors, as the majority of data collected was historical and may contain misinformation; that is, it might have been prepared for a variety of purposes in mind. Also, the data may be inaccurate or incomplete.

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APPENDIX "A" CPMS BENEFITS

The literature reviewed identified a number of benefits associated with the implementation of PM and CPMS.

(Hopson, 1984; Pengilly, 1984; Potter, 1984; Cooper, 1986; France, 1986; Quinn, 1986; Mackey, 1987; Means, 1987; Beadle, 1988; Pengilly 1988; Roblesky, 1988; Beadle 1989; Curnow, 1989; Jones, 1989; Laws, 1988; Thomas, 1989; Jenkins, 1990)

PM BENEFITS

Reduction in:

- 1) size scale of repairs
- 2) overtime
- 3) scrap, rejects, spoilage
- 4) premature replacement of parts and equipment
- 5) downtime of equipment
- 6) unit operating costs
- 7) part stock outs
- 8) standby equipment
- 9) bottlenecks
- 10) pollution (especially emergencies)
- 11) unnecessary repairs
- 12) non-routine maintenance
- 13) inventory carrying costs through minimization of spare parts, and better use of lead times

Improvement in:

- 14) quality of product
- 15) opportunity collateral
- 16) life of equipment
- 17) productivity of maintenance personnel
- 18) market share
- 19) equipment output
- 20) safety and protection for equipment
- 21) deferment of capital investment in additional capacity

CPMS BENEFITS

Improvement in:

- 1) paper work and its shuffling between departments
- 2) identification of costs
- 3) time, ness and accuracy of data
- 4) forecasting abilities for personnel (i.e. labor) needs
- 5) data accessibility for data users
- 6) confidence in data by users
- 7) replace/repair decisions
- 8) monitoring of warranties
- 9) identification of maintenance trends through the analysis of repair data
- 10) response to non-routine work
- 11) morale
- 12) ability to locate critical spare equipment

- 13) trend analysis for corrective maintenance
- 14) forecasting for sub-contracting
- 15) labor optimization
- 16) budget accuracy (i.e. not just an estimated percentage increase)
- 17) equipment maintainability costs can be examined when purchasing equipment
- 18) coordination with production departments

APPENDIX "B"

CPMS FEATURES

The literature review provides a number of features that a successful CPMS should possess. These criteria were utilized in determining a suitable case site. During the test, this list was used as a form of a checklist. The authors that have contributed to this list are Rex Pengilly, 1984; K. Bagadia, 1987; John Beadle, 1988; and Rae Simpson, 1988.

REPORTS GENERATED:

- general information on vendors, expected delivery dates, and parts on order.
- manpower requirements for routine maintenance. (logistics may provide details for non-routine maintenance).
- inspections to be scheduled while on-line or shut down.
- expected delivery dates and parts on order.
- work in progress, completed, required, on hold.

HISTORICAL DATA:

- equipment manufacturer's recommended spare part list and availability through cross referencing with warehouse inventory lists.
- equipment history referring to "little black book tips"¹ for both routine and non-routine maintenance.
- equipment overhaul procedures, standards, trades required, and specifications.
- equipment downtime.
- equipment lists by location and department.
- labor and material costs for each piece of equipment, component, manager, division, cost center, and crew for both routine and non-routine maintenance.
- warehouse and plant inventory listing (i.e. shops).
- library listings (for alternate parts or suppliers).
- spare parts and emergency spare listings.
- purchase history.
- service recalls, by machine, by department.
- emergency calls, by machine, by department.

¹ A "little black book" quite often refers to a notebook carried around by front line foremen containing information which is valuable to the accomplishment of their duties. When such information is installed upon a computerized preventive maintenance system, it becomes safer and is accessible to all.

- operator abuse indicators.
- track routine and non routine jobs outstanding and completed by equipment, component, manager, division, cost center and crew.

MANAGERIAL ASSISTANCE:

- provides preventive maintenance work sheets, checklists, and schedules.
- provides work order preparation guides, (i.e. job duration, crafts involved, material required, instruction).
- provides uniform work initiation process.
- provides uniform methods to measure and control work backlogs.
- allows new machinery to be reviewed for compatibility with existing equipment (i.e. the team of equipment has changed).
- provides procedures for obtaining approval and work authorizations.
- indicates expected change of component.
- indicates average life of component and those not matching average, are identified and studied.
- indicates manpower required to complete scheduled tasks.
- indicates suggested purchasing.
- indicates over stock warnings.
- indicates to production the overhauls or major jobs that are upcoming.
- ability to trigger restocking of parts through integration with warehouse systems.
- ability to identify overdue pm's.
- ability to identify resources required (i.e. labor, parts, tools).
- ability to reduce clerical functions and paper work.
- resource forecasting- to determine future requirements of spare parts and labor.

FLEXIBILITY:

- ability to force entries and cross reference data.
- ability to categorize equipment by type, fleet, crew, product line, cost center, division, manager.
- ability to perform what if scenarios.
- ability to adapt programming to existing and future plant facilities as well as current and future maintenance procedures.
- ability to bring new equipment and facilities on line

EQUIPMENT/PROGRAMING:

- ability to provide data integrity and cross referencing through central data base storage, controlled access, and a traceable system.
- ability to provide adequate documentation.
- ability to provide graphic capabilities (i.e. key performance indicators).
- ability to provide on-line data accessibility and transfer with the accounting, payroll, warehouse, and purchasing departments as well as maintenance supervisors and management.

- ability to identify value added costs and non-value added costs.
- ability to identify direct and indirect costs.
- ability to assist front line foremen.
- ability for the system to be understandable to all levels in the organization. The system should be designed for the end users, not computer experts (i.e. user friendly).
- posses sufficient staff with adequate knowledge.
- posses adequate hardware requirements (i.e. use of modems or hard wiring for access in the field).

APPENDIX "C" RESULTS OF CPMS CRITERIA CHECK LIST

YES NO

REPORTS GENERATED:

- 1) General information on vendors, expected delivery dates, and parts on order. *
- 2) Manpower requirements for routine maintenance. (logistics may provide details for non-routine maintenance). *
- 3) Inspections to be scheduled while on-line or shut down. *
- 4) Expected delivery dates and parts on order. *
- 5) Work in progress, completed, required, on hold. *

HISTORICAL DATA:

- 1) Equipment manufacture's recommended spare part list and availability through cross referencing with warehouse inventory lists. *
- 2) Equipment history referring to "little black book tips" for both routine and non-routine maintenance. *
- 3) Equipment overhaul procedures, standards, trades required, and specifications. *
- 4) Equipment downtime. *
- 5) Equipment lists by location and department. *
- 6) Track labor and material costs for each piece of equipment component, manager, division, cost center, and crew for both routine and non-routine maintenance. *
- 7) Warehouse and plant inventory listing (i.e. shops). *
- 8) Library listings (for alternate parts or suppliers). *
- 9) Spare parts and emergency spare listings. *
- 10) Purchase history. *
- 11) Service calls, by machine, by department. *
- 12) Emergency calls, by machine, by department. *
- 13) Operator abuse indicators. *
- 14) Track routine and non routine jobs outstanding and completed by equipment, component, manager, division, cost center and crew. *

MANAGERIAL ASSISTANCE:

- 1) Provides preventive maintenance work sheets, checklists and schedules. *
- 2) Provides work order preparation guides, (i.e. job duration, trades and material required, instruction). *
- 3) Provides uniform work initiation process. *
- 4) Provides uniform methods to measure and control work backlogs. *
- 5) Provides for new machinery to be reviewed for effects on existing equipment (i.e. team of equipment has changed). *
- 6) Provides procedures for obtaining approval and work authorizations. *
- 7) Indicates expected change of component. *
- 8) Indicates average life of component and those not matching average, are identified and studied. *
- 9) Indicates manpower required to complete scheduled tasks. *

	YES	NO
10) Indicates suggested purchasing.	*	
11) Indicates over stock warnings.	*	
12) Indicates to production the overhauls or major jobs that are upcoming.	*	
13) Ability to trigger restocking of parts through integration with warehouse systems.	*	
14) Ability to identify overdue preventive maintenance's.	*	
15) Ability to identify resources required (i.e. labor, parts, tools). ²	*	
16) Resource forecasting to determine future requirements of spare parts and labor.	*	

FLEXIBILITY:

1) Ability to force entries and cross reference data.	*
2) Ability to categorize equipment by type, fleet, crew, line, cost center, division, manager.	*
3) Ability to perform what if scenarios. ⁶	*
4) Ability to adapt programming to existing and future plant facilities as well as current and future maintenance procedures.	*
5) Ability to bring new equipment and facilities on line	

EQUIPMENT/PROGRAMING:

1) Ability to provide data integrity and cross referencing through central data base storage, controlled access, and a traceable system.	*
2) Ability to provide adequate documentation.	*
3) Ability to provide graphic capabilities (i.e. key performance indicators). ⁶	*
4) Ability to provide on-line data accessibility and transfer with the accounting, payroll, warehouse, and purchasing departments as well as maintenance supervisors and management.	*
5) Ability to identify value added costs and non-value added costs.	*
6) Ability to identify direct and indirect costs.	*
7) Ability to assist front line foremen.	*
8) Ability for the system to be understandable to all levels in the organization. The system should be designed for the end users, not computer experts, (i.e. user friendly) ⁷	*
9) Posses sufficient staff with adequate knowledge. ⁸	*
10) Posses adequate hardware requirements (i.e. use of modems or hard wiring for access in the field). ⁸	*

¹ Available but rarely used.

² Only used when needed for complex tasks.

³ Physically done by maintenance controller prior to bringing equipment on line.

⁴ If undetected by controller, or foremen via printouts, the task is rescheduled every week until completed.

⁶ Done by controller with data from system, (rarely used).

- 7 Orientation to system required.
- 8 Opinion of researcher.

APPENDIX "D"

THE RESEARCH PROCESS

The steps in this research were:

- 1) An audit checklist was prepared from benefits identified from the literature. This checklist served as a basis for the benefits identified during the study.
- 2) Features for a successful case study candidate were assembled.
- 3) A successful case study candidate was contacted for their approval and cooperation in the study. A six day on-site test was conducted to determine the suitability of the company based on the features identified for a successful CPMS.
- 4) Upon acceptance, a twelve day on-site test was conducted in order to determine the suitability of the company for the research. Familiarization with the company's CPMS and its primary¹ and secondary² data sources took place. This determined the universality of the CPMS, and the extent of the historical cost analysis that had to take place. Interviews took place with key personnel in order to familiarize them with the proposed research, and to inform them of

¹ Primary Data: "data that is collected for a specific purpose from original sources. The data does not currently exist in a compiled form and it is the task of the researcher to collect it in the most cost efficient and useful format possible for decision making purposes." (Davis & Cozens, 1985)

² Secondary Data: "data that has been collected by others for another purpose it is important to us because it can save considerable time and effort in solving the research problem at hand." (Davis & Cosenza, 1985)

their roles in the process. The site was also tested for the integrity of data and the ability to retrieve it.

- 5) The test results were analyzed for the suitability of the firm to the proposed research. The test site was accepted and approved by thesis advisory committee.
- 6) Upon approval of the selected company, a four week on site study took place in order to examine the extent of the achievement of the benefits identified in appendix "A". Company records and documents were examined, and staff from various levels completed a questionnaire. The following appendices indicate the sources utilized for their creation. The documents and records examined for this study were: 1) CPMS equipment database (See appendix "E" 'Equipment in Study'), 2) CPMS labor costs and labor time journals (See appendix "H" 'Overtime Hours'), 3) CPMS backlog and work completed data files (See appendix "I" 'Backlog and Work Completed'), 4) CPMS labor hour files, production schedules, and CPMS equipment cycle schedules (See appendix "J" 'Equipment downtime and usage'), 5) CPMS material and labor costs (See material and labor period study costs appendix "K"). From this data, I tried to verify the existence of CPMS benefits which were more tangible. (Refer to appendix "G"),
- 7) Upon completion of the on-site study, the data collected were examined for accuracy and appropriateness for verifying the benefits identified in the literature.

- 8) A follow-up visit to the site was arranged in order to validate the questionable data and collect some missing ones.
- 9) Data were then analyzed in order to develop the scores on the tangible and intangible benefits achieved, not yet achieved, or achieved but not yet recognized by the company.
- 10) The data generated from this analysis is utilized in an expert system shell for the purpose of creating a CPMS implementation job-aid. The main application of the expert system is to take a body of knowledge and form it into a knowledge base which can be utilized as a job aid or learning tool when faced with the task of justifying a CPMS. The software created is entitled "Computerized Preventive Maintenance System Job-aid Assistance Software". (Please refer to Appendix "R" for a description of the expert system shell used in this study)
- 11) Upon completion, the job-aid software was tested at the site. Three people were selected and asked to try the software. Each of those selected had been involved in the CPMS implementation process. They tried to use the software three times. The first time they tried it individually. This allowed the researcher to determine the suitability of the software at an individual level, and investigate its flexibility to suit individual needs. The second time they tried the software in a group setting. This was to determine the software's use as an organizational tool. The third time they used it once again individually; this time

they had chance to talk with others during the second test. The results of this test allowed the researcher to observe changes in users' preferences.

The results of the trial were used to evaluate the adaptability of the program, and the overall effectiveness of the job-aid software.

APPENDIX "E"
EQUIPMENT USED IN STUDY

EQ#	MTHS	EQ#	MTHS	EQ#	MTHS	EQ#	MTHS
BC510	40	HS501	40	PG558	40	SC029	32
BS001	30	HS502	40	PG559	40	SC031	40
BS004	32	IU501	40	PG560	36	SC033	40
CA121	40	JC501	40	PH500	32	SC035	35
CA123	32	JC502	36	PH501	40	SC049	40
CA128	35	JD010	40	RB002	40	SC055	34
CA129	32	JD012	40	RB003	40	SC056	38
CA130	31	JD013	40	RB007	40	SC058	36
CA500	40	JD014	36	RB008	40	TY502	40
CN501	40	LO502	40	RC510	40	TY503	40
CN505	40	LO503	31	SC015	40	VG500	40
CR508	40	LO506	40	SC016	40	VG501	40
CR529	40	LO508	38	SC019	40	VG503	40
DL502	40	LO513	30	SC021	40	VG504	36
FE501	40	LO527	32	SC022	40	VG505	36
FE502	40	MV063	31	SC023	40	VG506	36
HG006	40	PG500	36	SC024	40	VG507	36
HO500	40	PG550	40	SC025	40	VG508	36
HO501	40	PG554	40	SC026	40	VG509	36
HS500	36	PG556	40	SC027	34	VG513	40
						VG517	36

NOTE: (1) The equipment used in this study was actively recorded for at least 75% of the study duration. This permits a true reflection of the period since the CPMS installation.

(2) Equipment that was used for the entire duration (i.e. forty months) was used as a complete study sample in order to eliminate any chance of compromise. Such as would be the case in new machinery entered during the course of the study.

EQUIPMENT NOT USED IN STUDY

EQ#	MTHS	EQ#	MTHS	EQ#	MTHS	EQ#	MTHS	EQ#	MTHS	EQ#	MTHS
AC501	7	FX504	6	LO515	8	PG579	24	SC63R	8	UH501	24
BC500	8	GE302	28	LO516	22	PG585	12	SE040	24	UH510	12
BC504	4	GE303	6	LO519	10	PG651	24	SE500	24	UH513	11
BC516	4	GE503	24	LO520	6	PG652	24	SE501	24	UH516	12
BI560	20	GE504	6	LO521	12	RB004	28	SE502	12	UH530	12
BO501	25	GE508	6	LO522	24	RC500	6	SE503	12	UH532	12
BO502	25	GE520	10	LO523	6	RC506	6	SE504	24	UH534	12
BS002	14	HD500	24	LO524	6	RC512	6	SE505	24	UH551	24
BS003	16	HS500	25	LO525	29	RC514	4	SE506	24	VG530	24
BS006	28	HS503	25	LO526	6	RC518	28	SE507	12	WC502	24
BS007	12	HS504	25	MV011	6	RC522	26	SE508	12	WC504	24
CA000	4	JD007	16	MV027	10	RC524	6	SE509	12	WC507	12
CA119	10	JD008	25	MV036	20	SC009	26	SE512	24	WC508	12
CA124	8	JD009	16	MV046	18	SC01R	12	SE513	24	WE011	24
CA125	3	JD01R	28	MV049	18	SC017	24	SE514	24	WE012	24
CA126	27	JD011	25	MV050	20	SC018	24	SE515	12	WE504	24
CA127	3	JD015	17	MV062	12	SC02R	6	SE516	12	WE505	24
CA131	21	LI500	25	MV084	6	SC020	16	SE517	12	WE506	24
CN502	12	LI501	25	MV019	2	SC028	10	SE518	12	WE507	24
CN504	12	LO011	14	NDT52	20	SC032	28	SE519	12	WE508	24
CN508	21	LO016	9	PG259	14	SC034	28	SE520	24	WE509	24
CO500	25	LO019	6	PG501	24	SC037	24	SE521	24	WE511	24
CO501	25	LO500	5	PG551	24	SC045	23	SUB51	24	WE513	24
CO502	25	LO501	18	PG552	24	SC050	6	SH051	16	WE518	24
CO503	25	LO504	13	PG553	28	SC054	24	TI501	6	WE519	24
CO504	25	LO505	15	PG555	12	SC057	8	TI502	28	WE521	24
CO505	25	LO507	24	PG557	12	SC058	20	TR500	12	WL503	24
CR503	6	LO509	24	PG551	12	SC060	24	TY022	12	WL506	12
CR504	24	LO510	15	PG552	12	SC061	24	TY060	8	WT502	6
FX501	24	LO511	24	PG573	24	SC063	12	TY500	22		
FX502	24	LO512	28	PG574	24	SC62R	8	TY501	22		

NOTE: The above list of equipment was not used in the study as they were either transferred or moved around from various properties, used as spares only, or purchased or acquired during the course of the study data. Thirty months was used as a cutoff as it was decided that machines should be actively recorded for at least 75% of the study duration of forty months.

APPENDIX "F"

QUESTIONNAIRE

The following is a questionnaire utilized in order to examine the possible existence of the literature identified benefits outlined in appendix "A". The questionnaire utilizes the Likard Scale as it is a proven method of obtaining information of data that is hard to quantify. The respondent is to circle the numerical response that best suits his opinion. The numerical scale is weighted as follows:

[1] STRONGLY DISAGREE	[2] DISAGREE	[3] NO OPINION	[4] AGREE	[5] STRONGLY AGREE
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- 1) Since the implementation of the CPMS do you feel financial outlays have been reduced due to premature replacement of parts, equipment, or unnecessary repairs? [1] [2] [3] [4] [5]
- 2) In regards to the CPMS optimizing labor resources:
 - a) Do you feel job sequence planning has improved? [1] [2] [3] [4] [5]
 - b) Preparedness for work has improved? [1] [2] [3] [4] [5]
 - c) Coordination between departments has improved? [1] [2] [3] [4] [5]
- 3) Do you feel there has been an increase in opportunity costs due to the implementation of the CPMS? [1] [2] [3] [4] [5]
- 4) Do you feel there has been an improved identification of costs due to the implementation of the CPMS? [1] [2] [3] [4] [5]
- 5) Does the CPMS allow for equipment maintainability costs to be examined when purchasing equipment? [1] [2] [3] [4] [5]

- 6) In regards to inventory:
- a) Do you feel the CPMS has resulted in lower inventory carrying costs? [1] [2] [3] [4] [5]
 - b) Do you feel the CPMS has resulted in minimization of spare parts inventory? [1] [2] [3] [4] [5]
 - c) Do you feel the CPMS has resulted in better use of lead times? [1] [2] [3] [4] [5]
 - d) Do you feel the CPMS has resulted in a reduction in parts stock outs? [1] [2] [3] [4] [5]
- 7) Do you feel the CPMS has resulted in an increase in the life of equipment? [1] [2] [3] [4] [5]
- 8) Do you feel the CPMS has resulted in an increase in productivity of maintenance personnel? [1] [2] [3] [4] [5]
- 9) Do you feel the CPMS has resulted in a reduction of standby equipment:
- a) Critical Spares? [1] [2] [3] [4] [5]
 - b) Non-critical Spares? [1] [2] [3] [4] [5]
- 10) Do you feel the CPMS has resulted in capital investment being deferred or eliminated? [1] [2] [3] [4] [5]
- 10) Do you feel the CPMS has resulted in data being more timely? [1] [2] [3] [4] [5]
- 11) Do you feel the CPMS has resulted in data being more accurate? [1] [2] [3] [4] [5]
- 12) Do you feel the CPMS has allowed for improved forecasting for personnel needs? [1] [2] [3] [4] [5]
- 13) Do you feel the CPMS has contributed towards safety and protection for plant equipment? [1] [2] [3] [4] [5]
- 14) Has the introduction of the CPMS reduced the number of bottlenecks occurring at the facilities. [1] [2] [3] [4] [5]
- 15) Has the introduction of the CPMS reduced paper work and paper shuffling between accounting, payroll, purchasing, warehouse, and maintenance departments? [1] [2] [3] [4] [5]

- 16) Does the CPMS provide for clear and consistent work order instructions? [1] [2] [3] [4] [5]
- 17) Does the CPMS allow for improved budget accuracy? [1] [2] [3] [4] [5]
- 18) Has the CPMS improved data accessibility for users? [1] [2] [3] [4] [5]
- 19) Do you feel confident in the data generated by the CPMS? [1] [2] [3] [4] [5]
- 20) Has the CPMS contributed towards improved replace/repair decisions? [1] [2] [3] [4] [5]
- 21) Do you feel the CPMS has contributed towards an improved morale amongst workers? [1] [2] [3] [4] [5]
- 22) Has the CPMS improved trend analysis for corrective maintenance? [1] [2] [3] [4] [5]
- 23) Has the CPMS improved maintenance coordination with production departments? [1] [2] [3] [4] [5]
- 24) Do you feel the implementation of the CPMS has resulted in a reduction in pollution for:
 - a) Routine Maintenance? [1] [2] [3] [4] [5]
 - b) Emergency Maintenance? [1] [2] [3] [4] [5]
- 25) Do you feel the CPMS has improved responsiveness to non-routine work requests? [1] [2] [3] [4] [5]
- 26) Do you feel the CPMS has improved abilities in locating critical spars? [1] [2] [3] [4] [5]
- 27) Do you feel the CPMS has improved identification of maintenance trends through analysis of repair data? [1] [2] [3] [4] [5]
- 28) Do you feel the CPMS has improved forecasting abilities for subcontracting needs? [1] [2] [3] [4] [5]
- 29) Do you feel the CPMS has improved the monitoring of warranties. [1] [2] [3] [4] [5]

- 30) Do you feel the CPMS has resulted in an [1] [2] [3] [4] [5]
increase in capital investment as
additional capacity can be deferred of
eliminated?

APPENDIX "G"

ANALYSIS TECHNIQUES UTILIZED

The following identifies the analysis techniques and sources used in the analysis of the benefits studied. The numbers in parentheses refer to the question used to measure a specific benefit.

1) Reduced size scale of repair¹:

Historical Analysis: CPMS data tracked on material and labor costs.

2) Reduced overtime: (emergency labor hours)

Historical Analysis: CPMS data tracked on overtime labor hours.

3) Reduced scrap, rejects, spoilage:

Note: Analysis of this benefit was not applicable to case site as the product produced could not leave the system until an acceptable standard was achieved.

4) Reduced financial outlay due to premature replacement of parts and equipment, or unnecessary repairs².

Historical Analysis: CPMS data tracked on material and labor hours.

Questionnaire: Question #1.

5) Reductions in equipment downtime:

Historical Analysis: CPMS data tracked on regular and overtime labor hours.

6) Reduction in unit operating costs:

Historical Analysis: CPMS data tracked on material and labor costs.

7) Reduction in parts stock outs:

Questionnaire: Question #6d.

8) Reduction of standby equipment:

Questionnaire: Questions #9a and #9b.

- 9) Reduction in paper work and paper shuffling between departments:

Questionnaire: Question #15.

- 10) Reduction in pollution:

Questionnaire: Question #24a and #24b.

- 11) Reduction in unnecessary repairs:

Analysis of this benefit was not applicable to case site refer to note in (1) above.

- 12) Reductions in non-routine maintenance:

Historical Analysis: CPMS data tracked on material and labor costs, and backlog hours.

- 13) Reduction in bottlenecks³:

Historical Analysis: CPMS data tracked on overtime labor hours.

Questionnaire: Question #14.

- 14) Reduction in inventory carrying costs through minimization of spare parts, and better use of lead times.

Questionnaire: Questions #6a, #6b, and #6c.

- 15) Improvement in the quality of products:

Analysis of this benefit was not applicable to case site.

- 16) Improvement in identification of costs:

Questionnaire: Question #4.

- 17) Improvements in timeliness and accuracy of data:

Questionnaire: Questions #10 and #11.

- 18) Improved forecasting for personnel needs:

Questionnaire: Question #12.

- 19) Improved data accessibility for users:

Questionnaire: Question #18.

- 20) Improved confidence in data by users:

Questionnaire: Question #19.

- 21) Improved replace/repair decisions:
Questionnaire: Question #20.
- 22) Improved monitoring of warranties:
Questionnaire: Question #29.
- 23) Improved trend analysis for maintenance repairs:
Questionnaire: Question #22.
- 24) Improved response to non-routine work:
Questionnaire: Question #25.
- 25) Improved morale:
Questionnaire: Question #23.
- 26) Improved ability to locate critical spares:
Questionnaire: Question #26.
- 27) Improved identification of maintenance trends through analysis of repair data.
Questionnaire: Question #27.
- 28) Improved forecasting abilities for sub-contracting work:
Questionnaire: Question #28.
- 29) Improved labor optimization:
Historical Analysis: CPMS data tracked on regular and overtime labor hours.
Questionnaire: Questions #2a, #2b, and #2c.
- 30) Increased life of equipment⁴:
Questionnaire: Question #7.
- 31) Increased productivity of maintenance personnel:
Historical Analysis: CPMS data tracked on work backlog and completed.
Questionnaire: Question #8.

32) Increased market share:

Analysis of this benefit was not applicable to case site.

33) Increase in equipment output⁵:

Historical Analysis: Production records on machine time available for use and increase in usage.

34) Increased safety and protection for plant equipment:

Questionnaire: Question #13.

35) Increase in budget accuracy:

Questionnaire: Question #17.

36) Increases in capital investment for additional capacity can be deferred or eliminated:

Historical Analysis: CPMS data tracked on material and labor costs. Production data on tonnage mined.

Questionnaire: Question #30.

37) Increased savings due to the examination of equipment maintainability costs when purchasing equipment.

Questionnaire: Question #5.

38) Improved coordination with production departments:

Questionnaire: Question #31.

¹ Note: size scale of repair at the on site case study referred to both time and cost involved in the maintainability of equipment. As time and labor costs are directly proportional to each other, labor regular and overtime hours are seen as a dual measurement in regards to both cost and time.

² Note: the replacement of parts is scheduled by the CPMS based on the manufacturers recommendations, unless trial and error dictates alternative scheduling. Machines are still replaced only after a major component failure, or until the unit is rendered inoperable. This is usually a judgement call based on experience of the available personnel. Until the system was implemented, fire fighting approaches to maintenance were used. Thus, all repairs scheduled are deemed necessary.

³ Note: bottlenecks happen primarily to areas of continuous operation such as in hoisting procedures or in milling operations. Downed hourly equipment rarely reduced operational tonnage. An examination of overtime hours although not a direct measurement was a good indication of reduction in bottlenecks.

⁴ Note: tangible calculations can not be made as records of equipment prior to CPMS installation are either non-existent, or incomplete. Also comparison of equipment life to manufacture's quote is difficult due to differences in use and environment.

⁵ Note: output cannot be identified to a specific machine underground, due to the use of overtime, uniqueness of crews, number of men on a crew, environment conditions.

APPENDIX "H"
OVERTIME HOURS

<u>Month</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>		
January	856	848	808		
February	1075	337	479		
March	717	461	521		
April	587	333	737		
May	925	505	475		
June	630	442	358		
July	676	590	343		
August	856	600	530		
September	777	493	997		
October	939	726	800		
November	886	735	738		
December	580	807	530	88-89	88-90
TOTAL	9504	6877	7316	Change	Change
AVERAGE	792	573.08	609.67	+27.64%	+23.02%

APPENDIX "I"
STUDY PERIOD BACKLOG AND WORK COMPLETED IN HOURS

<u>Month/Year</u>	<u>Backlog</u> <u>1988</u>	<u>Completed</u> <u>1988</u>	<u>Backlog</u> <u>1989</u>	<u>Completed</u> <u>1989</u>	<u>Backlog</u> <u>1990</u>	<u>Completed</u> <u>1990</u>
January	7825	4586	6632	6183	4601	5831
February	7843	2882	5560	6421	4377	5331
March	7855	4857	5875	6924	3516	6490
April	8129	5065	6063	4965	2007	4833
May	8041	3435	6396	4789	2520	5026
June	8140	4368	5161	6230	3942	7009
July	8306	6781	5978	5283	2175	3622
August	8851	4185	5785	4898	2310	4309
September	6687	5823	5600	5607	3050	5451
October	7446	5743	4947	6522	1208	5687
November	7271	5658	4180	8029	1367	4046
December	6420	7234	3963	7434	1621	5829
TOTAL	92814	60617	66140	73285	32694	63464
AVERAGE	7735	5051	5512	6107	2725	5289
				88-89	88-90	
PERCENTAGE CHANGE IN WORK BACKLOG				-29%	-65%	
PERCENTAGE CHANGE IN WORK COMPLETED				21%	5%	

APPENDIX "J"

[illegible][illegible][illegible]

USAGE

<u>EQUIP/89</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>TOTAL</u>
SC016	0	0	0	0	0	0	0	0	16	62	99	0	177
SC019	76	53	0	16	28	36	14	3	65	54	10	219	574
SC021	2	20	0	0	9	14	18	38	30	65	0	55	251
SC022	80	75	42	102	73	73	264	51	0	0	0	86	846
SC023	25	58	70	2	0	20	16	13	15	5	23	97	344
SC024	26	70	36	62	31	133	84	20	21	25	49	1	558
SC025	132	238	139	65	66	60	187	159	248	219	135	117	1765
SC026	108	156	90	150	117	89	57	50	71	30	20	139	1077
SC031	179	71	176	337	220	271	232	138	259	253	173	113	2422
SC033	275	285	168	174	133	329	215	217	246	94	185	54	2375
SC049	215	362	155	350	218	160	55	102	258	118	101	115	2209
TOTAL													12598

DOWN TIME

<u>EQUIP/90</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>TOTAL</u>
SC016	16	16	8	8	50	38	24	0	52	16	28	20	276
SC019	8	16	8	8	18	60	18	64	76	4	28	16	324
SC021	8	8	8	8	41	0	0	0	22	24	78	24	221
SC022	32	8	0	8	15	22	16	24	30	16	8	15	194
SC023	8	8	8	8	11	0	0	0	8	4	0	0	55
SC024	0	8	8	16	44	16	92	12	12	0	0	0	216
SC025	40	16	6	8	24	4	4	16	280	64	42	20	524
SC026	8	100	8	10	4	23	96	176	42	8	256	34	765
SC031	16	36	40	20	74	29	23	57	42	112	12	19	480
SC033	16	24	8	8	13	15	28	12	82	80	60	22	368
SC049	16	100	8	8	50	25	248	114	128	32	24	20	773
TOTAL													4196

USAGE

<u>EQUIP/90</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>TOTAL</u>
SC016	219	90	3	50	52	36	27	34	76	65	30	42	724
SC019	146	56	63	34	92	8	16	9	39	61	25	35	584
SC021	22	53	3	146	22	0	0	0	17	17	0	26	306
SC022	46	60	0	0	51	83	76	57	107	45	43	46	614
SC023	8	10	64	46	0	0	0	0	3	32	44	59	266
SC024	86	100	51	109	82	60	49	44	6	5	0	12	604
SC025	186	78	258	20	57	34	0	23	4	129	236	212	1237
SC026	5	4	20	0	16	29	29	100	158	134	49	152	696
SC031	299	207	82	422	250	345	225	208	256	198	224	316	3032
SC033	120	145	67	42	172	106	65	64	45	6	90	101	1023
SC049	285	56	44	0	40	74	26	75	186	0	189	157	1132
TOTAL													10218

	DOWN TIME	USAGE	DOWN TIME AS % OF USAGE
1988	5190	12967	40%
1989	2468	12598	20%
1990	4196	10218	41%

APPENDIX "K" DECISION AID

An off-the-shelf expert system shell PC Easy+ was used to create the CPMS justification software.

An expert system shell is a development tool which is used in the creation of software programs that can aid and solve problems traditionally addressed by experts. PC Easy is recommended for the creation of small and medium size prototypes.

PC Easy was chosen for this study for the following reasons.

- 1) previous experience with package reduced learning phase.
- 2) ideally suited for the development and testing of prototypes.
- 3) permits access to advanced spreadsheet and database capabilities as well as DOS file applications.
- 4) permitted access to external graphic capabilities.
- 5) rule-entry language utilized a simple to learn English format.
- 6) powerful debugging capabilities such as identification and editing features reduced error tracing.
- 7) extensive on-line help reduced manual referencing.
- 8) the package was ideally suited for a non-programing expert.

The main application of PC Easy for this study was to take a body of knowledge (domain) and build a knowledge base.

APPENDIX "L"

			JAN88	FEB88	MAR88	APR88	MAY88	JUNE88	JUL88	AUG88	SEPT88	OCT88	NOV88	DEC88	TOTAL88
EQUIP.	MATERIAL	TOTAL	21336	53788	86743	36674	51963	56434	55302	107949	27365	75982	96511	77366	747813
EQUIP.	LABOR	TOTAL	39414	29336	44449	27672	46010	35531	32310	79151	40207	35623	51180	49335	510226
EQUIP.	MAT&LAB	TOTAL	60750	83124	131192	64346	97973	91965	87612	187100	67572	111605	148099	126701	1258039
														AVERAGE EQUIP.	31451

EQUIP. MATERIAL AVERAGE	248	625	1009	426	604	656	643	1255	318	884	1127	900	8696
EQUIP. LABOR AVERAGE	458	341	517	322	535	413	376	920	468	414	595	574	5933
EQUIP. MAT&LAB AVERAGE	706	967	1525	748	1139	1069	1019	2176	786	1298	1722	1473	14628
											AVERAGE EQUIP.		366

STUDY	MATERIAL	TOTAL	17312	48546	60729	26479	42251	52678	50380	83591	19892	58507	78683	68814	607862	
STUDY	LABOR	TOTAL	31322	20993	34989	22807	38534	28239	26804	58853	28337	27200	35316	36727	390121	
STUDY	MAT&LAB	TOTAL	48634	69539	95718	49286	80785	80917	77184	142444	48229	85707	113999	105541	997983	
															AVERAGE EQUIP.	24950

STUDY	MATERIAL	AVERAGE	339	952	1191	519	828	1033	988	1639	390	1147	1543	1349	11919
STUDY	LABOR	AVERAGE	614	412	685	447	756	554	526	1154	556	533	692	720	7649
STUDY	MAT&LAB	AVERAGE	954	1364	1877	966	1584	1587	1513	2793	946	1681	2235	2069	19568
AVERAGE EQUIP.														489	

	<u>JAN89</u>	<u>FEB89</u>	<u>MAR89</u>	<u>APR89</u>	<u>MAY89</u>	<u>JUN89</u>	<u>JUL89</u>	<u>AUG89</u>	<u>SEPT89</u>	<u>OCT89</u>	<u>NOV89</u>	<u>DEC89</u>	<u>TOTAL89</u>
EQUIP. MATERIAL TOTAL	83556	73555	50508	53966	28051	23572	38485	31799	64342	56836	43449	95256	641916
EQUIP. LABOR TOTAL	97673	41508	38923	33509	28296	28087	28571	32405	43289	37451	36081	31452	475030
EQUIP. MAT&LAB TOTAL	183136	115465	89359	82988	57817	49795	69201	78719	93521	94444	89090	126708	1116946
												AVERAGE EQUIP.	27924

EQUIP. MATERIAL AVERAGE	972	855	587	628	326	274	448	370	748	661	505	1108	7464
EQUIP. LABOR AVERAGE	1136	483	453	390	329	327	332	377	503	435	420	366	5524
EQUIP. MAT&LAB AVERAGE	2129	1343	1039	965	672	579	805	915	1087	1098	1036	1473	12988
											AVERAGE EQUIP.		325

STUDY	MATERIAL	TOTAL	71686	64522	45339	46445	22559	20915	33822	27545	59759	38660	40372	94241	564406	
STUDY	LABOR	TOTAL	71067	31183	32966	28053	23187	22933	24127	22449	36867	31274	29390	26037	378038	
STUDY	MAT&LAB	TOTAL	144660	96407	78233	70011	47616	41984	60094	64509	82536	70091	79322	120278	942444	
															AVERAGE EQUIP.	23561

STUDY	MATERIAL	AVERAGE	1406	1265	889	911	442	410	663	540	1172	758	792	1848	11067
STUDY	LABOR	AVERAGE	1393	617	646	550	462	450	473	440	723	613	576	511	7413
STUDY	MAT&LAB	AVERAGE	2836	1890	1534	1373	934	823	1178	1265	1618	1374	1555	2358	18479
														AVERAGE EQUIP.	462

		<u>JAN90</u>	<u>FEB90</u>	<u>MAR90</u>	<u>APR90</u>	<u>MAY90</u>	<u>JUN90</u>	<u>JUL90</u>	<u>AUG90</u>	<u>SEP90</u>	<u>OCT90</u>	<u>NOV90</u>	<u>DEC90</u>	<u>TOTAL90</u>
EQUIP. MATERIAL	TOTAL	41635	73103	52765	62686	57181	27196	26910	37741	39083	80084	66827	71796	637007
EQUIP. LABOR	TOTAL	31947	32434	34933	31925	36343	31536	24553	36029	35883	28764	31158	29325	388326
EQUIP. MAT&LAB	TOTAL	73582	107368	88030	93083	92361	59303	51012	74356	75192	108646	97610	102672	1025333
														AVERAGE EQUIP. 25633

EQUIP. MATERIAL	AVERAGE	484	850	614	729	665	316	313	439	454	931	777	835	7407
EQUIP. LABOR	AVERAGE	371	377	406	371	423	367	286	419	417	334	362	341	4515
EQUIP. MAT&LAB	AVERAGE	856	1248	1024	1082	1074	690	593	865	874	1263	1135	1194	11922
														AVERAGE EQUIP. 298

STUDY MATERIAL	TOTAL	37903	66213	40880	59974	50140	22860	18924	33270	34740	68972	62625	70036	566537
STUDY LABOR	TOTAL	25344	25633	31108	27976	30445	24656	20687	31344	31140	25287	27740	25883	327243
STUDY MAT&LAB	TOTAL	63247	93618	72290	86354	79221	48057	39071	65200	65992	93874	89508	95919	893780
														AVERAGE EQUIP. 22345

STUDY MATERIAL	AVERAGE	743	1298	802	1176	983	448	371	652	681	1352	1228	1373	11109
STUDY LABOR	AVERAGE	497	503	610	549	597	483	406	615	611	496	544	508	6417
STUDY MAT&LAB	AVERAGE	1240	1836	1417	1693	1553	942	766	1278	1294	1841	1755	1881	17525
														AVERAGE EQUIP. 438

		<u>JAN91</u>	<u>FEB91</u>	<u>MAR91</u>	<u>APR91</u>	<u>TOTAL91</u>	1988	1989	1990	88-89	88-90
							<u>TOTAL</u>	<u>TOTAL</u>	<u>TOTAL</u>	<u>CHANGE</u>	<u>CHANGE</u>
EQUIP. MATERIAL	TOTAL	34081	101826	51622	63379	250908	747813	641916	637007	14%	15%
EQUIP. LABOR	TOTAL	31709	32820	37358	31803	133690	510226	475030	388326	7%	24%
EQUIP. MAT&LAB	TOTAL	65790	134646	88980	95182	384598	1258039	1116946	1025333	11%	18%
						76920	31451	27924	25633	11%	18%
EQUIP. MATERIAL	AVERAGE	396	1184	600	737	2918	8696	7464	7407	14%	15%
EQUIP. LABOR	AVERAGE	369	382	434	370	1555	5933	5524	4515	7%	24%
EQUIP. MAT&LAB	AVERAGE	765	1566	1035	1107	4472	14628	12988	11922	11%	18%
						894	366	325	298	11%	18%
STUDY MATERIAL	TOTAL	32930	95798	48012	58612	235352	607862	564406	566537	7%	7%
STUDY LABOR	TOTAL	30306	30044	32908	28588	121846	390121	378038	327243	3%	16%
STUDY MAT&LAB	TOTAL	63236	125842	80920	87200	357198	997983	942444	893780	6%	10%
						71440	24950	23561	22345	6%	10%
STUDY MATERIAL	AVERAGE	646	1878	941	1149	4615	11919	11067	11109	7%	7%
STUDY LABOR	AVERAGE	594	589	645	561	2389	7649	7413	6417	3%	16%
STUDY MAT&LAB	AVERAGE	1240	2467	1587	1710	7004	19568	18479	17525	6%	10%
						1401	489	462	438	6%	10%

END

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