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A Prototype Industrial Maintenance Software System to Apply a Proactive Approach to Equipment Failure

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Abstract

This project proposes a technical solution to create a proactive approach to industrial equipment maintenance for a large paper manufacturing facility.

The traditional method for scheduling maintenance on manufacturing equipment uses a reactive approach. Reactive maintenance essentially means to perform repairs on equipment after failure has occurred; the process of these repairs begins by acquiring needed replacement part(s) utilizing a SAP (Systems Applications Products) system for authorization and ordering. Actual repairs are carried out by craftsmen based on their general knowledge of a specific trade and any previous experience concerning the failed equipment. The part(s) order through the SAP system must be cross referenced to a storeroom catalog to obtain required serial numbers associated with specific parts; this is a time consuming procedure which adds considerable downtime to the equipment in need of repair. This reactive approach to equipment repair results in a loss of equipment availability, component damage, and inefficient use of maintenance resources.

The goal of this project is to produce a prototype of a software system that will demonstrate the ability to increase equipment availability by utilizing a proactive approach to industrial maintenance. The prototype will include an equipment specific monitoring system, and a relational database system for storing equipment information.

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Chapter One: Introduction/Executive Summary

Thesis Statement

The application developed in this project provided a technical solution, through the use of a relational database and equipment monitoring system, to create a proactive approach to equipment maintenance for a large paper manufacturing facility. Moreover, the database and monitoring system is generic in nature, and can be applied to a variety of industrial manufacturing equipment.

Executive Summary

Industrial manufacturers are widely implementing computer systems for their operations. Database software plays a major role in the manufacturing industry; monitoring and controlling are the two major uses of this technology. These systems can be used for a number of other applications; an example would be to initiate a proactive maintenance management system.

The goal of this project is to produce a prototype of a software system that will demonstrate the ability to increase equipment availability by utilizing a proactive approach to industrial maintenance, and be used to decrease equipment down-time when catastrophic failure occurs. The prototype system was designed for and tested at a paper manufacturing facility located in the mountains of Virginia. For the purpose of this project 'PaperTech' will be used as a pseudonym for this factory. PaperTech manufactures heavy weight paperboard and is one of the largest paperboard manufacturing corporations worldwide. The system was designed in two parts, which includes a generic monitoring system for individual manufacturing systems or equipment, and a relational database for storing equipment information.

The Project prototypes proved to be effective at initiating a proactive approach in PaperTech's maintenance department; this facility employs systems and equipment that is found throughout the manufacturing industry, the processes used to create and implement this project may be utilized in various manufacturing applications.

The completed project:

1. Provided a system to aid in the identification of potential equipment failure before actual catastrophic failure occurred.
2. Enables craftsmen, planners, and foremen to electronically obtain information regarding repair/replacement parts, which include vendor recommendations for installation, skills required, and previous life-cycle of component being repaired/replaced.
3. Provided a method for determining the locations that specific spare parts can be used, and the number of specific spare parts in inventory.
4. Increased equipment availability by reducing the time required for routine and break-down maintenance.

Background

Traditional maintenance programs focused on a reactive approach to equipment failure. The operating conditions of critical plant machinery, equipment, or systems were given less concern than breakdowns or production interruptions. The only focus was on how quickly repairs to the machine or system could be made and returned to service. As long as the machine functioned at a minimally acceptable level, the maintenance program was considered adequate. There are two factors associated with this type of maintenance

approach that result in high and/or repeated repair costs: 1) poor planning and 2) incomplete repairs.

The first factor of reactive maintenance is that most repairs are poorly planned because of time constraints imposed by production schedules. This results in ineffective manpower utilization and inefficient use of maintenance resources. Reactive maintenance will cost three to four times more than the same repair(s) when it is well planned (Higgins 2.3.).

The second factor of reactive maintenance is that it focuses on what is needed to get the equipment back on line, and not on the cause of the failure. An example would be a drive motor failure which interrupts production. A reactive maintenance program will focus on replacing the drive motor without regard to what caused the failure, or how many times this particular drive motor has failed. It is not unusual for a production department to keep several of the same spare components on hand due to continued failure of the component in question. This is inefficient and results in increased inventory and maintenance costs.

Research concerning industrial manufacturing during the last decade indicates a shift from reactive to proactive maintenance. The typical proactive approach adopted by these industries is based on vendor recommendations for equipment expected life-cycle, which focuses on ideal operating conditions. Using these recommendations, maintenance is planned based on which system components have reached the end of their lifecycle. The central focus of the traditional proactive approach is planning, and does not address catastrophic or incalculable equipment failure. Figure 1.1 demonstrates the significant increase in

manufacturers who have adopted a proactive maintenance program based on planning in the last decade.

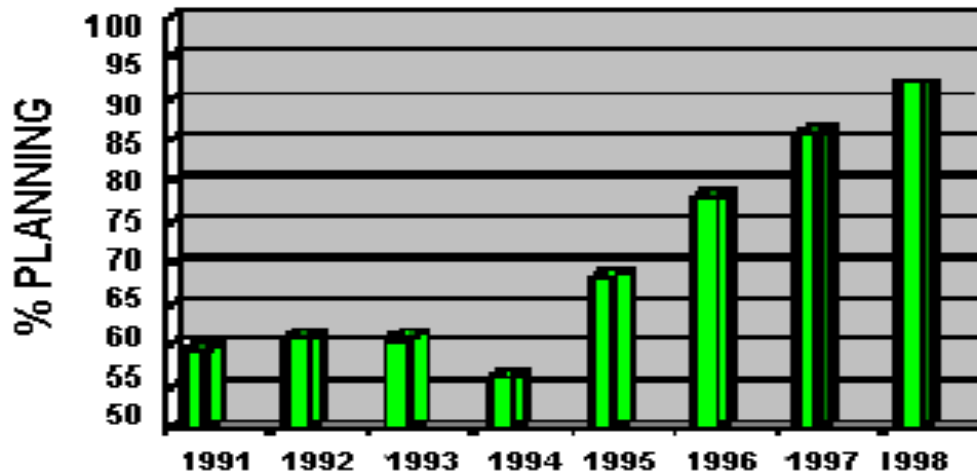


Figure 1.1 Proactive planning for industrial maintenance from 1991-1998.
Copyright (2002) The Plant Maintenance Resource Center.

The current trend in the manufacturing industry is to keep costs low in order to remain competitive in the global market place. Maintenance is a major cost associated with manufacturing. This cost includes, but is not limited to, labor for repairs, replacement parts, and lost production due to equipment being offline. PaperTech is constantly researching ways to improve the management of their maintenance departments.

Currently, PaperTech employs vibration analysis, along with vendor life-cycle recommendations, in an attempt to create a proactive maintenance program. A vibration-based proactive maintenance program utilizes an instrument containing a small microprocessor that is specifically designed to acquire, condition, and store both time and frequency domain vibration data. The instrument is used for checking

the mechanical condition of machines at periodic intervals and includes a microprocessor with solid-state memory for recording the overall vibration level of selected plant machinery.

There are several limitations to creating a proactive maintenance program through the use of vibration analysis. The major issue with this approach is that the root cause of potential component or system failure cannot be determined; there is no historical information regarding the operation of the component in question, and basically the method can only be used for rotating equipment. Also, using portable vibration analysis equipment requires an additional labor cost that may result in insufficient manpower to obtain the maximum benefits possible from this method. For the most part, vibration analysis is only performed on equipment that has already begun to fail; this results in additional components, other than the component responsible for the failure, experiencing unnecessary damage.

While PaperTech's current proactive maintenance program has improved the efficiency of the maintenance program, there is still a need to become more efficient. PaperTech competes in a global marketplace where only the most efficient manufacturers can expect to survive.

There are a number of processes used by PaperTech's maintenance program to maintain the production equipment and systems being utilized in the plant. Two of these processes were determined to offer the greatest opportunity to improve the company's maintenance program through the use of a software application. The two processes are: monitoring of production equipment and requisitioning of

replacement/repair parts. These processes and their implementations will be discussed in greater detail later in the paper.

The prototype software system developed to improve these two processes includes an equipment specific monitoring system, and a relational database for storing equipment information. This prototype is generic in nature, and can be used in other maintenance programs concerning industrial manufacturing.

The monitoring process currently employed by PaperTech is performed on an interval basis, with the time between monitoring dependent on the equipments importance in the manufacturing process. An example would be primary manufacturing equipment being monitored on a daily basis, while secondary support equipment would be monitored on a weekly basis. This monitoring usually consisted of a visual inspection of the equipment, and determining if the equipments output was acceptable.

The first part of the software system developed enabled the maintenance department to monitor the operation of a chosen piece of equipment on a continuous basis. Also, data in the form of vacuum, pressure, power, or amperes was used to determine the equipments actual efficiency. The equipments actual efficiency was then compared to a vendor specified efficiency to determine any potential for equipment failure.

The current method for acquiring a needed replacement part(s) utilizes a SAP (Systems Applications Products) system for authorization and ordering. Actual repairs are carried out by craftsman based on their general knowledge of a specific trade and any previous experience concerning the failed equipment. Currently, the

part(s) ordered through the SAP system must be cross referenced to a storeroom catalog to obtain required serial numbers associated with specific parts; this is a time consuming procedure which adds considerable downtime to the equipment in need of repair. This approach to equipment maintenance results in a loss of equipment availability, increased occurrence of incorrect part(s) requisition, and inefficient monitoring and control of inventory.

The second of the two parts of the software system developed for this project is a relational database. This will increase the efficiency of the distribution of part(s) used by the maintenance department, while also increasing the efficiency of inventory monitoring and control. Additionally, the database has the ability to provide information concerning specialty tools that may be needed for the installation of certain part(s) when the part in question is requisitioned. Also, the database system has the ability to track a given part as to the craftsman who checked the part out, where the part was used, and the time of service since the part was replaced last. The benefits derived from the application of a relational database for this situation include: to create a more efficient method for obtaining repair part(s), to identify problem areas where part(s) are not remaining in service for their rated lifecycle, and to assist craftsman in the installation of part(s) by providing information concerning vendor recommendations for specialty tools that may be needed for proper installation.

Business Need

In June of 2000 PaperTech initiated a company wide Enterprise Resource Planning (ERP) program to streamline and link all their business enterprises. This application of electronic technology was made due to a need to become more competitive in the global marketplace; in order to maintain a competitive edge, the company had to improve their business processes.

There were nine business processes affected by the ERP program. These included: customer service, planning/scheduling, procurement/payables, logistics, production operations, general ledger, asset management, business planning and operations analysis, and maintenance. Three of these processes were identified as important to customer satisfaction. These were customer service, planning/scheduling, and production operations. The other six, while considered necessary, were determined not to be a customer differentiator; this determination led to a central focus being placed on the first three processes, while less attention was given to the other six.

Maintenance was linked to the ERP program by functional location and equipment asset. In other words, maintenance was viewed as an asset with a physical location with the equipment used in the maintenance department being the asset that could be moved from functional location to functional location. Maintenance personnel were not included in the ERP program or considered a resource of the company.

The ERP program did not address any potential improvements in PaperTech's maintenance program, or take into consideration the opportunities for cost reductions

associated with equipment downtime, spare part inventory, or labor, through the application of an electronic medium.

Project Hypothesis

The main hypothesis to be proved for a prototype software system designed specifically for industrial maintenance was that it could be used to apply a proactive approach to equipment maintenance. Also, to prove how monitoring of individual pieces of equipment, in conjunction with a relational database, can be used to increase equipment availability, maintenance efficiency, and result in operating cost reduction.

Maintenance records for PaperTech indicate equipment availability averages ninety-four (94) percent. This is an average for all the manufacturing equipment located in PaperTech's Virginia based paper manufacturing plant. The hypothesis was also tested by proving the prototype's ability to raise the equipment availability of one piece of equipment by no less than two (2) percent utilizing the software system designed for this project. This percentage was based on the maintenance records for a selected piece of equipment.

The prototype software system needed to be generic in nature, so that the hypothesis could be proven when applied to different types of manufacturing equipment. This generic characteristic applied to both the monitoring system and relational database which comprised the project prototype.

Project Scope and Constraints

The scope of the project is limited to small, secondary support equipment. Access to vendor data and past maintenance history is available for secondary support equipment. However, research of primary equipment was not feasible due to

manufacturing schedules, which limited access. Access to secondary, non-critical equipment provided suitable components for testing the prototype.

The main limitation of secondary systems includes the absence of large numbers of programmable controllers. These systems use basic instrument probes, flow meters, and control valves for operation; the required operating values for testing the monitoring system of the prototype can be obtained from this equipment

The current database software being used to control primary manufacturing equipment will not be available for testing, but system specifications and operating parameters will be available for developing the database portion of the prototype. The secondary systems which will be used for testing require many of the same repair/replacement parts used in primary systems; these repair/replacement parts are also requisitioned and installed in the same manner as primary systems .

The initial costs of the project will be insignificant due to the availability of hardware through cooperating manufacturing companies. PaperTech has provided access to their manufacturing facilities and equipment records; the cost of creating the prototype program will be insignificant and the test component for the system is present in other manufacturing systems, which coincides with the generic nature of the prototype.

A large scale application of the prototype program would require a significant budget to be applied to primary manufacturing systems, which is not the purpose of this project. The purpose of this project is to provide a prototype to demonstrate the system's effectiveness, and to provide a model for larger applications. While the

prototype is generic in nature, it will have the basic functionality necessary to demonstrate the idea of the project.

Terminology

Those unfamiliar with industrial maintenance or manufacturing operations may not recognize some of the terms used in this paper. A glossary of terms used in this paper is provided in Appendix A.

Summary

This project proposed a prototype software application designed specifically for a large manufacturing facility. The prototype included a two part software system that demonstrates how the monitoring of individual system components along with the utilization of a relational database can increase equipment availability, and can be used to create a proactive approach to industrial maintenance.

Chapter Two: Review of Literature and Research

General Research on the Project

”In the present era of globalization, competition for export pulp and paper markets is fierce, and the North American industry can hardly afford to rest on its laurels”(Smook G.). This statement sums up the situation facing North American paper manufacturers; globalization demands that manufacturers become more competitive and utilize all available resources at their disposal. Software systems can play a major role in helping create and maintain the competitive edge these companies will need to stay in business.

With the increased availability and decreased costs of computer applications, the benefits of computerization are becoming more accessible to all areas of the manufacturing industry. The methods for applying computer applications vary, but the benefits to manufacturing can be classified into four basic types:

- Cost reduction
- Greater access to information
- Improved planning
- Increased control

(Higgins, L.)

Cost reduction is the most recognized benefit of computer aided manufacturing. This is normally accomplished through the application of computerization to perform work with less effort, thus reducing the number of employees required for a task. Concerning maintenance in a manufacturing facility, a computer application can be used to improve the efficiency of a planner by reducing errors. Standard work orders

can be stored on a computer disk and modified as needed. Also, a computer application can be used to manage inventories of parts and stores, and reduce the cost associated with training a new planner.

Increased access to information is invaluable to manufacturing; computer applications make information readily accessible by storing data in retrievable form and by facilitating data manipulation and reporting. A database system for a specific manufacturing application, such as maintenance repair work, can provide quick answers to questions such as:

- What vendor supplied a specific piece of equipment?
- What environment can a part be used in? An example would be if the part was cast out of brass, which would indicate it was suitable for only non-corrosive environments.
- How long since the part in question was last changed?

Improved planning results from greater access to information along with the speed and flexibility of an information system. This enables manufacturing to improve their planning and coordinating efforts. An example would be when the application is applied to a maintenance department, manpower plans, preventive maintenance determinations, and part inventories can be planned with production schedules to maintain the maximum output for a facility.

Increased control is attained from a computer application through the increase in information availability and improvements in planning. Quick access to information coupled with better planning results in improved control of a manufacturing facility.

A better informed maintenance employee can more readily apply a proactive approach to work tasks, rather than waiting till a piece of equipment fails.

Most, if not all, North American manufacturers use electronic applications to carry out their business processes including to control production lines used in their business. Process operations today are highly automated, and many paper mills now utilize computer control. North America paper manufacturing prefers large scale production facilities with high equipment and employee productivity. All of these requirements add up to huge capital investments. For example, “a 1000 ton per day Greenfield bleached kraft pulp mill is now estimated to cost in excess of one billion dollars” (Smook G.). Note, this example includes just the pulp mill which generates the stock required to produce paper; this figure does not include the cost of a paper machine for processing the pulp, a boiler for generating the large power requirements, a wood yard for processing chips, or a bleaching plant for oxidizing the pulp.

This is an extremely high investment for an industry that is experiencing an unparallel growth in competition. For a paper manufacturing business where the average investment of one skilled worker is one million dollars to be successful, the maximum productivity must be extracted from both the production equipment and the employees used to maintain the process. Software applications can be utilized to ensure that the business in question is getting the maximum return on investment from their employees and production facilities.

There are three factors that will affect a well-designed paper manufacturing facilities productivity and profitability.

- Operating efficiency-this is the marketable paper tonnage that is actually produced as opposed to what could have been produced during the same time frame. This factor is heavily influenced by equipment availability and employee performance.
- Speed of production-this is controlled by a production departments operators and supervision. This factor is influenced by the operating condition of the equipment contained in a given production line.
- Marketability-this is the demand for the paper grade that is being produced, and is influenced by the quality of the paper and technical service provided to the customer.

Marketability is outside the scope of this project, and no issues were pursued concerning this factor. While Speed of Production could be affected by this project, it is also outside the basis for the theory concerning this project. Operating efficiency will be the focus of this paper, along with the factors that influence the efficiency of PaperTech's mill in general. Special emphasis will be placed on the bleaching operation used for generating the pulp to be used in the paper process.

Research Specific/Relevant to the Project

PaperTech's bleaching plant is similar to other operations in North America, which utilize down flow or up flow towers to provide retention time for the bleaching reactions, followed by vacuum washers to remove reaction products. Major auxiliary equipment includes various types of pumps for moving the stock and mixers for blending in steam and chemicals.

With a series of up flow towers, all stages must be operated simultaneously, since the stock continuously overflows the top at the same rate as the bottom feed. In other words, all primary equipment must be operating at comparative speeds and efficiencies for the operation to work; a failure in any part of the system will result in a shutdown of the total system and loss of production. Maximum equipment availability is essential to PaperTech's Virginia based mill to ensure the viability and success of the mill.

The bleaching operation at PaperTech's Virginia based mill utilizes three bleaching lines to produce the stock required by four paper machines located at the facility. The bleaching lines are classified as Unit A, Unit B, and Unit C. According to the December Summary Report for the bleach plant, Unit A averaged 90.4% equipment availability, which was below a goal of 93.2%. Equipment failure and repair was listed as the cause of equipment not being available for production 1.5 % of the time. B Unit averaged 91.2% equipment availability for December with a goal of 93.3% availability. Equipment failure and repair was listed as responsible for 3.6% of equipment unavailability (Pierce, B.).

C Unit is the Virginia based mill's newest bleaching unit; it has the capacity to process over one thousand tons per day of hardwood stock. Being the most modern of the three bleaching units made C Unit the primary choice for applying the theory this project is based on. Also, the technology used in the operation of C unit is cutting edge, and applies the latest computer applications for control.

The C unit operates using the same process as A and B unit with the exception of being under more stringent standards with regard to the Environmental Protection

Agency (EPA). C Units equipment availability for the month of December was 88.3 % vs a goal of 97.7%. Equipment failures and repair accounted for 2.7% of equipment being unavailable for production purposes. Note 8.7% of equipment down time was attributed to support system interruptions, i.e. boiler outage resulting in insufficient power availability. Appendix B contains a copy of the December Summary Report document concerning the three bleaching units at PaperTech's Virginia based mill.

“Vibration monitoring and analysis are two of the most often used predictive maintenance technologies. Used in conjunction with other process-related measurements, such as flow, pressure, and temperature measurements, vibration analysis can provide the means to first schedule maintenance and ultimately to eliminate the need for corrective maintenance tasks (Higgins, L.)”. There are two issues with this approach to equipment maintenance. The first is that for vibration analysis to diagnose deteriorating equipment, the equipment in question must be in the first stages of failure. The second issue is that vibration analysis is applied on an interval basis or when equipment noise indicates a need for analysis. The conclusion of these observations is that while vibration analysis can eliminate the degree of equipment failure, it is only effective after some degree of equipment damage has occurred.

Vibration analysis is the current monitoring method used by PaperTech for predicting mechanical, electrical, and process related problems that may lead to equipment failure; loss of equipment availability resulted in 2.7% of the lost production for Unit C during the month of December 2005. This figure indicates that

there is room for improvement in the method used for monitoring production equipment.

The software monitoring system developed as one part of this project may be applied to system components of this process to prove that equipment availability can be increased through continuous monitoring for potential equipment failure. While the monitoring system may reduce the degree of equipment failure, it is inevitable that some type of failure will occur. The second part of this project, a relational database, may then be applied to speed up the repair process, thus reducing the loss of production and increasing equipment availability.

The theory behind the monitoring system was to compare actual operating values with ideal operating values on a continual basis to detect prolonged decreases in equipment operating efficiencies. The actual operating values could be taken from control values, flow-meters, and other types of programmable logic controllers already prevalent throughout the manufacturing environment; ideal operating values could be obtained from the vendor of the equipment being monitored. Upon detecting a prolonged decrease in operational efficiency in a piece of equipment, the prototype would generate an alarm including the percent drop in efficiency.

This type of monitoring system would detect a decline in equipment efficiency when it begins as opposed to the standard vibration analysis method, which would be applied when the equipment was experiencing a higher degree of failure. Also, this type of monitoring would identify the failing component more quickly than the trial and error process of vibration analysis.

The current method utilized by PaperTech for carrying out maintenance after failure has occurred uses a process which begins by acquiring a needed replacement part(s) utilizing a SAP (Systems Applications Products) system for authorization and ordering. Actual repairs are carried out by craftsman based on their general knowledge of a specific trade and any previous experience concerning the failed equipment. Currently, the part(s) ordered through the SAP system must be cross referenced to a storeroom catalog to obtain required serial numbers associated with specific parts; this is a time consuming procedure which adds considerable downtime to the equipment in need of repair. This approach to equipment maintenance results in a loss of equipment availability, creates a steep learning curve for new craftsmen, increased occurrence of incorrect part(s) requisition, and inefficient monitoring and control of inventory.

The theory behind the relational database part of this project was to increase the efficiency of the distribution of part(s) used by the maintenance department, while also increasing the efficiency of inventory monitoring and control. Additionally, the database will have the ability to provide information concerning specialty tools that may be needed for the installation of certain part(s) when the part in question is requisitioned. Also, the database system will provide the ability to track a given part as to the craftsman who checked the part out, where the part was used, and the time of service since the part was replaced last.

The benefits derived from the application of a relational database for this situation include: to create a more efficient method for obtaining repair part(s), to identify problem areas where part(s) are not remaining in service for their rated lifecycle, and

to assist craftsman in the installation of part(s) by providing information concerning vendor recommendations for specialty tools that may be needed for proper installation.

Potential Contributions of the Project in Manufacturing

“Manufacturing today utilizes computers for two primary purposes: controlling and reporting” (Ottino C.) Distributed control systems are the preferred mode of controlling production processes; this is accomplished by deploying large numbers of small computers throughout the facility. This distribution puts the controlling unit close to the equipment in operation. These smaller computers or microprocessors, which are designed and programmed for specific tasks, are easier to justify both technically and economically. The ability to select the appropriate sophistication of control technique for each specific process unit provides for the functional distribution of control throughout the entire process.

Reporting is the second major use of computers in manufacturing today. This application covers a wide range of topics including sales, production, and economics; more specific applications include cost analysis, inventory analysis, system analysis, and customer requirements.

“In view of the complexity of modern manufacturing processes, and the constant efforts to improve overall performance, a sophisticated information and analytical system can be a valuable tool for both management and operating personnel. “Waye, D.)”. The statement above summarizes the narrow focus of modern information systems as applied to manufacturing; by limiting an information system to only

controlling and reporting applications, the total benefits possible are not derived from what is usually a capital investment.

This project could add to the manufacturing industry by broadening the uses and applications of the information and analytical systems already present in the manufacturing industry. Most modern manufacturing processes today utilize computers and microprocessors to handle complex control schemes, including variable instrument parameters. This means that most of the hardware required for the project is already present in manufacturing systems.

The contribution of this project to the manufacturing industry would be to demonstrate how the monitoring of individual system components can increase equipment availability, and be used to create a proactive approach to industrial maintenance. Also, the project will demonstrate how a relational database can be applied to increase the efficiency of the distribution of part(s) used by a maintenance department, enable maintenance employees to perform repair work more efficiently, and also increase the efficiency of inventory monitoring and control.

Summary

The research concerning the global competition faced by the manufacturing industry, and the drive to reduce costs while increasing efficiency, supports the need to develop new applications for electronic information systems. An evaluation of the current uses for computer systems in manufacturing indicated that a system developed specifically for maintenance purposes could provide a number of benefits.

There are still manufacturing plants located in North America and especially in developing countries that use a reactive approach to maintenance. The generic nature

of this project would allow its application to these facilities to increase their operating efficiency. “Typical maintenance operations currently perform at levels between 10-40% efficiency where a reactive approach to maintenance scheduling is used.

(Leonard, J.) “

Chapter Three: Methodology

Feasibility Assessment

The feasibility of producing both a prototype monitoring program and database system that could be applied to actual production equipment needed to be determined. The cooperation of PaperTech in allowing access to the manufacturing equipment located at their Virginia based facility was essential to the success of the project. These issues were addressed through interviews and meetings with department superintendents, engineers, and planners.

The major constraints in the project were identified to be the availability of actual test conditions. While access to vendor data was available, research of primary equipment systems would be limited due to manufacturing schedules. Access to secondary, non-critical equipment would be possible, and would provide suitable components for testing the prototype. The main limitation of secondary systems included the absence of large numbers of programmable controllers. These systems use basic instrument probes, flow meters, and control valves for operation; the required operating data for testing the prototype program was determined to be obtainable from this equipment

The current database software being used to control primary manufacturing equipment would also not be available for testing, but system specifications and operating parameters could be obtained for developing the prototype. The secondary systems which would be used for testing are generally not controlled through a database due to the simplistic nature of the equipment. However, the same

documentation concerning equipment operation is maintained for secondary equipment as is for primary equipment systems.

Due to the testing requirements for the prototype system, a production line with detailed records of past production and equipment performance needed to be determined. Bleaching Units A, B, and C, located in the Virginia based mill was determined to offer the needed documentation. This documentation is required by the EPA, and includes specific information concerning equipment efficiencies that was required for this project. For clarification purposes, the total equipment availability percentage for 2004 along with the percentages for January and February of 2005 concerning all three of the bleaching lines located at the Virginia based mill are contained in documents 1, 4, and 7 in Appendix C. These documents are broken down into a month by month basis for 2005, and provide percentage of unit availability, along with causes of production interruptions. Also, information concerning CLo₂ usage for each unit is provided.

Secondary support systems, while not as production specific as primary manufacturing systems, still have a major impact on the cost of production. The theory behind this project was that through the utilization of a software system, a proactive approach to industrial maintenance could be applied. A proactive approach to maintenance would theoretically result in increased availability of production equipment, and a reduction of operating costs. Documents 3, 6, and 9 in Appendix C lists the CLO₂ usage and beaching costs for Units A, B, and C respectively; these usages and costs may be reduced by applying the theory of this project.

Procedures

This project utilized the traditional phases of project management and used the Waterfall method for system lifecycle development. Interviews with craftsmen, engineers, planners, and foremen substantiated the need for the project, and aided in defining the scope of the project. Being able to conceptualize of how equipment availability impacted the final costs associated with manufacturing applications was essential to designing this project.

The maintenance costs for December 2004 were over budget by \$289,000 (Pierce, B.) concerning the bleaching department at the Virginia based facility. While the latest information technology is used in PaperTech's bleaching department, it is limited to control and reporting applications. This indicated the potential for increasing equipment availability, thus reducing costs, by concentrating on other applications of this technology.

"Off the shelf" software applications to support the monitoring portion of the project were not found, however, the SAP system currently used by the PaperTech Corporation could be used to apply the database part of the project. The SAP system was available on a limited basis for this project, but any modifications or additions to the system were prohibited. Any new applications for the SAP system would have to be first proven, and then authorized before being utilized. This necessitated designing a prototype to prove the effectiveness of the project theory.

The first portion of this project involved designing a customized monitoring system. A prototype monitoring system was designed, developed, and tested with past production and maintenance data. The system was designed based on a single

component contained in Unit C bleaching line. It was determined that the component selected for the project should have a minimum of three operating parameters concerning induction, discharge, and power. These are three of the most basic parameters associated with production equipment, and were within the scope of the generic application for this project.

The component selected for the prototype monitoring program is a Fume Exhauster Fan (FEF). This component is used in the manufacture of Chlorine Dioxide (ClO₂) as part of a Rotobed Scrubber system contained in the Unit C bleaching line. The FEF operates with an induction of static pressure rated at 19 IWG (In WG). The Discharge of the FEF is rated at an average of 7,500 CFM (Cubic Feet per Minute). The FEF's average power requirement is 33.6 BHP (Brake Horsepower), which is received from a 50 HP motor operating at 1800 RPM drawing 100 amperes of power. The purpose of the FEF is to produce a vacuum inside the scrubber tower to extract ClO₂ gas. The manufacturing specifications for the FEF are located in documents 12, 13, 14, and 15 in Appendix C.

Vibration analysis is the typical method for evaluating the operating condition of the component; this evaluation is performed on a weekly basis. Past maintenance records indicates two cases of severe equipment failure during the past year, which may have been prevented by utilizing a continuous monitoring approach. The FEF is critical to the efficient operation of the Rotobed Scrubber system, but has been designated as a secondary support system. This designation is due to the Rotobed Scrubber system's ability to operate without the FEF. However, without the FEF in operation it becomes necessary to vent ClO₂ gas to the atmosphere, which results in

mandatory fines from the EPA. These characteristics and requirements made the FEF the ideal choice for application of the monitoring system created for this project. Time restraints of this project necessitated applying the monitoring program to a system component that had experienced some type of failure within the past year.

Designing a customized database application was the second activity for this project; this was the more difficult of the two portions of the prototype software application. There are six characteristics of a maintenance process that needed to be included in the database. These include:

- Craftsmen-employees who actually carry out the maintenance work.
- Part(s)-this is the replacement or repair component installed during the repair task.
- Equipment-this is the production component that is in need of repair.
- Vendor-this is the supplier of the part(s) and/or the provider of the equipment in need of repair.
- Department-this is the production area which contains the equipment in need of repair.
- Tool-this includes any vendor recommended specialty tool recommended for proper installation of a part.

The current method utilized by PaperTech begins by acquiring a needed replacement part(s) utilizing a SAP (Systems Applications Products) system for authorization and ordering. Actual repairs are carried out by craftsman based on their general knowledge of a specific trade and any previous experience concerning the failed equipment. Currently, the part(s) ordered through the SAP system must be

cross referenced to a storeroom catalog to obtain required serial numbers associated with specific parts. Samples from the storeroom catalog was obtained and reviewed to determine the required information needed in the database for specific parts.

PaperTech's maintenance program assigns craftsmen to specific departments based on his or her trade designation, and number of years employed. Through interviews with maintenance foreman, it was determined that there was a need to include the experience of craftsmen in the reports generated by the database. This was accomplished through the addition of employee hire date in the table designated as craftsmen.

Interviews with planners determined that vendor data would be a useful resource to include in the database. Planners confirmed that determining which vendor supplied a given piece of equipment as being a time consuming and often difficult task.

Craftsmen interviews determined that the installation of specific parts required the use of specialty tools, which were vendor recommended and required for proper installation. An example would be a motor/pump coupling that required a laser alignment to be performed. While some motor/pump couplings could be aligned through the use of a dial indicator, other more modern designs required the use of a laser alignment tool. The prototype database was determined to need the capability of providing information regarding vendor recommended specialty tools for installation of specific parts.

Scope creep was an ever present challenge as there are a number of maintenance applications that the prototype monitoring system and database system could be

applied to. By limiting the monitoring system to one system component and the database system to repair/replacement parts, the scope of the project was controlled. However, the generic nature of the monitoring system and the narrow focus of the database leave the opportunity for future additions of functionality open.

System Development Life Cycle-Waterfall Model

The development of both portions of this project followed the five components of the systems development lifecycle (SDLC) utilizing the Waterfall method. Following the waterfall life cycle model, each life cycle phase was completed in sequence and then the results of the phase flowed on to the next phase. Figure 3.1 below provides the basic design of this model including illustrating how one stage leads to the next.

SDLC-Waterfall Method

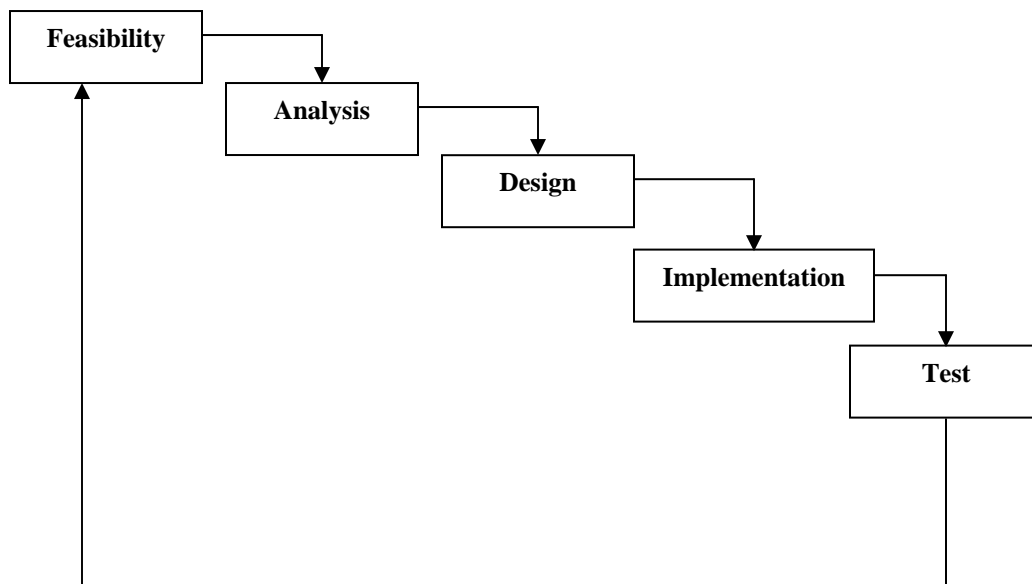


Figure 3.1-WaterFall Model

For the monitoring component of the prototype, the methodology began with selecting a piece of production equipment that would provide the needed operational

characteristics. These characteristics included and were limited to a piece of equipment that utilized induction, discharge, and power requirements; this would provide the needed input data to the monitoring system necessary to prove one part of the project theory.

The equipment selected for application of the prototype monitoring system was the Fume Exhaust Fan. The achievement of this application will be to demonstrate that equipment availability percentages can be increased by utilizing continuous monitoring of system components, which results in a proactive approach to industrial maintenance. An Activity Diagram is shown in Appendix C, Diagram 1 to help understand how the system will be applied and where data will be obtained in relation to the FEF's operation.

For the database portion of the prototype, the methodology first began with examining the storeroom catalog currently in use. The arrangement of data in the catalog concerning the parts inventoried in the storeroom was examined and a determination was made which data would be included in the prototype database system. Interviews with Craftsmen, engineers, planners, and foremen were conducted to establish additional requirements to provide a customized database application.

In order to develop the database and ensure it contained the necessary data, a data set (Appendix D, Diagram 1) was created based on a combination of the storeroom catalog and recommendations obtained through interviews. The dataset was used to create one large table; the table was not in its first normal form (1NF) due to having repeating groups. The normalization process was applied and the table was divided into six tables (Appendix D, Diagram 2), which were applied to the creation of an

Entity Relationship Diagram (ERD) (Appendix D, Diagram 3), which was used to construct the database.

Other steps included researching the requirements for operation of the database. Currently, the catalog system in place does not require personal identification for requisitioning parts, so the database was determined not to require a log in page. Each maintenance shop contains a computer which will have the capability of accessing the database. One interface for entering a part number, which will contain a menu of available options used for generating the requested report, and an interface for inserting, deleting, or modifying an entry was developed.

Analysis Phase

One of the most important activities included in the analysis phase is the gathering of information. It was important to record all the information gathered concerning the prototype system, and then identify what information could be used in the project while still remaining within scope. The information gathered could be classified as either functional requirements or technical requirements.

The monitoring system portion of the project would be designed for the Fume Exhauster Fan (FEF) which is part of the Unit C bleaching line at PaperTech's Virginia based mill. Controlling components were identified and researched to determine the technical requirements the prototype monitoring system would need.

Analysis of the FEF determined that the component utilizes three Process Logic Controllers (PLC) for controlling purposes. The PLCs used are the F&P Series 53MC2002A high performance Micro-DCI controller. This is a microprocessor-based, programmable device that is adaptable for service in the majority of process

control applications. The resident firmware permits field selection of any one of 13 discrete control strategies. A factory supplied default program is used to initialize accessible data points in the controller. This feature minimizes the amount of configuration data that must be entered to customize controller operating parameters for the PLC's specific application.

The principle of operation for the PLCs compares the process variable value with the set point variable and derives a deviation signal. The PLC operates on deviation signal by an adjustable action. The PLC's objective is to produce an output signal for controlling the operation of the FEF. The prototype monitoring program for this project will incorporate the output signal to monitor the performance of the FEF.

The database of the F&P Series 53MC2002A high performance Micro-DCI controller (PLC) contains two basic variable types. The data can be represented as an alphanumeric text string or a positive integer value. Analysis of the PLCs controlling the FEF discovered the equipment uses a positive integer value for representation of process variables. This indicated that the program written for the monitoring program would need to assign variables as type integer. In other words, the use of variables as type integer will satisfy the technical requirement of integrating the values transmitted by the PLC into the C++ prototype program.

Analysis concerning the second portion of the project, the relational database, involved reaffirming the requirements as defined through interviews with planners. The reasoning for reviewing the requirements with planners was based on their majority use of the proposed prototype database system. While the database could be used by other employee classifications, planners have the most interaction with the

current storeroom catalog, vendors, and part(s) requisitions. Requirements proposed by craftsmen, engineers, and foreman were presented to the planners for review and recommendations. Six functional requirements determined for the prototype database are listed below.

1. The database must provide a report of all parts an individual craftsman has requisitioned in a specific timeframe.
2. The database must provide a report of what department a specific part can be used in.
3. The database must provide a report of total parts used by maintenance during the past month.
4. The database must provide a report of the number of a specific part in stock.
5. The database must provide a report of what production departments a specific part can be used in.
6. The database must generate a report of specialty tools required for installation of specific parts when part(s) are requisitioned.

Design Phase

The design phase for the monitoring system began with creating a Collaboration Diagram (Appendix C, Diagram 2). This allowed a conceptual interpretation of the objects utilized in the FEF to obtain operating data, and how the data is directed to the prototype monitoring system, which would be considered the use case for this application. A Use Case diagram (Appendix C, Diagram 3) was also created concerning the monitoring system; this provided a more detailed visualization of the system as applied to the FEF.

While the programming requirements for this application did not justify incorporating the Object Oriented approach, a Class Diagram (Appendix C, Diagram 4) was created. This was provided for future reference. In keeping with the scope of this project, a simple program written in C++ provided the required functionality for application of the project theory to the FEF. The prototype monitoring program is generic in nature, and can be applied to other applications with modest modifications. However, for the full potential of the project theory to be realized, it would have to be applied to large primary production equipment, which would justify applying the Object Oriented methodology.

The program utilizes one loop and a function call to monitor the equipment. As stated previously in this paper, the database of the F&P Series 53MC2002A high performance Micro-DCI controller (PLC) contains two basic variable types. The data can be represented as an alphanumeric text string or a positive integer value. The PLCs controlling the Fume Exhauster Fan (FEF) uses a positive integer value for representation of process variables. Based on this requirement, the prototype program has been assigned variables as type integer. This integrates the values transmitted by the PLC into the C++ prototype program. The C++ program created for the prototype monitoring system application is provided in Appendix C, Diagram 5.

The design phase for the prototype database system followed the Entity Relationship Diagram (ERD). One large table was created based on the ERD; the normalization process was then applied which resulted in a final design of six tables.

Once the six tables were created, the relationships between the tables were identified. This was accomplished based on the ERD diagram. Primary keys were chosen based on columns that provided a unique entity. Referential integrity was ensured by determining foreign key relationships. The Visio program used to construct the diagram identifies the Primary Keys with a PK designation and a Bold, Underlined font. The Foreign Keys are identified through the location of the connection points between the tables; this method for identifying the Foreign Keys proved to be confusing. A Data Dictionary (Appendix D, Diagram 4) was constructed as a reference for aiding in determining Primary Key and Foreign Key designations.

The design process for the prototype database was not difficult due to the generic nature of the design. The six tables were divided according to unique entities with each entity containing a unique identification number. Based on the prototype database's application as primarily a part requisition tool, the table designated as PART was the central link to the other tables. The DDL utilized to create the logical design of the database is provided in Appendix D, Diagram 5.

Implementation Phase

The Implementation phase for the monitoring system portion of this project consisted of identifying past performance of the FEF. This was necessary before application of the prototype monitoring system in order to obtain benchmark data to be used later in the project. The main reason for choosing the FEF as the component for this project was due to the extensive records maintained concerning its operation. This is a mandatory requirement set down by the Environmental

Protection Agency (EPA). The specific purpose of the FEF is to exhaust Chlorine Dioxide (ClO₂) gas from a scrubber tower, which is a heavily regulated process by the EPA. Another reason for choosing the FEF as the project's component is due to the extensive use of PLCs for monitoring the operation of the FEF. EPA regulations require that the PLCs continually monitor and verify that the FEF is operating properly and that the differential pressure across the tower is within permissible limits.

The vendor specified performance of the FEF was also identified during the implementation phase. According to vendor data, the Fume Exhauster Fan (FEF) was subjected to a test-run after final assembly to insure that fan operation meets and/or exceeds the standard specifications. The testing date for the FEF was 7/16/01, and was conducted with the fan mounted and tested on a rigid base. The fan shaft was tested at a rate of 3200 revolutions per minute (RPM) while being supplied a static pressure of 19 in-Hg (Vacuum). The discharge rate was measured in Cubic Feet per Minute (CFM) at 7500. The fan was powered by a 50 horsepower motor turning at 1600 revolutions per minute (RPM) drawing 100 amperes power. The power was delivered to the fan shaft through a 2:1 reduction gear assembly.

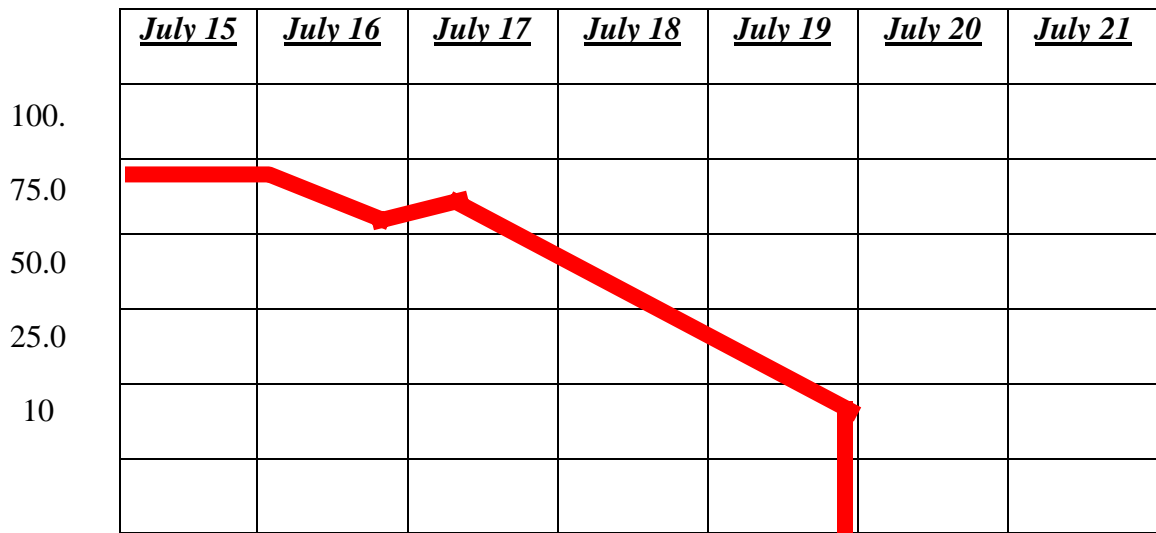
The three main performance variables obtained from this information is:

1. Input-19 in-Hg (Vacuum)
2. Output-7500 CFM (Discharge)
3. 100 amperes (Power)

These three values have been assigned to the comparison variables used in the C++ program created for this project.

The operational records of the FMF used in this project are in the form of a three dimensional chart which utilizes Static Pressure (IWG-Vacuum), Cubit Feet per Minute (CFM-Discharge), and Brake Horsepower (BHP-Power). For comparison purposes, the historical data presented in the FMF operational three-dimensional chart was divided into two charts. One chart was used to compare static pressure verses cubic feet per minute, and the other chart was used to compare static pressure and brake horsepower. The data presented in the two charts was derived from the period July 15, 2003 to July 21, 2003. This choice of timeframe is due to equipment failure which occurred during this time period.

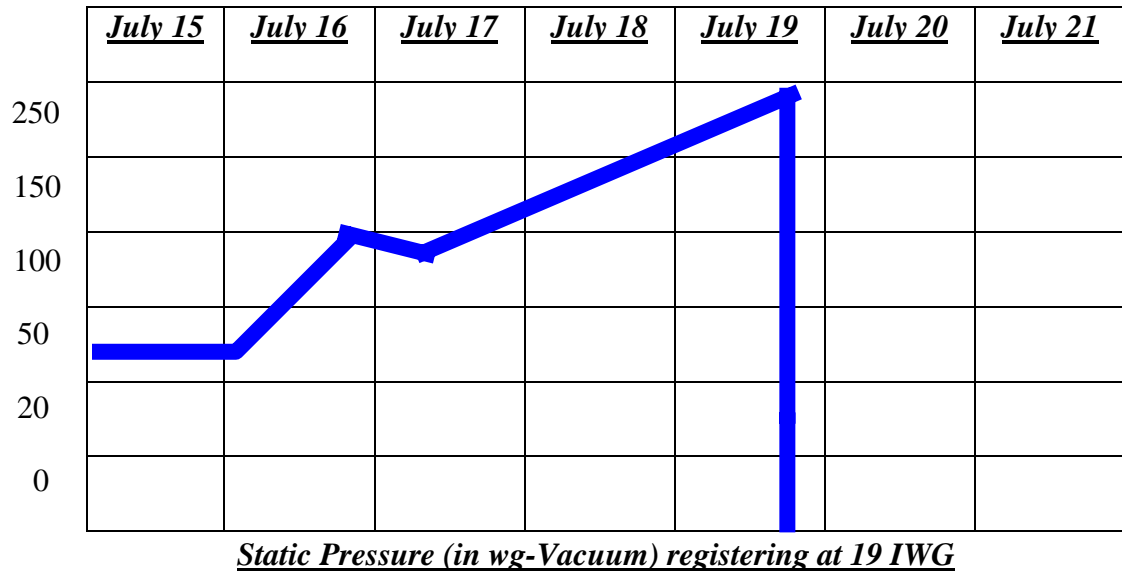
**Cubic Feet
Per Minute
In 100 CFM
(Discharge)**



Static Pressure (in wg-Vacuum) registering at 19 IWG

Failure of the FMF occurred at approximately 2:30 A.M. July 19, 2003.
 Figure 3.2- FEF actual operating static pressure verses cubic feet per minute

Brake Horsepower (BHP)
Measured in Amperes (Power)



Failure of the FMF occurred at approximately 2:30 A.M. July 19, 2003.
 Figure 3.3-FEF actual operating static pressure verses brake horsepower

The insertion of vendor data for the comparison variables ended the implementation phase of the monitoring program. The next and most critical phase in regards to proving the project theory will be the test phase.

The implementation phase concerning the prototype database portion of this project involved populating the database with data. This included actual data concerning craftsmen, parts, departments, equipment, vendors, and tools. The DDL used to populate the database with this data is provided in Appendix D, Diagram 6.

Reports were the next step in the implementation of the prototype database. The reports developed were based on the six functional requirements determined in the analysis phase. Since this was a prototype database, to be used for demonstration purposes to aid in proving the project theory, the reports were designed to be viewed

on the computer screen only. The SQL queries designed to create the reports is provided in Appendix D, Diagram 7.

The last step in preparing the prototype database was determining the user interface requirements. The users that this database was designed for include planners, foremen, and craftsmen, these individual users require a variety of information concerning the replacement/repair parts used on a multitude of equipment in various types of departments. Currently, the catalog system in place does not require personal identification for requisitioning parts, so it was determined that the database would not require a log in page.

Each maintenance shop contains a computer kiosk which could have the capability of accessing the database. There will be one interface for entering a part number, which will contain a menu of available options used for generating the requested report, and an interface for inserting, deleting, or modifying an entry.

The database will utilize a displayed interface to enter a part number, which will display a list of links to the following reports:

Report 1: Craftsman Requisitions for Specific Time Period

Report 2: Department Part Can Be Used In

Report 3: Total Parts Consumed During a Specific Time Period

Report 4: Number of Part in Stock

Report 5: Production Departments Part Approved for Use In

Report 6: Tool Required for Part Installation

These reports will provide sufficient system operability of the prototype database for demonstration purposes.

Test Phase

The test phase was crucial to generating the evidence needed to prove the project theory. Both portions of the project, the monitoring system and database, were tested for functionality to identify any errors or bugs in the two systems. More importantly, the test phase created the documentation that will be used in the project presentation to justify the application of both elements of this project.

The test data used for the monitoring portion of this project was determined based on the past performance of the Fume Exhauster Fan (FEF), and the vendor specified operating values for the FEF. There are five sets of values which were used for testing. The following are the sets of values entered into the prototype program including the resulting output from the program.

1. Vacuum-19, Discharge-7500, Power-100

Program Output: **“Normal Operation”**

2. Vacuum-19, Discharge-7200, Power-100

Program Output: **“Low Discharge, Possible Failure”**

3. Vacuum-19, Discharge-7500, Power-125

Program Output: **“High Power, Possible Failure”**

4. Vacuum-19, Discharge-7200, Power-125

Program Output: **“Low Discharge, Possible Failure”**
“High Power, Possible Failure”

5. Vacuum-10, Discharge-7200, Power-125

Program Output: **“Low Vacuum, Possible Failure”**
“Low Discharge, Possible Failure”
“High Power, Possible Failure”

*The prototype program is designed to give a warning for low vacuum although this is unlikely to occur during the operation of the FEF.

The next step in testing the prototype monitoring system was to compare the program displays with the maintenance history of the FEF. The historical data concerning the Fume Exhaust Fan (FEF) shows a dip in performance on July 16th and 17th 2003 (see figure 3.2 and 3.3). At this point the process logic controllers were indicating that there was a potential for equipment failure, which did occur on July 19th 2003.

This translates into a three day warning of potential failure, which could have been used to prevent the massive equipment damage that resulted on July 19th. The results obtained from the prototype program demonstrate that the program can be used as an early warning system for potential equipment failure, and increase the percentage of equipment availability.

Had the prototype monitoring system been installed prior to the equipment failure of July 19th, the FEF could have been shutdown, repaired, and put back into service within approximately six hours. This estimate is based on the cause of the failure, which was determined to be a worn pillar bearing supporting the impeller shaft. When failure occurred on July 19th, the impeller shaft came loose from the pillar bearing and exited the side of the fan housing causing damage to the fan impeller, fan housing, drive shaft, and attached piping.

The prototype monitoring system would have generated a warning based on the increase in amperage required to turn the impeller shaft, and the decrease in cubic feet per minute discharge that occurred on July 16th and 17th.

Due to the demonstration purpose of the prototype database, the six reports identified in the design phase were used as test data. The information used to

populate the database in the design phase was used as test data. A query for each report was performed to verify that the data could be entered, and to ensure that the data entered was saved. Next, random selection of the reports was performed to ensure that the reports could be selected in any order depending on the preference of the user.

The narrow focus of the database as being applied only to parts requisition was not a factor in the testing phase. Also, the limited functionality of the database did not have a negative impact on the documentation generated. This was an important actuality due to the significance the documentation will have in regard to the presentation of the project.

Proving the project theory to upper management in the PaperTech organization will be accomplished by validating both components of the project. This validation is heavily dependent on the documentation and demonstration provided in the testing methods used in this phase.

Deliverables

The measurement of the success of each phase was based on the deliverable(s) that resulted from the diligence to complete the phase in question. Beginning with establishing the need for the project theory, and progressing through the various phases to successfully create a working prototype to support its application, is the basis for judging this project a success. The deliverables for this project resulting from each phase included the following:

Analysis Phase Deliverables

- Documentation of Fume Exhauster Fan (FEF) and Process Logic Controllers (PLC)
- Functional Requirements for Database

Design Phase Deliverables

- Collaboration Diagram for Monitoring System
- Use Case Diagram for Monitoring System
- Class Diagram for Monitoring System
- C++ Program for Monitoring System
- Entity Relationship Diagram (ERD) for Database
- Data Dictionary for Database
- Document of DDL Language used to create Database

Implementation Phase Deliverables

- Vendor Specified Operation for the FEF used in the Monitoring System
- Performance Variables for the FEF
- Operational Records for the FEF
- Charts (2)-Static Pressure/Cubic Feet per Minute, Static Pressure/Brake-Horsepower
- Design of User Interface for Database
- Reports (6) Database has capability of generating

Test Phase Deliverables

- Five sets of Values used to test the Monitoring System
- Documentation for Test Results demonstrating the success of the Monitoring System

Project System Requirements

Monitoring System

- Software-Microsoft Office, Microsoft Visual Studio.Net, Microsoft Project, Microsoft Visio
- Hardware-Computer with Athlon XP-M or higher processor, Microsoft XP or more advanced operating system, removable hard disc (CD) capability.
Process Logic Controller utilizing integer variables.

Database System

- Software-Microsoft Access, Microsoft Works Database or Oracle Domain: remote.world. Microsoft Visio
- Hardware-Computer with Athlon XP-M or higher processor, Internet access, Microsoft XP or more advanced operating system, removable hard disc (CD) capability

Outcomes

The success of the project was based on the prototype's ability to increase equipment availability by applying a proactive approach to equipment maintenance; this was accomplished through the application of two customized information systems. The project was divided into two parts with both portions contributing to the realization of the project goals. The two components which constitute the project are a monitoring system and a relational database.

The monitoring system required proof of its potential effectiveness; this was accomplished through demonstration by comparing the output of the prototype to historical data concerning the operation of a system component; the component used

in this case was a Fume Exhauster Fan. An analysis of the project's achievements compared to the project goals provides credible evidence that equipment availability can be increased through the utilization of a software monitoring system. The measurement of performance for this project was to raise the equipment availability while utilizing the existing controllers already included in the equipment design. The test data indicates that a three day warning would have been output by the prototype program concerning the equipment failure incurred by the FEF. By taking a proactive approach to the system warning, the FEF would have experienced a six hour loss of equipment availability instead of the approximately thirty-six hours lost. In other words, the FEF would have increased its availability by thirty hours during the month of July, 2003.

The next phase for the project will be to make copies of the prototype program and tests results, which will be distributed to department management for evaluation. Also, a Power Point presentation will be developed for demonstration purposes.

The testing phase utilized past operational records for comparison purposes to determine the viability and effectiveness of the project. The research into the component selected for application of the monitoring system, the FEF, revealed additional data that can be used to justify the application of both portions of this project.

The main goal behind the project theory was to increase equipment availability, which would result in lower costs to the business. These costs included both maintenance cost associated with the repair of production equipment, and lost profitability which results from equipment failure. While this goal was proven and

obtained, there appears to be a number of other justifications for applying the theory of this project to PaperTech's production facilities.

PaperTech maintains an environmental policy which states that compliance is non-negotiable. One hundred percent compliance with all applicable laws, regulations and company policies is mandatory. The three basic elements of this policy are water permits, air requirements, and maximum achievable control technologies (MACT) requirements. Research into these policies indicates that both the monitoring system and database created in this project would have a dramatic impact on the compliance of PaperTech's Virginia based facility.

Concerning the water permits, all discharge effluent that is not suitable for recycling back into the production process is sent to a central Waste Treatment Plant (WTP). The bleaching operation, which utilizes the FEF used in this project for its production process, generates streams of acidic effluent. This effluent is recycled into the bleaching process to minimize the impact of the acidic wastewater on the WTP. Equipment failure necessitates the bypassing of process systems, which results in higher amounts of acidic wastewater being sent to the WTP. The WTP must raise the pH of the clarifiers to effectively treat the higher amounts of acidic wastewater. The monitoring system designed in this project can effectively reduce this occurrence, and the database portion of the project will reduce the timeframe for the WTP addressing increased amounts of acidic wastewater.

Other applications of the project's deliverables for ensuring compliance with water permits would be their application to the black liquor (caustic) carryover from the pulp department or the white water effluent produced by the paper machine

departments. Loading (Biological Oxygen Demand), flow, and temperature are all characteristics of a manufacturing process where raw materials are used; all these attributes can be negatively influenced by decreases in equipment availability.

The bleaching department located at PaperTech's Virginia based plant operates under an air permit issued by the Environmental Protection Agency (EPA). Carbon Monoxide emission is limited to 992 tons per year for PaperTech's bleaching department based on this permit. Emissions are calculated annually based on throughput and stack test results. These calculations would be directly influenced by any decline in equipment failure attributed to the monitoring system, and specifically affected by the databases ability to increase the performance and efficiency of the maintenance department as applied to equipment failure.

Title V of the Maintenance Operations Procedures manual states that maintenance must be scheduled for air pollution control equipment on a predetermined basis, and that an inventory of spare parts must be maintained. Both components of the project can in effect be applied to this mandate.

The Maximum Achievable Control Technology (MACT) requirements for PaperTech's bleaching operation states that all bleach lines must have scrubbers; also chlorine emissions must be maintained at less than 10 parts per million. The MACT requirements maintain that if scrubber flow from any of the scrubbers used for A, B, or C Units fall below 22 gallons per minute for more than 60 minutes, then documentation is required for the following:

- What caused the event
- Steps taken to correct the problem

By limiting the potential for catastrophic equipment failure, the monitoring system portion of this project would contribute to the compliance of the MACT requirements. Depending on the nature and severity of inevitable equipment failure, the database portion of the project could eliminate some incidents of the scrubbers falling below 22 gallons per minute for more than 60 minutes.

Summary

The methodology used in this project followed the established guidelines for project management and lifecycle development as applied to software applications. The Waterfall Model used to develop the phases of the project proved to be effective in developing both components of the final application. Each phase successfully generated the research, documentation, and deliverables needed to initiate the succeeding phase. Following this methodology resulted in the completed project exceeding the expectations predicted by the project theory. Also, the project was completed in the predetermined timeframe while maintaining the scope of the application.

Chapter Four: Project History

Project Origin

PaperTech is the culmination of a merger between two moderately sized paper manufacturing businesses. This merger took place during December of 2002 and was a joint effort between the two enterprises to create a worldwide organization capable of competing in an increasingly global economy. To provide better control and increased efficiency PaperTech initiated a Systems Applications Products (SAP) program. The main focus of this program was applied to the various business processes which the new corporation was composed of. These processes included a folding carton division, a fine papers division, a specialty chemical division, and a bleached paperboard division.

After the initial merger was complete, PaperTech began initiating a policy of refocusing their business processes to concentrate on the most profitable entities of the organization. The folding carton division was sold; this decision was based on the increasing competition from overseas producers, which made the profitability of the division marginal and declining. This sale allowed PaperTech to channel additional resources to their main business entity, which was the actual manufacturing of assorted types of paper.

The next major realignment for PaperTech was the sale of their fine papers division. This decision was not based on a lack of profitability, but on the future market for the type of paper being manufactured by this process. China has begun an industrial revitalization in their country, which includes the construction of fine paper manufacturing facilities. These facilities are estimated to be online producing paper

within the next five years. Due to the low wage and lack of environmental controls required in China, it was determined unfeasible for PaperTech to attempt to compete with China in the fine papers market. The decision was made that the value of the fine papers division would decrease as China's construction efforts neared completion, which was the basis for the decision to sale the division while its value was high.

This left PaperTech with two main business processes, the specialty chemicals division and the paperboard division. The specialty chemicals division produces a line of products that consists of carbon, turpentine, and other chemicals which are manufactured from the byproducts of the pulping process used in manufacturing paper. This is the most efficient method for disposing of these byproducts, so the specialty chemicals division was maintained. However, the resources obtained from the sale of the other divisions were applied toward modernizing the paperboard division.

The modernization process included the SAP system mentioned earlier in this paper; other upgrades included new pollution control equipment, more computer controls, and higher capacity production lines. The modernization that PaperTech has been through during the past few years has enabled the company to maintain a competitive edge in the global marketplace. However, to maintain this edge, the company must obtain the highest return on the investments made.

The traditional formula used for financial decisions concerning PaperTech's paperboard division basically stated that a large return was needed to justify a relatively small investment. Also, while equipment was considered a resource of the

company, the normal operating procedure was to run it till failure occurred. These ideals were based on a marketplace that held little competition due to the shortage of available paperboard needed for packaging.

These ideals are now outdated, and the current operating procedure for production equipment is to obtain the maximum output from the equipment while maintaining operational integrity. This statement best sums up how the idea for this project began.

Project Management

The techniques of project management were utilized in this project to create a project timeline that would satisfy the requirements determined in the analysis phase. Also, the technique of risk management was applied to identify any potential problems; this was done to ensure that problem areas could be addressed before they resulted in a negative impact on this project. The resources used for the project was not an issue due to already having access to the programs and hardware needed to complete the project. However, the scope of the project proved to be an ever present challenge as the potential applications of the project are enormous.

Due to the potential application of the project's deliverables to any type of manufacturing equipment, risk identification, change management, and quality management was determined to be a required part of the project management utilized in this paper.

The severity of any risks identified will dictate the course of action to be taken. There are three methods which were used for dealing with project risks. These methods include:

1. **Risk Severity 1 to 3**-MENTION-This method involves becoming aware of the potential risk, but does not require any action to be taken.
2. **Risk Severity 4 to 6**-MONITOR-At this level of severity, the status of the risk will be monitored throughout the lifecycle of the project, and upgraded if necessary.
3. **Risk Severity 7 to 10**-MODIFY-The consequences of this type of risk requires that changes be implemented to reduce or eliminate the risk. These changes must take into consideration evaluation of Scope, Schedule, and Resources.

Document 2 in Appendix B provides a listing of the project risks along with the severity rating for each risk.

The change management used in this project involved a four point evaluation of the change in question. Document 3 and 4 in Appendix B lists potential changes associated with the monitoring system and database created for this project along with the impact a change would have on the four points.

The quality management used in the creation of this project followed a five column table format which included comments concerning each completed task. Document 5 in Appendix B contains the quality management used for the monitoring system and document 6 in Appendix B contains the quality management for the database.

Project Timeline (Gant Chart)

The project was initially conceptualized and proposed for the class MSC 680 Project Management. The project theory was deemed acceptable to be used as the

professional project to gain accreditation in the MSCIT program at Regis School for Professional Studies. The following Gantt chart provides the schedule followed in the completion of the phases involved to create this project.

ID	Phase	Start	Finish	Duration	Jan 2005	Feb 2005	Mar 2005	Apr 2005	May 2005		
								4/5	4/10	4/17	4/24
1	Feasibility	1/2/2005	2/1/2005	31d	[Blue bar]						
2	Analysis	2/1/2005	3/17/2005	45d		[Blue bar]					
3	Design	3/17/2005	4/15/2005	30d			[Blue bar]				
4	Implementation	4/16/2005	4/29/2005	14d				[Blue bar]			
5	Test	4/30/2005	5/29/2005	30d					[Blue bar]		

Figure 4.1-Gantt Chart of Project Timeline with Respect to the Phases Completed

The project schedule provided in the form of a Gantt chart was created using Microsoft Visio Professional Edition. The breakdown of allowable time for each phase provided a method for ensuring that the project was completed on schedule.

Network of Achievements and Milestones

The progress of the project is depicted in the Network of Achievements diagrams provided in Appendix C Diagram 6 for the monitoring system, and Appendix D Diagram 8 for the database system. A diagram was created for each component of the project to provide a visual representation of the steps completed; these steps, when combined together, represent the completed project. Also, each milestone for both the monitoring system and database were identified and labeled accordingly.

How Project Was Chosen

The project theory originally was to use a database system to create a maintenance scheduling program. The main component of the system would have been a database for storing equipment efficiency ratings. A secondary component of the system would have included an information system for generating work-orders, inventory control, and scheduling of maintenance work.

This theory required a massive project scope, and was deemed unrealistic to use for the professional project assignment. This characteristic presented two choices: either drop the project theory altogether or limit the scope. It was decided that by limiting the application of the project to demonstration purposes, the scope of the project could be controlled.

It was also decided that a monitoring system could be developed and applied to a single component, which could provide test data to be used as credible evidence for the project theory. The database portion of the original project idea would be included as a means to improving the efficiency of the maintenance department in general.

Information, historical data, equipment access, and support were readily available from PaperTech personnel and records. This proved to be a valuable resource; when coupled with the techniques and processes derived from classes taken at Regis, the project succeeded in reaching its established goals.

Project Limitations

The major limitations in the project was the availability of primary equipment systems, which were limited due to manufacturing schedules. Access to secondary, non-critical equipment was allowed, and provided suitable equipment for testing the prototype monitoring system. The main limitation of secondary systems included the absence of large numbers of programmable logic controllers (PLC). However, the bleaching processes used by PaperTech is so heavily regulated that many secondary systems have PLCs that are not present on older legacy systems. A production component, the fume exhauster fan, was found to have the PLCs required for the

monitoring portion of the project; this was in lieu of the fume exhauster fan being a classified as part of a secondary support system.

The current database software being used to control primary manufacturing equipment was not available for the project, but system specifications and operating parameters was available for developing the database. Also, access to PaperTech's SAP system was limited to documentation and protocol procedures for its operation. However, interviews of PaperTech personnel provided the needed requirements for developing a prototype database model.

Project Results

The purpose of this project was to produce a prototype of a software application that demonstrated how the monitoring of individual system components combined with the utilization of a custom database could increase equipment availability, and could be used to create a proactive approach to industrial maintenance. This demonstration was accomplished in part by comparing the output of the prototype monitoring system to historical data concerning the operation of a system component; the component used in this case was a Fume Exhauster Fan. The customized database portion of the project provided demonstration of the theory through the generation of reports based on maintenance test data. An analysis of the project's achievements compared to the project goals provides credible evidence that equipment availability can be increased through the utilization of the project's software system.

Summary

The prototype industrial maintenance software system provides a method for applying a proactive approach to equipment maintenance and repair. While the prototype system was developed for use in PaperTech's Virginia based facility, the generic nature of the application is such that the potential applications of the system are many. With a few minor design changes the system can be customized for use by other manufacturing plants; even manufacturing facilities which produce products other than paperboard could apply the prototype's design to their maintenance processes.

Chapter Five: Lessons Learned and Future Evolution of Project

Lessons Learned

The competitive nature of a global economy demands that business enterprises obtain the maximum return on investments; these investments include the employees who comprise the organizations work force. These demands encompass employees being self motivated and directed. The experience of managing a project of this size allowed me to become more proficient concerning these characteristics.

Past courses taken at Regis gave me the knowledge to complete each phase of the project. Project management as applied to a real world application was a new experience for me. The insight gained gave me a new perspective concerning costs and benefits associated with potential software applications. I have over twenty years experience concerning maintenance procedures performed on manufacturing equipment, and after completion of this project I now have a greater respect for the dedication and hard work required to develop a software process. While the magnitude of this project may be insignificant when compared to other real world enterprises, the same procedures and principles learned could be applied to these larger applications.

The familiarity gained from the continuous use of Microsoft Project, Microsoft Word, Microsoft Visio, Microsoft Visual Studio.net and Oracle's SQL gave me a high degree of proficiency regarding the use of these design tools. These skills can be applied to future projects and be valuable qualifications concerning future employment opportunities.

Once the feasibility assessment was complete the flow of the project was smooth and no major problems were encountered. This provided credible evidence to me of the value in using a specific methodology for project management. No time was wasted on determining what the next step in the project would be. The project moved forward at an encouraging pace, which allowed me to efficiently use all the resources available for the project.

The Waterfall model used for development of this project is based on completion of one phase before beginning the next. I learned that there is some flexibility to this model; it is more of a set of guidelines to follow than a strict format where compliance is mandatory. There was some overlapping of the stages in both conceptualization and design. An example is while I was conducting interviews and performing research, I was already making notes about how the design of the system may be accomplished.

While there was some flexibility in the model utilized for this project, it was understood that completion of milestones needed to be identified to ensure the project schedule was maintained. Too much time spent on one phase would have an adverse affect on the project schedule and other phases. This concern was addressed by creating a Network of Achievements diagram for both components of the project. As a milestone was completed it was added to the diagram. This gave a conceptual representation of how the project was progressing.

Due to the components developed in this project being prototypes for demonstration purposes, costs were not an issue. However, following good project management techniques necessitated addressing this issue to some extent. This

proved to be a valuable experience concerning real world issues in managing a project.

The initial costs of the project were insignificant due to the availability of hardware and software obtained previously for course work at Regis University. Also, PaperTech provided access to their training center, manufacturing facilities and equipment records. The main components for the monitoring system were already present in the manufacturing systems for control, which negated any issues with cost.

The prototype database and monitoring system would require a significant budget to be applied to primary manufacturing systems, which was not the purpose of this project. The purpose of this project was to provide a prototype to demonstrate the systems effectiveness, and to provide a model for larger applications. Appendix B-Diagram 7 provides an estimated budget for the project; this was created to satisfy any potential questions that may arise concerning the costs associated with the project.

Future Progression of Project

The next logical evolution of this project would be its application to actual production equipment in a live manufacturing operation. The most likely candidates for this application would be secondary support equipment to begin with. This is standard procedure in manufacturing plants when applying new technology. A more thorough evaluation of the cost/benefits can then be determined. Upon successful operation of the project theory pertaining to secondary processes, the theory would then be applied to primary production equipment.

The application of the project model to secondary manufacturing equipment would require minor modifications to the project components; this characteristic allows for its application to a variety of equipment and systems. Concerning the monitoring system portion of the project model, additional variables may be needed. This would not be a major problem; the only additional requirements would be the variable itself accompanied by a value to be used as a comparison variable. The code for incorporating the additional variables into the program would require only minor changes.

The next evolution for the database portion of the project model would be its inclusion in PaperTech's SAP system. This would require a review of the requirements that were used to develop the project's database model. PaperTech's information systems department would need to be included in this evolution along with the planners, engineers, and other maintenance personnel who use the SAP system on a regular basis.

Following the usual process in manufacturing for applying new technology, the database model could be applied in the SAP system to include parts which constitute secondary production systems. After an evaluation of the cost/benefits associated with its SAP system application, the database model could then be upgraded to include primary production equipment.

An estimate for the time required for the project model to achieve the level of application described above is approximately two to five years. There is a general mentality prevalent throughout the manufacturing industry that if a process is profitable it should not be changed. However, given the increasing competition being

experienced in the paper manufacturing sector, it is possible that the project model could be applied more quickly. The timeframe for the project model's progression is heavily dependent on its ability to increase equipment availability and the proportion of the increase.

Conclusions

Developing this project to prove its theory to increase equipment availability provided both educational and job related experience.

The inclusion of the project's monitoring system model into manufacturing processes can and will provide factual data that defines the actual mechanical condition of each component contained in the process before they become serious. The database model provides a method for efficiently obtaining all the needed information to expedite equipment repairs in a timely fashion. The result of applying both portions of this project to an industrial maintenance application is a method for instituting a proactive approach to industrial equipment maintenance.

Summary

The prototype industrial maintenance software system was designed for this project to apply a proactive approach to industrial equipment maintenance. This design included a prototype monitoring system and prototype relational database specifically designed for industrial maintenance applications. The project was developed over a five month period with the central focus of the application being a paper manufacturing facility located in Virginia. The project was initiated based on the approval of the original proposal created for MSC 696A, and completed to satisfy the keystone professional project requirement for Regis University's School for

Professional Study. The degree being sought is a Master of Science in Computer Information Technology, which was the basis for choosing a software application for the project.

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Appendices

Appendix A: Glossary of Terms

Listed below are the terms used in this paper which are specific to the manufacturing industry, and may be unfamiliar some readers.

Auxiliary Equipment: equipment used to improve the characteristics and quality of a product manufactured in a given process.

Bleaching Line: Series of rotary drum washers used to oxidize pulp and remove filtrate.

Catastrophic Failure: Sudden equipment failure on a large scale.

Craftsmen: A skilled worker who specializes in a specific craft, i.e. pipefitter.

Critical Plant Machinery: Equipment contained in a production facility that will result in a manufacturing stoppage if failure occurs.

Database System: An organization of components that define and regulate the collection, storage, management, and use of data in a database environment.

Equipment Availability: Percentage of time that equipment is available for production purposes.

Equipment Efficiency: This is the actual output of a component compared to the vendor specifications for the component.

Flow Towers: Tall tanks where a product is pumped in the bottom and comes out the top or vice versa. A chemical is typically added while the product is traveling through the tank, which allows a mixing action to occur.

Foreman: Individual responsible for directing the work flow of craftsmen and other personnel related to equipment maintenance.

PaperBoard: Heavy weight paper used in packaging.

Planners: Personnel who evaluate, plan, and obtain parts for maintenance repairs.

Primary Production Equipment: See Critical Plant Machinery.

Proactive Approach: Method of anticipating developments before they actually happen.

Production Schedules: This is a predetermined timeframe which results from an agreement between a manufacturing facility and a customer.

Prototype: A test model of a system, process, or component.

Reactive Approach: Method of rectifying developments after they actually happen.

Secondary Production Equipment: Equipment that provides support to primary production equipment. The loss of this type of equipment does not result in a stoppage of production, but it does make the process less efficient.

Specialty Tools: These are tools utilized for a narrow range of tasks, i.e. laser alignment tool.

Systems Applications Products (SAP) System: Off-the-Shelf software program used to support business processes.

Vendor: A supplier of equipment part(s) and processes usually associated with a manufacturer on a contract basis.

Vendor Recommendations: This is information concerning the installation instructions, required maintenance, and expected operational output for a specific piece of equipment.

Vibration Analysis: A method for measuring the vibration of a piece of rotating equipment.

Appendix B-Project Diagrams and Documents**Document 1-December Summary Report for PaperTech's Bleaching Plant****PaperTech**

Phone	Virginia Mill	Fax
To: xxxxxxxxxxxx Fiberline Superintendent		Date: January 3, 2005
From: xxxxxxxxxxxx Bleach Room Assistant Supt.		CC:
Subject: December Summary Letter		

Compliance

- Achieved 0 environmental exceedences (0 YTD)
- Achieved 0 FRA excursions (0 YTD)

Financial

- Over budget variances are;
 - Maintenance spending over plan by \$289K
 - Outside service over plan by \$17K, big hitters – \$17K Steam Chiller work, \$5K Acid Unloading Pan, \$5K C-Unit Air Compressor Duct
 - Maintenance material over plan by \$149K, big hitters – \$13K SCF Wire, \$21K 3A Sewer Line, \$17K Loop Tuning Software, \$15K 3C Washer Drains, \$11K D2 Tower Drain Valve, \$31K D2 Risor Tube Block Valve, \$28K 1C to 3A Jumper Line, \$40K 1A Washer Dilution Pump Bowl and Check Valve

Productivity

- Averaged 393 t/d pine production on A-Unit vs 470 t/d goal (425 t/d YTD)
 - Below target production 26 days
- Averaged 90.4% availability on A-Unit vs 93.2% goal (94.4% YTD)
 - 1.5% Equipment Failures, 4.2% #2 R/B Outage
- Averaged 646 t/d hwd production on B-Unit vs 670 t/d goal (669 t/d YTD)
 - Below target production 13 days
- Averaged 91.2% availability on B-Unit vs 93.3% goal (94.2% YTD)
 - 3.6% Equipment Failures
- Averaged 859 t/d hwd production on C-Unit vs 1010 t/d goal (936 t/d YTD)
 - Below target production 27 days
- Averaged 88.3% availability on C-Unit vs 97.7% goal (94.6% YTD)
 - 2.7% Equipment Failures, 8.7% Scheduled
- Averaged 53 t/d production on the ClO₂ generator (57 t/d YTD)
- Averaged 94.0% availability on the ClO₂ generator (97.2% YTD)
 - 3.0% Scheduled, 2.5% Full

Document 2-Project Risks with Severity Rating

<i>Project Component</i>	<i>Component Approved? Y/N</i>	<i>Component Scheduled? Y/N</i>	<i>Requirements Met? Y/N</i>	<i>Project Risk? Y/N</i>	<i>Risk Severity Scale 1-10</i>
Project Definition	Y	Y	Y	N	
Planning Complete	Y	Y	Y	Y	3
Resources Available	Y	Y	Y	Y	5
Milestones Identified	Y	Y	Y	N	
Deliverables Identified	Y	Y	Y	N	
Documentation	Y	Y	Y	N	
Requirements Understood	Y	Y	Y	N	
Requirements Changed	Y	Y	N	Y	6
Scope	Y	Y	Y	Y	6
Procurement	Y	Y	Y	Y	5

Document 3-Change Management for Monitoring System

<i>Project Component</i>	<i>Change Component? Y/N</i>	<i>Modify Schedule? Y/N</i>	<i>Modify Budget? Y/N</i>	<i>Documentation Update? Y/N</i>	<i>Impact Other Components? Y/N</i>
Component #1 Component Selection	NO	NO	NO	NO	NO
Component #2 Create Activity Diagram	NO	NO	NO	NO	NO
Component #3 Identify Use Cases	NO	NO	NO	NO	NO
Component #4 Create Class Diagram	NO	NO	NO	NO	NO
Component #5 Create Collaboration Diagram	NO	NO	NO	NO	NO
Component #6 Create C++ Program	NO	NO	NO	NO	NO
Component #7 Identify Software Functions of Logic Controllers	NO	NO	NO	NO	NO
Component #8 Integrate Functions	NO	NO	NO	NO	NO

Document 4-Change Management for Database System

<i>Project Component</i>	<i>Change Component? Y/N</i>	<i>Modify Schedule? Y/N</i>	<i>Modify Budget? Y/N</i>	<i>Documentation Update? Y/N</i>	<i>Impact Other Components? Y/N</i>
Component #1 Business Requirements	NO	NO	NO	NO	NO
Component #2 Create Tables	NO	NO	NO	NO	NO
Component #3 Create ERD Diagram	NO	NO	NO	NO	NO
Component #4 Write DDL script to Create Database	NO	NO	NO	NO	NO
Component #5 Write DDL to Populate Database with Test Data	NO	NO	NO	NO	NO
Component #6 Write DDL to Create Queries for Reports	NO	NO	NO	NO	NO
Component #7 Design Interfaces	NO	NO	NO	NO	NO
Component #8 Write DDL to Generate Test Documentation	NO	NO	NO	NO	NO

Document 5-Quality Management for Monitoring System

Task #	Reviewer	Project Component	Comments	Complete Y/N
1	Persinger	Select Project Component	A Fume Exhauster Fan was selected due to available data and conformity to project requirements.	Y
2	Persinger	Create Activity Diagram	The diagram was designed utilizing Microsoft Word.	Y
3	Persinger	Identify Use Cases	The diagram was designed utilizing Microsoft Visio.	Y
4	Persinger	Create Class Diagram	The diagram was designed utilizing Microsoft Visio	Y
5	Persinger	Create Collaboration Diagram	The diagram was designed utilizing Microsoft Visio	Y
6	Persinger	Create C++ Program	The program was created using Microsoft Visual Studio, and was designed to interact with the PLCs in the project component.	Y
7	Persinger	Identify Software Functions of Logic Controllers	The software functions were obtained from vendor supplied documentation for the PLCs used in the operation of the FEF.	Y
8	Persinger	Integrate Software Functions into Program	The PLCs utilize positive integer variables. These variables have been integrated into the C++ program.	Y
9	Persinger	Identify Past Performance of Component	The past performance of the FEF were obtained from operations records for the CLo2 system. This information was in three dimensional chart form.	Y
10	Persinger	Identify Vendor Specified Performance for Component	The performance data for the FEF was obtained from documentation supplied by the New York Blower Company, manufacturer of the FEF.	Y

11	Persinger	Enter Test Data into Program	The test data used was a combination of vendor and past performance data concerning the operation of the FEF	Y
12	Persinger	Compare Program Recommendations with Component Maintenance History.	A comparison of results without the prototype program and results using the prototype program was conducted. Observations from this data was presented.	Y

Document 6-Quality Management for Database System

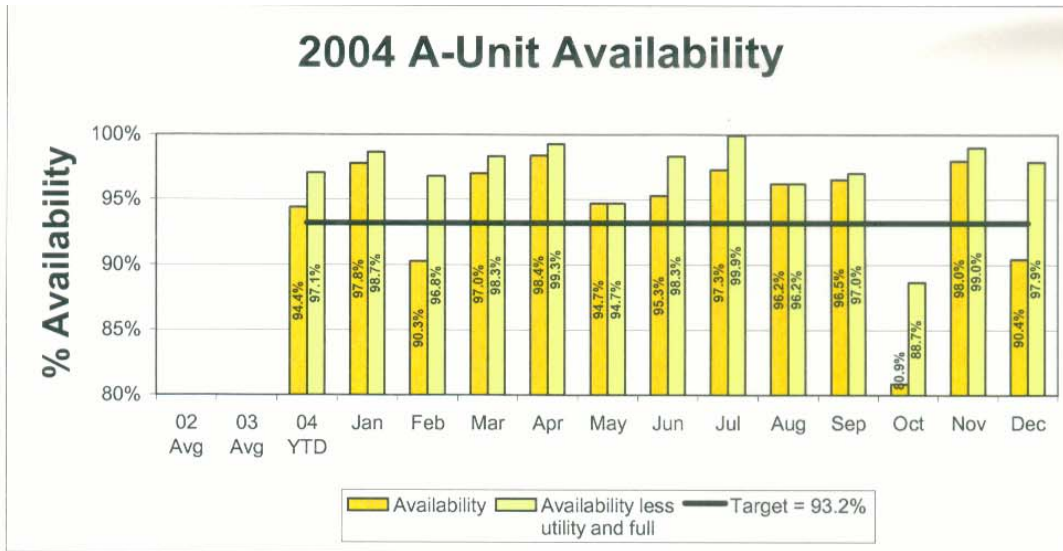
Task #	Reviewer	Project Component	Comments	Complete Y/N
1	Persinger	Establish Business Requirements	There were six characteristics of a maintenance process established as requirements for the system.	Y
2	Persinger	Create Tables	The six tables created utilized the Microsoft Visio Program	Y
3	Persinger	Create ERD Diagram	The diagram was designed utilizing Microsoft Visio.	Y
4	Persinger	DDL Script to Create the Database	Oracle's SQL language was used to write the DDL script.	Y
5	Persinger	DDL Script to Populate the Database	The database was populated with test data. No real persons were depicted in its creation	Y
6	Persinger	DDL Script to Create Report Queries	The report queries created were based on the six reports derived from interviews with planners.	Y
7	Persinger	Design Interfaces	The database interfaces were designed according to existing methods. This will help with the integration of the database concerning the potential users of the system.	Y
8	Persinger	Create DDL Test Data	The purpose of the test data was to establish a method for demonstration the operation of the prototype database.	Y

Document 7- Approximate budget for project

Project Component	Source	Cost
Case tools	Was already obtained from earlier classes taken at Regis and used in this project. If needed Microsoft Project could realistically have been used to create most of the project.	\$150.
Database system	Was designed using Oracle's remote.world available online.	\$0
Process Logic Controllers for obtaining data from production equipment.	May be purchased from a vendor, if not already available in the manufacturing environment. PLCs already present in the production equipment were utilized for this project.	\$600
Off-the-shelf software program(s)	PaperTech's SAP system could be used to initiate the database portion of the project if access were available. This cost is an estimate based on an hourly rate.	\$500
Monitoring system.	Was created using programs obtained for use in classes taken through Regis University.	\$0
Total		\$1,250.

Appendix C-Prototype Monitoring System Documentation and Diagrams

Document 1-A Unit Availability

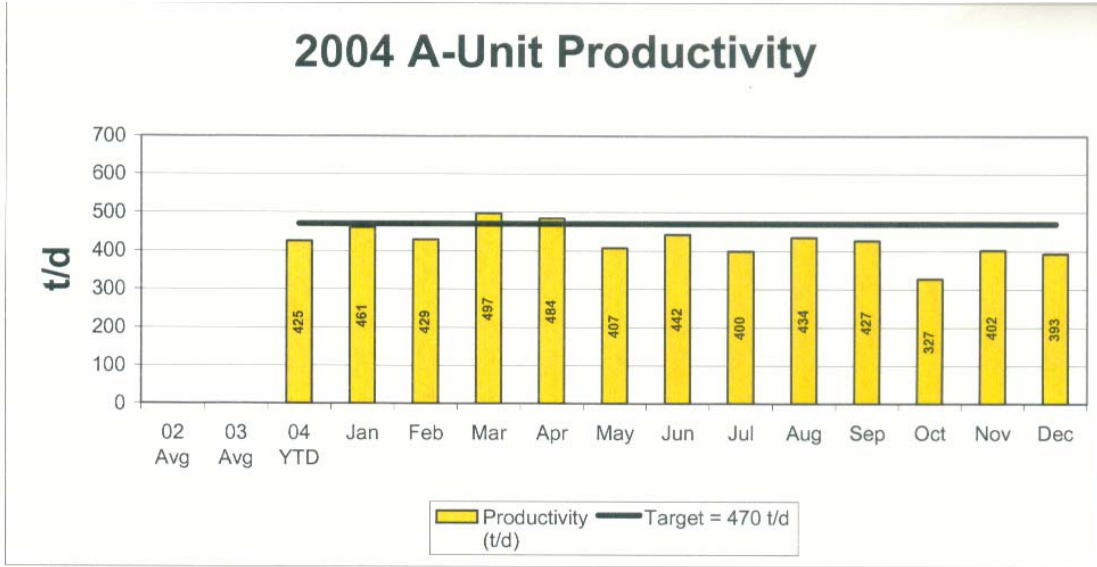


Month	Scheduled		Full		Equipment Failures		Utility Failures	
	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)
Target	-	1.5%	-	0.0%	-	<0.5%	-	0.0%
January	0	0.0%	0	0.0%	600	1.3%	390	0.9%
February	1130	2.7%	0	0.0%	195	0.5%	2735	6.5%
March	740	1.7%	590	1.3%	0	0.0%	0	0.0%
April	60	0.1%	375	0.9%	255	0.6%	0	0.0%
May	1200	2.7%	0	0.0%	1170	2.6%	0	0.0%
June	120	0.3%	1320	3.1%	595	1.4%	0	0.0%
July	0	0.0%	160	0.4%	30	0.1%	1020	2.3%
August	105	0.2%	0	0.0%	1585	3.6%	0	0.0%
September	870	2.0%	0	0.0%	420	1.0%	210	0.5%
October	4680	10.5%	660	1.5%	380	0.9%	2825	6.3%
November	0	0.0%	0	0.0%	435	1.0%	440	1.0%
December	285	0.6%	1485	3.3%	650	1.5%	1860	4.2%
YTD	9190	1.7%	4590	0.9%	6315	1.2%	9480	1.8%

Comments;

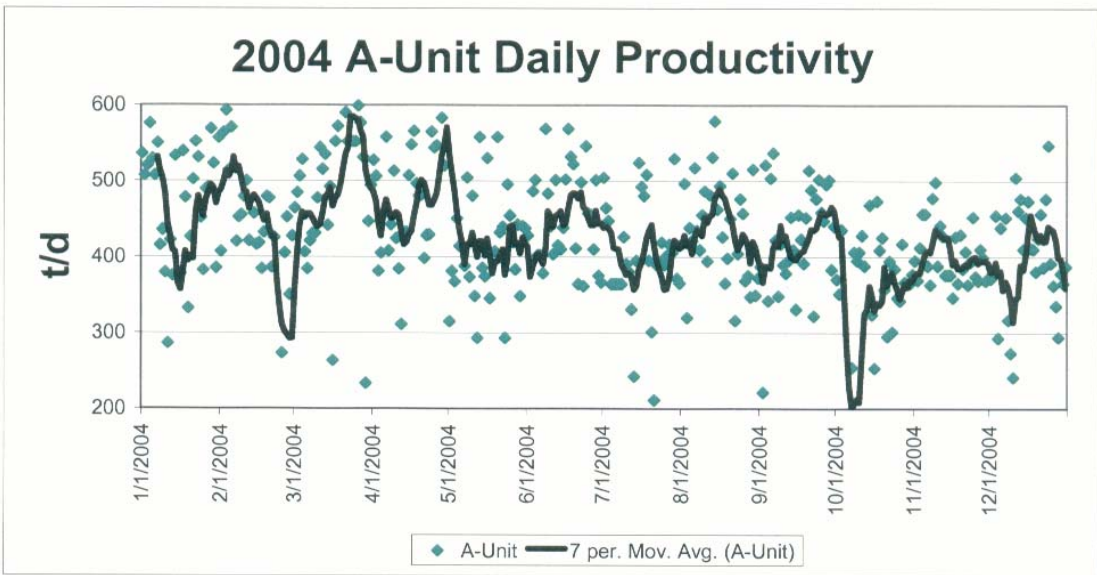
- January Failure: 600 Replace SW dil. Pump; Utility Failure: 390 #9 boiler switch gear failure
- February Failure: 195 Plug D2 tower stock pump; Utility Failure: 2465 #2 R/B Outage, 270 NCG PLC Failure
- March No equipment or utility related down time
- April Failure: 165 PLC power supply failure, 90 Swing washer sealing over
- May Failure: 270 D2 Chemical mixer rack (lose fuse), 285 3A TSP Electrical issues
Utility Failure: 615 Low ClO2 inventory
- June Failure: 90 Low ClO2 inventory, 505 3A TSP Feeder screw failure
- July Failure: 30 Primary Scrubber Pump Coupling Failure; Utility Failure: 1020 Recovery Outage (no stock)
- August Failure: 755 Low ClO2 inventory, 665 D1 Chemical Mixer, 165 Swing Washer Problems
- September Failure: 420 D1 Risor Expansion Joint Failure; Utility Failure: #6 Boiler Problems
- October Failure: 310 Unplug 2A Steam Mixer Nozzles, 70 D2 Chemical Mixer Speed Switch
Utility Failure: 2825 #1 R/B Problems
- November Failure: 170 Unplug SW Steam Mixer Nozzles, 265 Low ClO2 Inventory
Utility Failure: 440 #1 R/B Water Wash
- December Failure: 170 D2 Chemical Mixer Speed Switch, 480 1A Repulper Screw Failure (Change TSP)
Utility Failure: 1860 #2 R/B Outage (no stock)

Document 2-A Unit Productivity

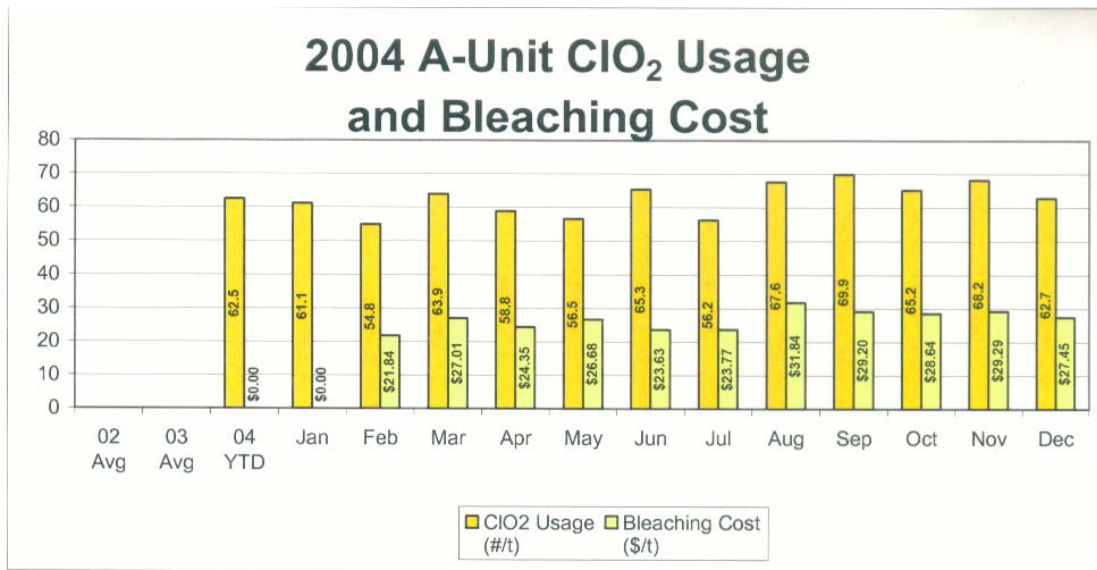


Comments;

- January** Below goal productivity 13 days
- February** Below goal productivity 19 days
- March** Below goal productivity 9 days
- April** Below goal productivity 13 days
- May** Below goal productivity 25 days
- June** Below goal productivity 18 days
- July** Below goal productivity 25 days
- August** Below goal productivity 21 days
- September** Below goal productivity 23 days
- October** Below goal productivity 29 days
- November** Below goal productivity 28 days
- December** Below goal productivity 26 days



Document 3-A Unit ClO₂ Usage & Bleaching Cost



Comments;

January

February

March

April

May

June

July

August

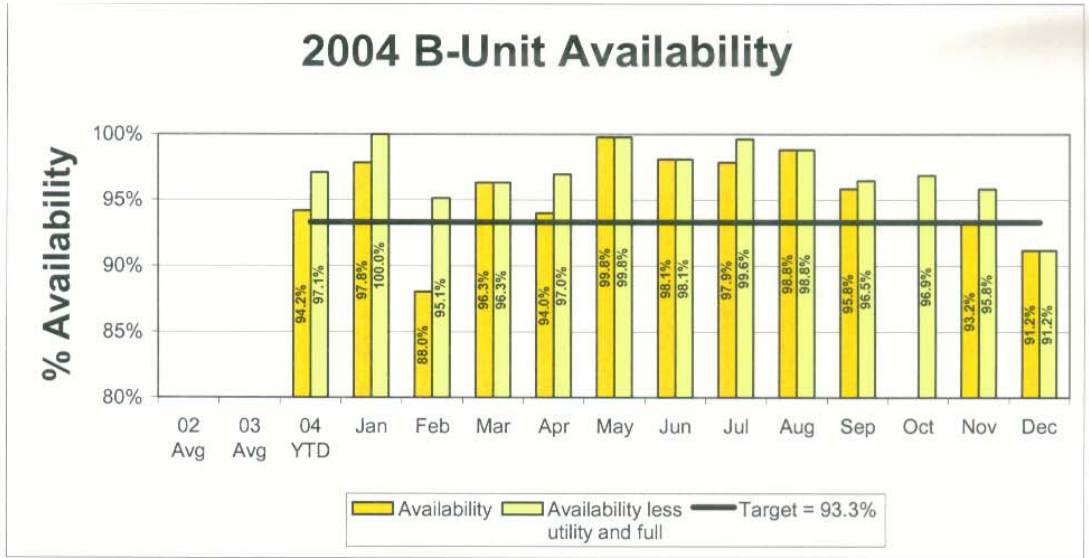
September

October

November

December

Document 4-B Unit Availability

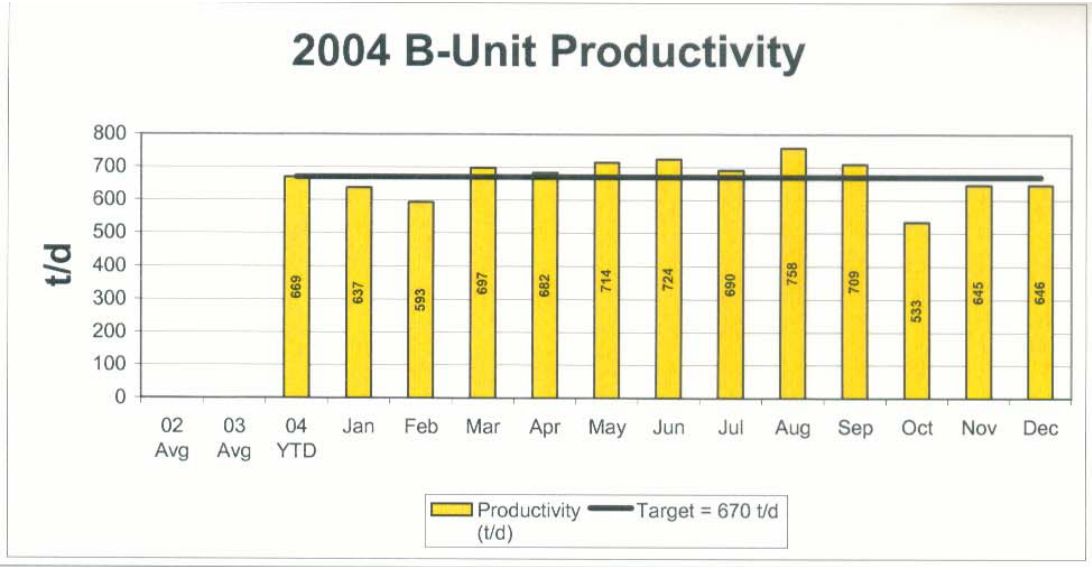


Month	Scheduled		Full		Equipment Failures		Utility Failures	
	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)
<i>Target</i>	-	1.5%	-	0.0%	-	<0.5%	-	0.0%
January	0	0.0%	240	0.5%	0	0.0%	720	1.6%
February	1825	4.4%	300	0.7%	205	0.5%	2665	6.4%
March	0	0.0%	0	0.0%	1640	3.7%	0	0.0%
April	1310	3.0%	0	0.0%	0	0.0%	1285	3.0%
May	0	0.0%	0	0.0%	100	0.2%	0	0.0%
June	370	0.9%	0	0.0%	450	1.0%	0	0.0%
July	0	0.0%	0	0.0%	160	0.4%	785	1.8%
August	0	0.0%	0	0.0%	520	1.2%	0	0.0%
September	855	2.0%	270	0.6%	670	1.6%	0	0.0%
October	570	1.3%	120	0.3%	825	1.8%	7885	17.7%
November	645	1.5%	0	0.0%	1155	2.7%	1155	2.7%
December	2355	5.3%	0	0.0%	1585	3.6%	0	0.0%
YTD	7930	1.5%	930	0.2%	7310	1.4%	14495	2.8%

Comments;

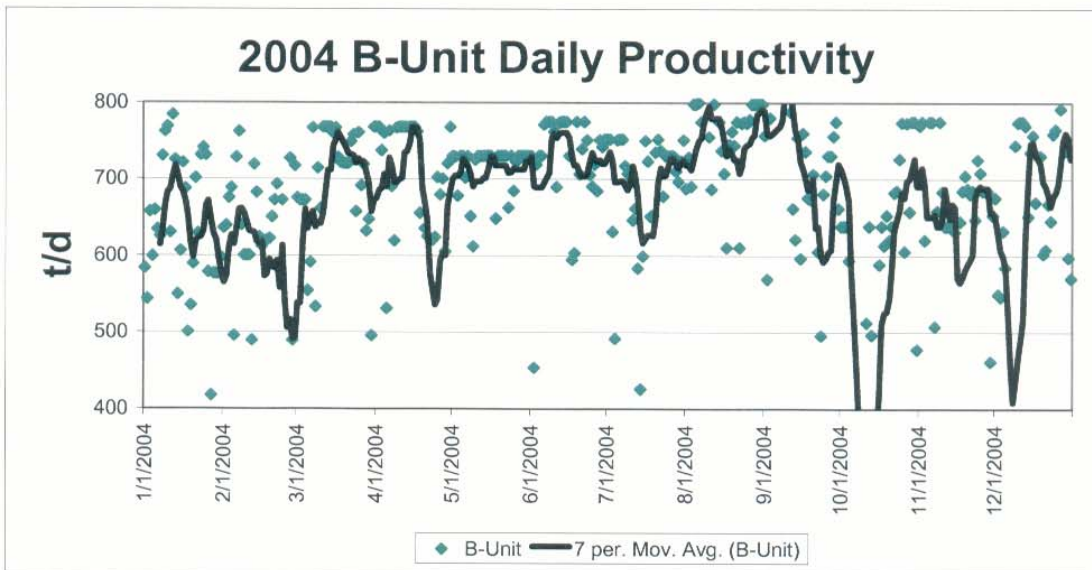
- January Utility Failure: 280 Out of chips, 440 Full of weak liquor
- February Failures: 205 Mini breaker failure
Utility Failure: 1675 #2 R/B outage, 935 full of weak liquor, 495 NCG PLC failure
- March Failures: 330 4B Tower stock pump ground, 420 1B stub shaft failure, 740 5B TSP failure, 150 4B TSP actuator brace failure
- April Failures: No mechanical failures
Utility Failure: 340 #6 power boiler failure, 825 #1 R/B outage, 120 Pumping from 500 t
- May Failures: 100 Low ClO2 inventory
- June Failures: 450 Low ClO2 inventory
- July Failures: 100 Hole in 4B Washer dilution flange, 60 Primary scrubber pump coupling failure
Utility Failure: 786 Out of stock 3x
- August Failures: 280 4B TSP Repairs, 240 Low ClO2 inventory
- September Failures: 420 3B TSP Bearing Failure, 250 Low ClO2 inventory
- October Failures: 555 5B TSP Sheave Failure, 270 5B Washer Dilution Pump Seal failure
Utility Failure: 7675 #1 R/B Problems, 210 #2 R/B Trip/#8 Boiler Tube Leak
- November Failures: 120 4B Washer Wire, 570 Low ClO2 inventory, 465 4B Repulper dil valve/1B wire plugged
Utility Failure: 1155 #1 R/B Water Wash
- December Failures: 735 5B TSP Discharge Gasket/Valve, 280 1B Incline Conveyor Motor, 180 5B Washer Dilution Coupling, 240 4B TSP in service

Document 5-B Unit Productivity

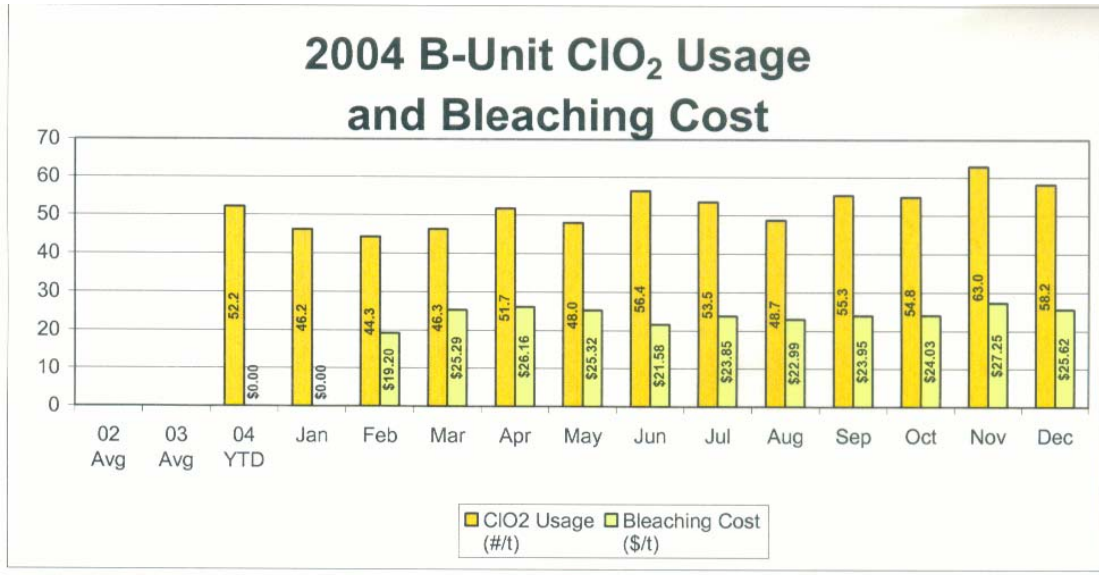


Comments:

- January** Below goal productivity 19 days
- February** Below goal productivity 18 days
- March** Below goal productivity 8 days
- April** Below goal productivity 10 days
- May** Below goal productivity 4 days
- June** Below goal productivity 3 days
- July** Below goal productivity 9 days
- August** Below goal productivity 2 days
- September** Below goal productivity 8 days
- October** Below goal productivity 26 days
- November** Below goal productivity 14 days
- December** Below goal productivity 13 days



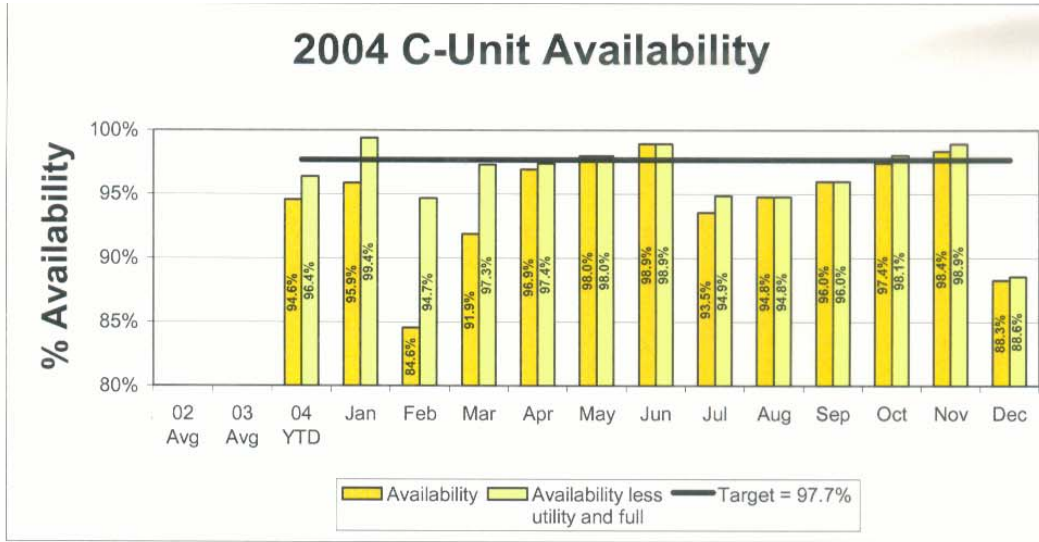
Document 6-B Unit ClO₂ Usage & Bleaching Cost



Comments;

- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December

Document 7-C Unit Availability



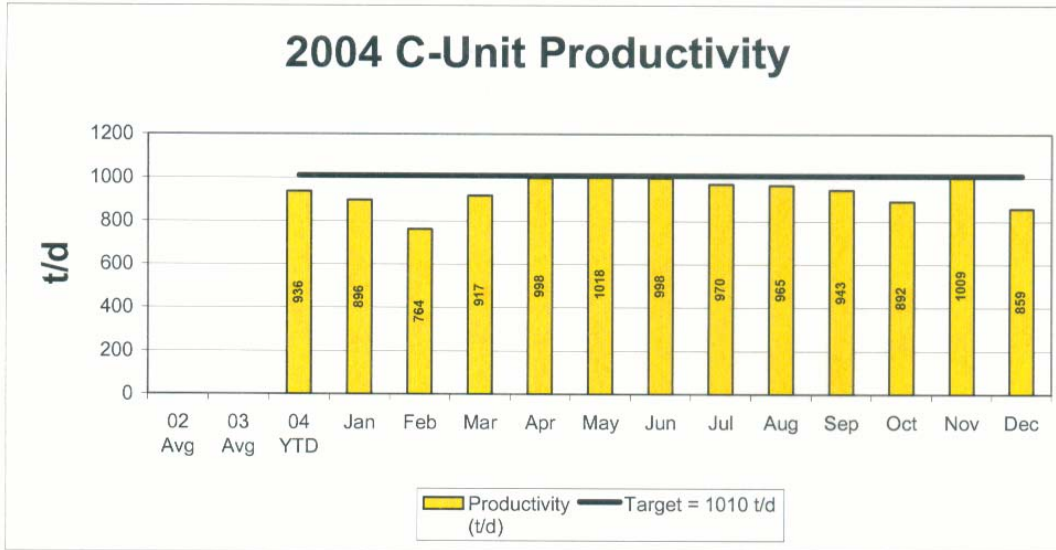
Month	Scheduled		Full		Equipment Failures		Utility Failures	
	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)
<i>Target</i>	-	1.5%	-	0.0%	-	<0.5%	-	0.0%
January	0	0.0%	225	0.5%	270	0.6%	1345	3.0%
February	795	1.9%	0	0.0%	1430	3.4%	4215	10.1%
March	0	0.0%	0	0.0%	1200	2.7%	2430	5.4%
April	820	1.9%	0	0.0%	300	0.7%	200	0.5%
May	0	0.0%	0	0.0%	890	2.0%	0	0.0%
June	0	0.0%	0	0.0%	455	1.1%	0	0.0%
July	1590	3.6%	0	0.0%	705	1.6%	585	1.3%
August	780	1.7%	0	0.0%	1553	3.5%	0	0.0%
September	900	2.1%	0	0.0%	835	1.9%	0	0.0%
October	670	1.5%	0	0.0%	200	0.4%	270	0.6%
November	0	0.0%	0	0.0%	455	1.1%	255	0.6%
December	3890	8.7%	0	0.0%	1220	2.7%	120	0.3%
YTD	9445	1.8%	225	0.0%	9513	1.8%	9420	1.8%

Comments;

- January Failure: 270 10 pressure trips on 2C
Utility Failure: 455 No chips, 530 #9 boiler switch gear failure, 360 Full of weak liquor
- February Failure: 400 3C Washer MC discharge line/MC valve, 135 PLC trip, 175 2C Steam gasket failure, 615 Start-up problems, 60 Washer drive cooling problems
Utility Failure: 990 Full of weak liquor, 2100 #2 R/B outage, 610 NCG PLC failure
- March Failure: 885 Pressure transmitter failures (1C & 3C); Utility Failure: 2430 D-line operational issues (D3)
- April Failure: 300 Pressure trips; Utility Failure: 200 #6 Power boiler failure
- May Failure: 135 Prebreaker choked, 230 2C Tower MC pump trips, 510 3C Purge water line failure
- June Failure: 455 2C Washer/Tower MC Pump Problems
- July Failure: 340 2C Rupture disk, 160 Pressure trips, 75 Press cooling water solenoid, 100 2C MC pump/SP
Utility Failure: 585 #1 R/B Water wash
- August Failure: 665 Press Problems, 228 1C Air Regulator Failure, 215 2C Pressure Trips, 445 3C Scraper Amps/Pressure
- September Failure: 540 2C Rupture Disk (x2), 135 2C MC Pump Trip, 100 2C Pressure Trips (start-up), 60 2C Feed Chute Level
- October Failure: 65 2C Tower MC Pump Trip, 2C Rupture Disk Failure (High), 30 2C Washer Air Take Off
Utility Failure: 270 #2 R/B Trip/#8 Boiler Tube Leak
- November Failure: 115 Press Plugged, 300 2C MC Pump Scaled, 30 Unplug 2C Steam Mixer
Utility Failure: 255 Power Failure

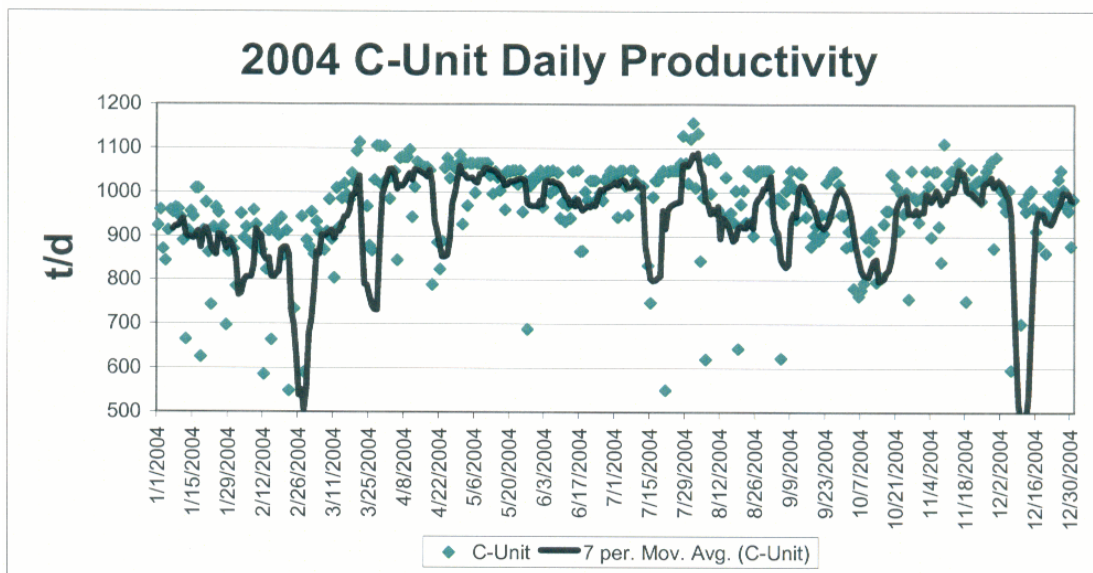
Document 8-C Unit Productivity

December Failure: 680 Press Hydr. Cooling Solenoid/Plugged Press, 210 Replace Bleached Storage Control Valve 180 1C Trips x 3
 Utility Failure: 120 #2 R/B Outage (no stock)

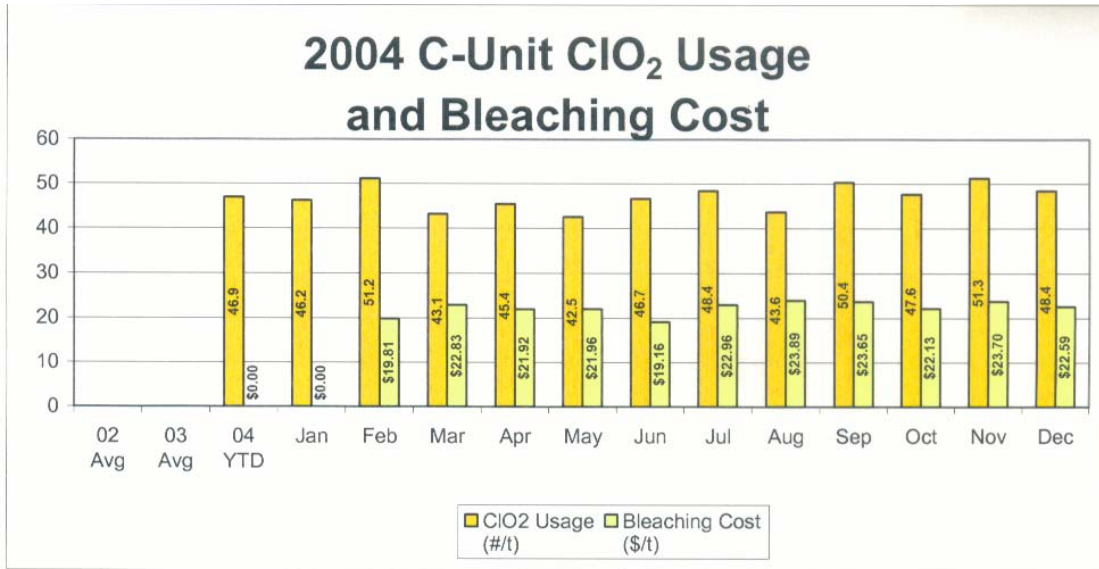


Comments;

- January Below goal productivity all month
- February Below goal productivity all month
- March Below goal productivity 20 days
- April Below goal productivity 8 days
- May Below goal productivity 7 days
- June Below goal productivity 14 days
- July Below goal productivity 8 days
- August Below goal productivity 15 days
- September Below goal productivity 19 days
- October Below goal productivity 27 days
- November Below goal productivity 8 days
- December Below goal productivity 27 days

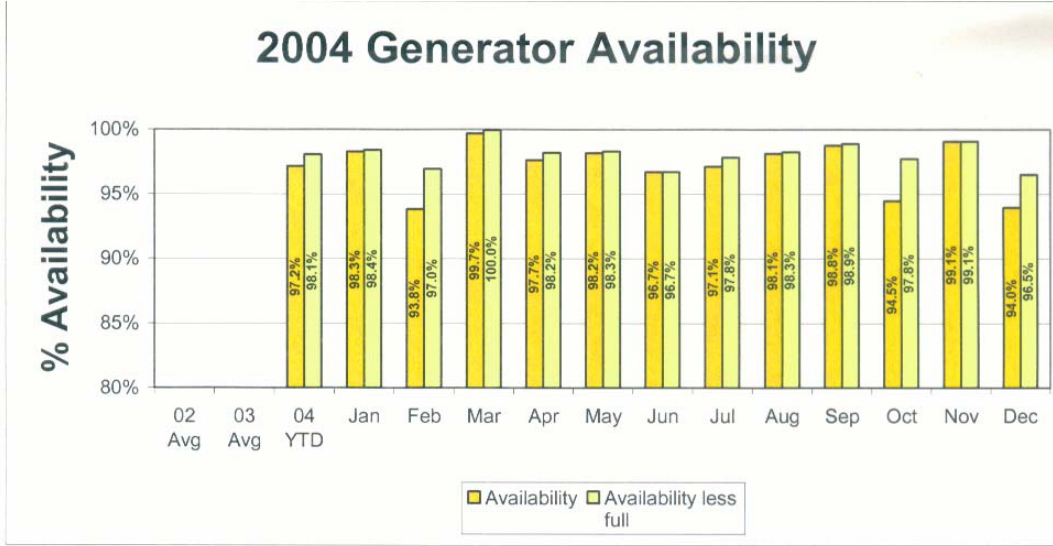


Document 9-C Unit CLO₂ Usage & Bleaching Cost



- Comments;
- January
 - February
 - March
 - April
 - May
 - June
 - July
 - August
 - September
 - October
 - November
 - December

Document 10-Generator Availability

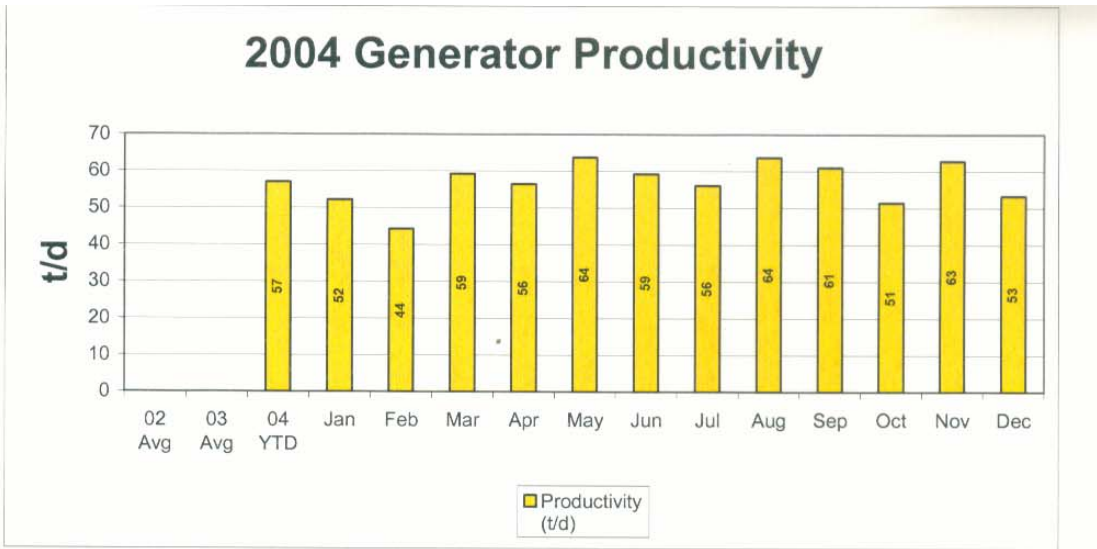


Month	Scheduled		Full		Failures		Decomps	
	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)
<i>Target</i>	-	1.5%	-	0.0%	-	<0.5%	-	0.0%
January	0	0.0%	60	0.1%	615	1.4%	85	0.2%
February	1155	2.8%	1305	3.1%	95	0.2%	20	0.0%
March	0	0.0%	120	0.3%	15	0.0%	0	0.0%
April	465	1.1%	240	0.6%	120	0.3%	190	0.4%
May	0	0.0%	60	0.1%	300	0.7%	450	1.0%
June	580	1.3%	0	0.0%	560	1.3%	275	0.6%
July	840	1.9%	315	0.7%	10	0.0%	110	0.2%
August	80	0.2%	60	0.1%	450	1.0%	237	0.5%
September	300	0.7%	55	0.1%	0	0.0%	165	0.4%
October	760	1.7%	1470	3.3%	0	0.0%	240	0.5%
November	0	0.0%	0	0.0%	35	0.1%	360	0.8%
December	1360	3.0%	1130	2.5%	110	0.2%	90	0.2%
YTD	5540	1.1%	4815	0.9%	2310	0.4%	2222	0.4%

Comments;

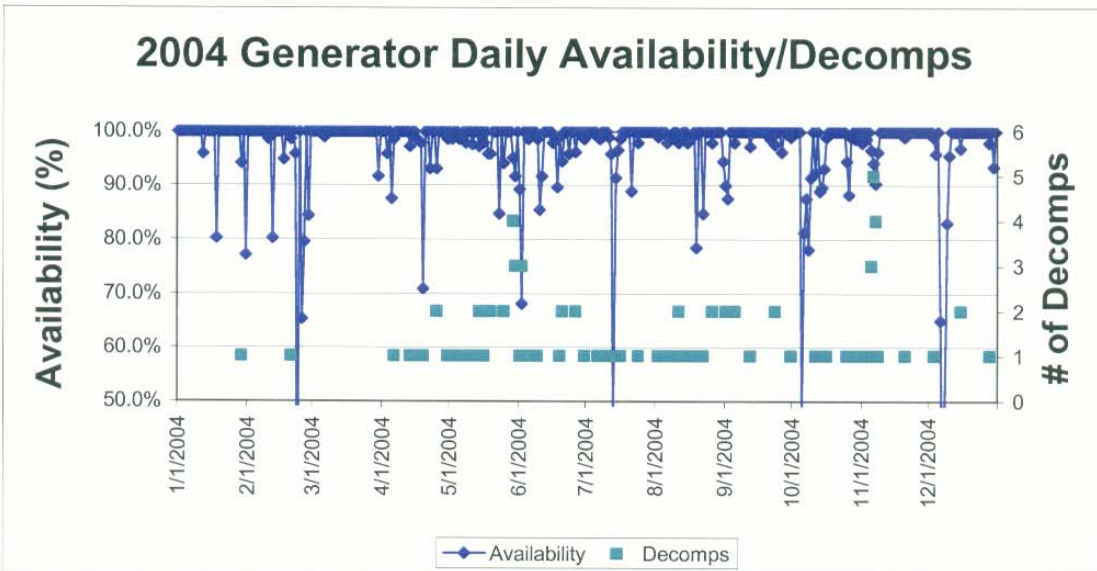
- January Failure: 285 Out of acid, 330 #1 transfer pump seal failure
- February Failure: 20 Chiller S/D (not needed), 75 Methanol control valve failure
- March Failure: 15 Generator trip on low g/l
- April Failure: 100 Hole in SCF return line, 20 Chiller S/D by Trane
- May Failure: 220 MeOH flow meter failure, 80 Chiller problems
- June Failure: 430 Chiller problems (purge unit) [Decomps up significantly May/June 18/12 vs avg 2]
- July Failure: 10 ICC Gas temp probe failure
- August Failure: 450 #3 Chiller Problems [Decomps up again in August, 6 related to unloading acid trucks]
- September Failure: None
- October Failure: None
- November Failure: 35 High ClO2 Strength [Decomps associated with high temperature problems on 5, 6, 7]
- December Failure: 95 Cooling Tower Basin Empty

Document 11-Generator Productivity



Comments;

- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December



Document 12-Induction Fan

FUME EXHAUSTER FAN

_____ Industries Inc

Subject: nyb File No: V12253-100
 P.O. No: 01540-02
 Tagging Data: BI Job # 01540

The fans on the subject reference number were test-run after final assembly to insure the vibration levels meet the nyb standard or acknowledged specification. These vibration levels are obtained with the product mounted and tested on a rigid base. Vibration levels may vary after installation due to mounting arrangement, misalignment, or shipping abuse.

Testing Data

Fan Type/Size: <u>241 FE Fan</u>	Fan No: <u>1</u>
CFM: <u>7500</u>	SP: <u>19.000</u>
RPM: <u>3200</u>	
Testing Instrument: <u>CSI</u>	Serial No. <u>01503</u>
Calibration Date: <u>7/16/01</u>	Filter Position: <u>IN</u>
Unit of Measure: <u>In/Sec</u>	Permitted Vibration: <u>.15</u>

The fan bearing vibration at the test RPM is as follows:

	Horizontal	Vertical
Inboard: in/sec	<u>.04</u>	<u>.14</u>
Outboard: in/sec	<u>.13</u>	<u>.13</u>

8/17/01
 Date

Test Operator



Document 13-Induction Fan

Table 1 - BEARING SETSCREW TORQUE, lb.-in.

Setscrew Diameter	Manufacturer				
	Link-Belt	Sealmaster	SKF	McGill	Dodge
#10	40	--	35	35	--
1/4	90	65	50	85	--
5/16	185	125	165	165	160
3/8	325	230	290	290	275
7/16	460	350	350	--	--
1/2	680	500	620	--	600
5/8	1350	1100	1325	--	1200
3/4	2350	--	--	--	2000

Note: Split pillow block bearings are fixed to the shaft with tapered sleeves and generally do not have setscrews.

FAN MAINTENANCE

nyb fans are manufactured to high standards with quality materials and components. Proper maintenance will ensure a long and trouble-free service life.

Do not attempt any maintenance on a fan unless the electrical supply has been completely disconnected and locked. In many cases, a fan can windmill despite removal of all electrical power. The rotating assembly should be blocked securely before attempting maintenance of any kind.

The key to good fan maintenance is regular and systematic inspection of all fan parts. Inspection frequency is determined by the severity of the application and local conditions. Strict adherence to an inspection schedule is essential.

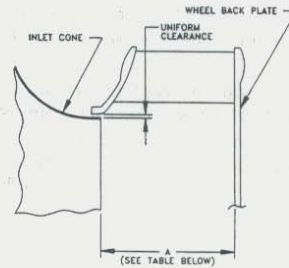
Regular fan maintenance should include the following:

1. Check the fan wheel for any wear or corrosion, as either can cause catastrophic failures. Check also for the build-up of material which can cause unbalance resulting in vibration, bearing wear and serious safety hazards. Clean or replace the wheel as required. FRP parts should not be cleaned with sharp objects which could damage the laminated surface.
2. Check the V-belt drive for proper alignment and tension (see section on V-belt drives). If belts are worn, replace them as a set, matched to within manufacturer's tolerances. Lubricate the coupling of direct-drive units and check for alignment (see section on couplings).
3. Lubricate the bearings, but do not over lubricate (see the bearing section for detailed specifications).
4. When lip-type shaft seals are provided, lubricate them with "NEVER-SEEZ" or other anti-seize compound.
5. During any routine maintenance, all setscrews and bolts should be checked for tightness. See the table for correct torques.
6. To install a new wheel/shaft assembly insert the shaft into the bearings but do not tighten setscrews. Position wheel/shaft assemblies using the proper clearances as shown in Figure 3 and Table 2. Once wheel/shaft assembly is aligned properly in housing, tighten bearing setscrews.
7. All FRP fans have neoprene foam tape gasketing between major housing components. When these components are separated and reassembled the gasketing must be replaced.
8. Check the soundness of all parts. Any evidence of exposed glass fiber should result in immediate replacement of the FRP part.

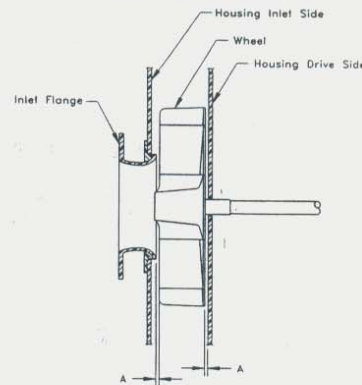
Table 2 - WHEEL POSITION DIMENSION "A" [Inches]

	FE	FE	GFE	FPB
	Med. pres. Arr. 1, 9 & 10	Hi Pres. Arr. 1 & 9	Arr. 1, 9 & 10	
12	--	--	41/2	--
15	--	--	53/8	--
18	63/4	63/4	7	1/4
22	--	--	--	1/4
24	91/8	91/8	91/4	--
28	--	--	--	1/2
30	111/8	115/8	111/4	--
36	131/2	14	131/4	--
42	151/2	161/8	153/8	--
48	173/4	183/8	171/2	--
54	20	203/4	193/4	--
60	221/4	--	215/8	--

Fume Exhauster (FE)
General Purpose Fume Exhauster (GFE)



Pressure Blower (FPB)



Radial Fume Exhauster (RFE)

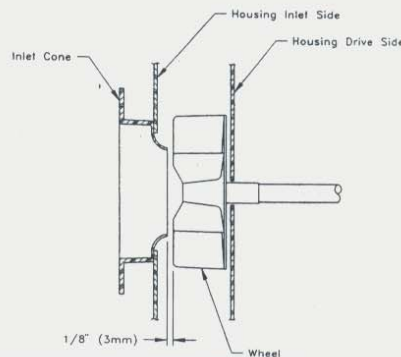


Figure 3

Document 14-Induction Fan

COMMON FAN PROBLEMS

Excessive Vibration

A common complaint regarding industrial fans is "excessive vibration". **nyb** is careful to ensure that each unit is precisely balanced prior to shipment; however, there are many other causes of vibration including:

1. Loose mounting bolts, setscrews, bearings or couplings.
2. Misalignment or excessive wear of couplings or bearings.
3. Misaligned or unbalanced motor.
4. Bent shaft due to mishandling or material impact.
5. Accumulation of foreign material on the wheel.
6. Excessive wear or erosion of the wheel.
7. Excessive system pressure or restriction of airflow due to closed dampers.
8. Inadequate structural support, mounting procedures or materials.
9. Externally transmitted vibration.

Inadequate Performance

1. Incorrect testing procedures or calculations.
2. Fan running too slowly.
3. Fan wheel rotating in wrong direction or installed backwards on shaft.
4. Wheel not properly centered relative to inlet cone.
5. Damaged or incorrectly installed cut off sheet or diverter.
6. Poor system design, closed dampers, air leaks, clogged filters, or coils.
7. Obstructions or sharp elbows near inlets.
8. Sharp deflection of airstream at fan outlet.

Excessive Noise

1. Fan operating near "stall" due to incorrect system design or installation.
2. Vibration originating elsewhere in the system.
3. System resonance or pulsation.
4. Improper location or orientation of fan intake and discharge.
5. Inadequate or faulty design of supporting structures.
6. Nearby sound reflecting surfaces.
7. Loose accessories or components.
8. Loose drive belts.
9. Worn bearings.

Premature Component Failure

1. Prolonged or major vibration.
2. Inadequate or improper maintenance.
3. Abrasive or corrosive elements in the airstream or surrounding environment.
4. Misalignment or physical damage to rotating components or bearings.
5. Bearing failure from incorrect or contaminated lubricant or grounding through the bearings while arc welding.
6. Excessive fan speed.
7. Extreme ambient or airstream temperatures.
8. Improper belt tension.
9. Improper tightening of wheel setscrews.

REPLACEMENT PARTS

It is recommended that only factory-supplied replacement parts be used. **nyb** fan parts are built to be fully compatible with the original fan, using specific alloys and tolerances. These parts carry a standard **nyb** warranty.

When ordering replacement parts, specify the part name, **nyb** shop and control number, fan size, type, rotation (viewed from drive end), arrangement and bearing size or bore. Most of this information is on the metal nameplate attached to the fan base.

For assistance in selecting replacement parts, contact your local **nyb** representative or visit: <http://www.nyb.com>.

Example: Part required: Wheel
 Shop/control number: B-10106-100
 Fan description: Size 36 Fume Exhauster
 Clockwise rotation
 Arrangement: 1
 Bearing: Sealmaster MPD, 2-11/16" Bore

Suggested replacement parts include:

Wheel and Shaft Assembly	Component parts:
Bearing	Damper
Shaft Seal	Motor
	Coupling
	Sheaves
	V-Belts

LIMITED PRODUCT WARRANTY

All products are warranted by **nyb** to be free from defects in materials and workmanship for a period of one (1) year after shipment from its plant, provided buyer demonstrates to satisfaction of **nyb** that the product was properly installed and maintained in accordance with **nyb**'s instructions and recommendations and that it was used under normal operating conditions.

This warranty is limited to the replacing and/or repairing by **nyb** of any part or parts which have been returned to **nyb** with **nyb**'s written authorization and which in **nyb**'s opinion are defective. Parts not manufactured by **nyb** but installed by **nyb** in equipment sold to the buyer shall carry the original manufacturer's warranty only. All transportation charges and any and all sales and use taxes, duties, imports or excises for such part or parts shall be paid for by the buyer. **nyb** shall have the sole right to determine whether defective parts shall be repaired or replaced.

This warranty does not cover any customer labor charges for replacement of parts, adjustments or repairs, or any other work unless such charges shall be assumed or authorized in advance, in writing, by **nyb**.

This warranty does not cover any product which, in the judgment of **nyb**, has been subject to misuse or neglect, or which has been repaired or altered outside **nyb**'s plant in any way which may have impaired its safety, operation or efficiency, or any product which has been subject to accident.

This warranty shall be null and void if any part not manufactured or supplied by **nyb** for use in any of its products shall have been substituted and used in place of a part manufactured or supplied by **nyb** for such use.

There are no warranties, other than those appearing on the acknowledgement form **INCLUDING NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE**, given in connection with the sale of the goods sold hereunder. The buyer agrees that his sole and exclusive remedy, and the limit of **nyb**'s liability for loss from any cause whatsoever, shall be the purchase price of the goods sold hereunder for which a claim is made.

Document 15-Induction Fan

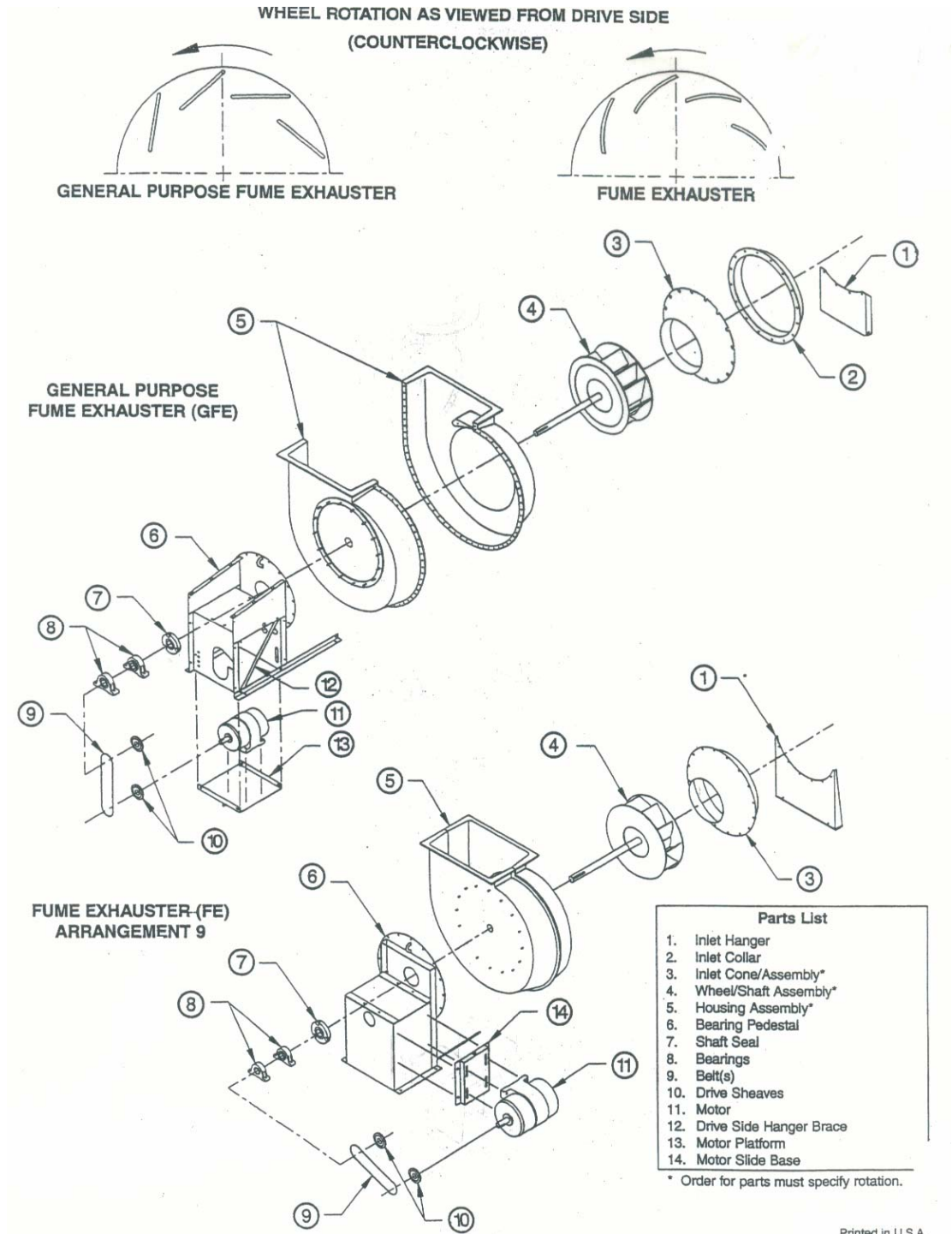


Diagram 1-Activity Diagram for Monitoring System.

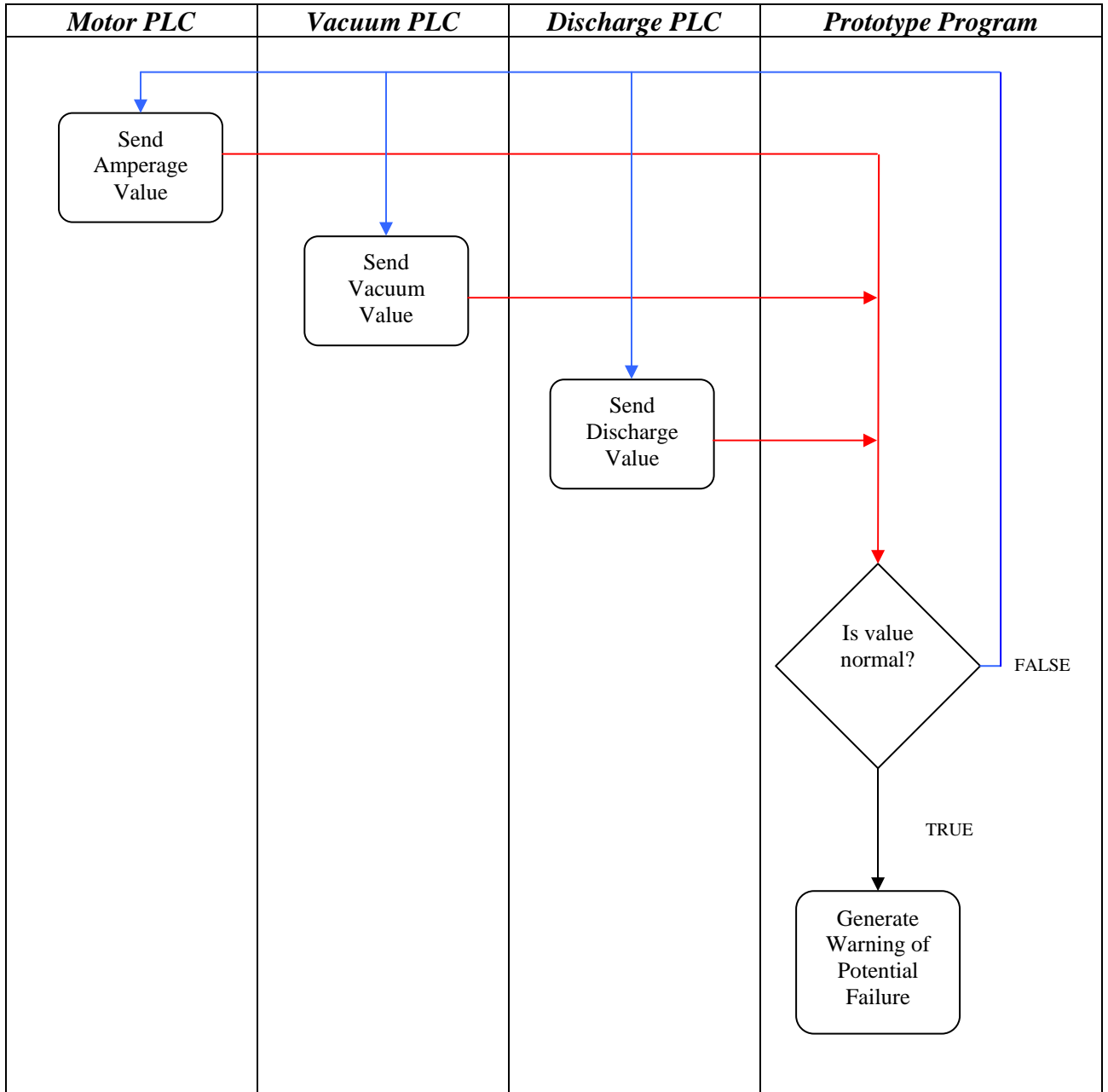


Diagram 2-Collaboration Diagram for Monitoring System

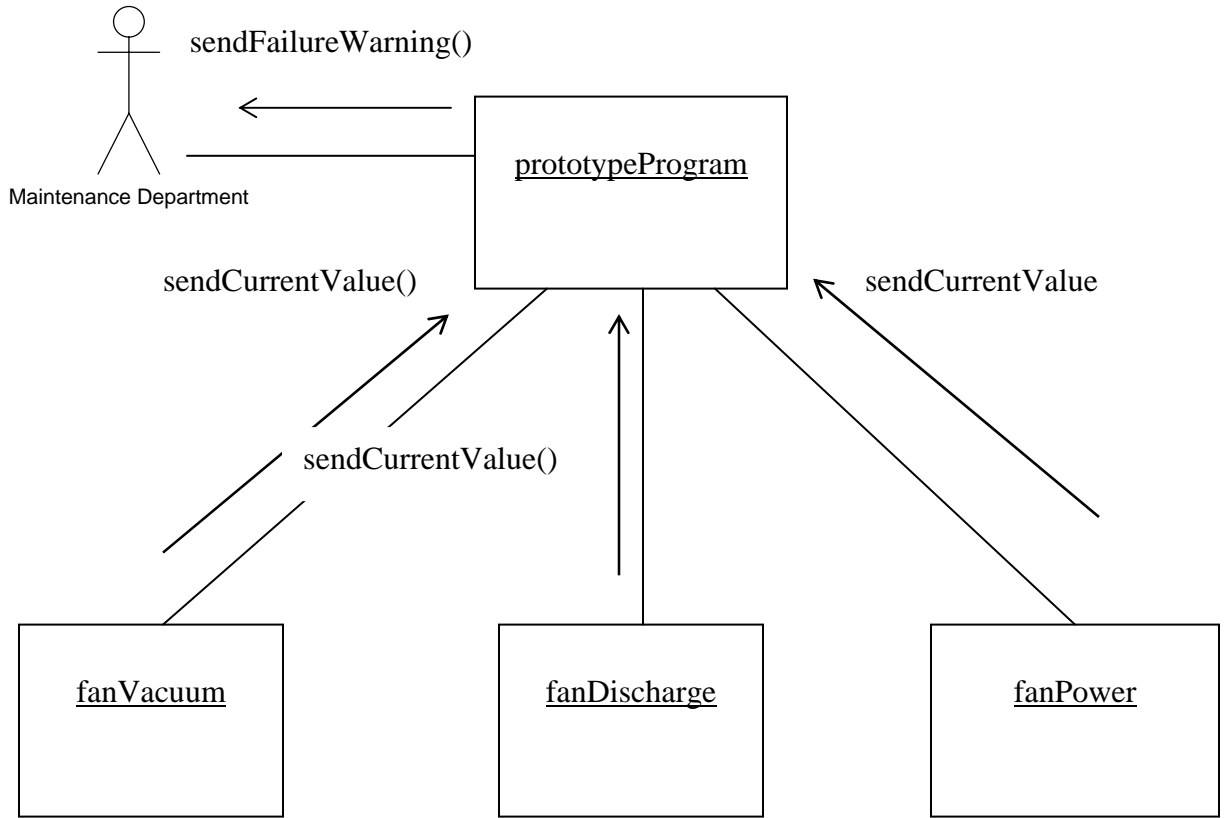


Diagram 3-Use Case Diagram for Monitoring System

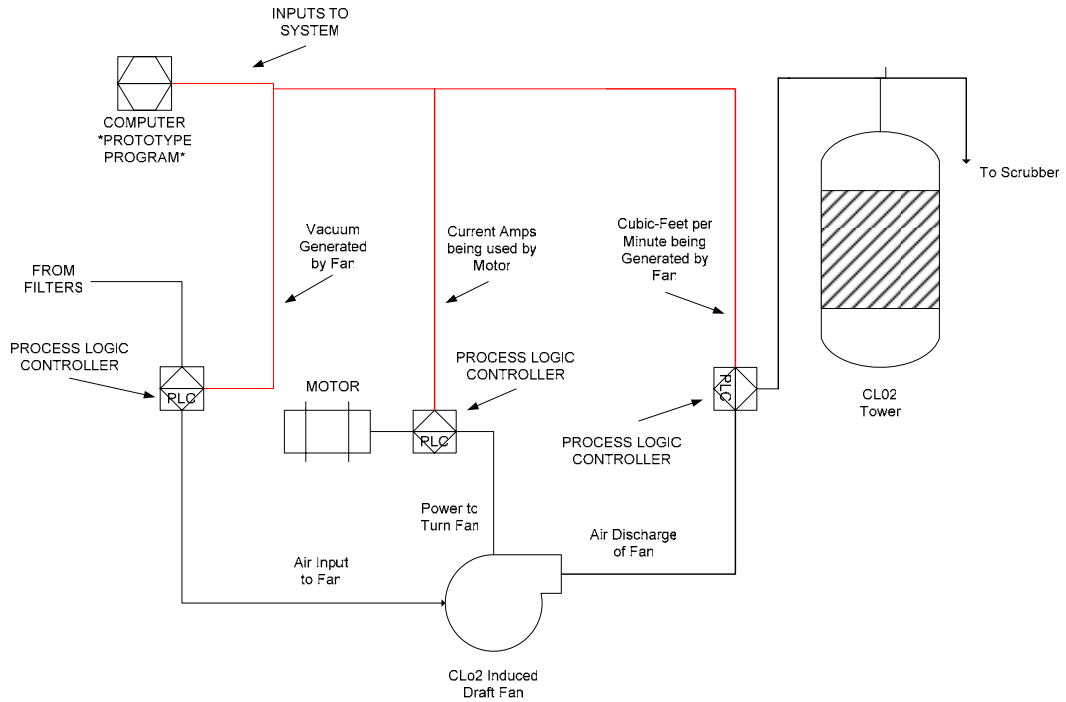


Diagram 4-Class Diagram for Monitoring System

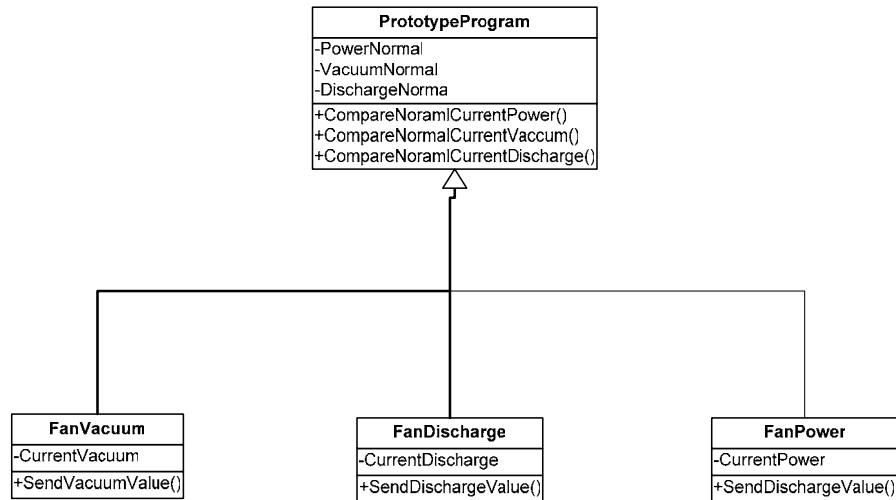


Diagram 5-Coded Program for Monitoring System

```

#include <iostream>
using namespace std;
void Prototype(int, int, int);

int main()
{
    int Vacuum, Discharge, Power, Stop;
    do
    {
        cout << "Enter Value for Vacuum:";
        cin >> Vacuum;

        cout << "Enter Value for Discharge.";
        cin >> Discharge;

        cout << "Enter Value for Power.";
        cin >> Power;

        Prototype(Vacuum, Discharge, Power);

        cout << "Enter 0 to stop or any other key to continue.";
        cin >> Stop;
    }
    while(Stop!=0);
    return 0;
}

void Prototype(int Vacuum, int Discharge, int Power)
{
    int NormalV=19, NormalD=7500, NormalP=100;

    if(Vacuum < NormalV)
        cout << "Low Vacuum, Possible Failure\n";

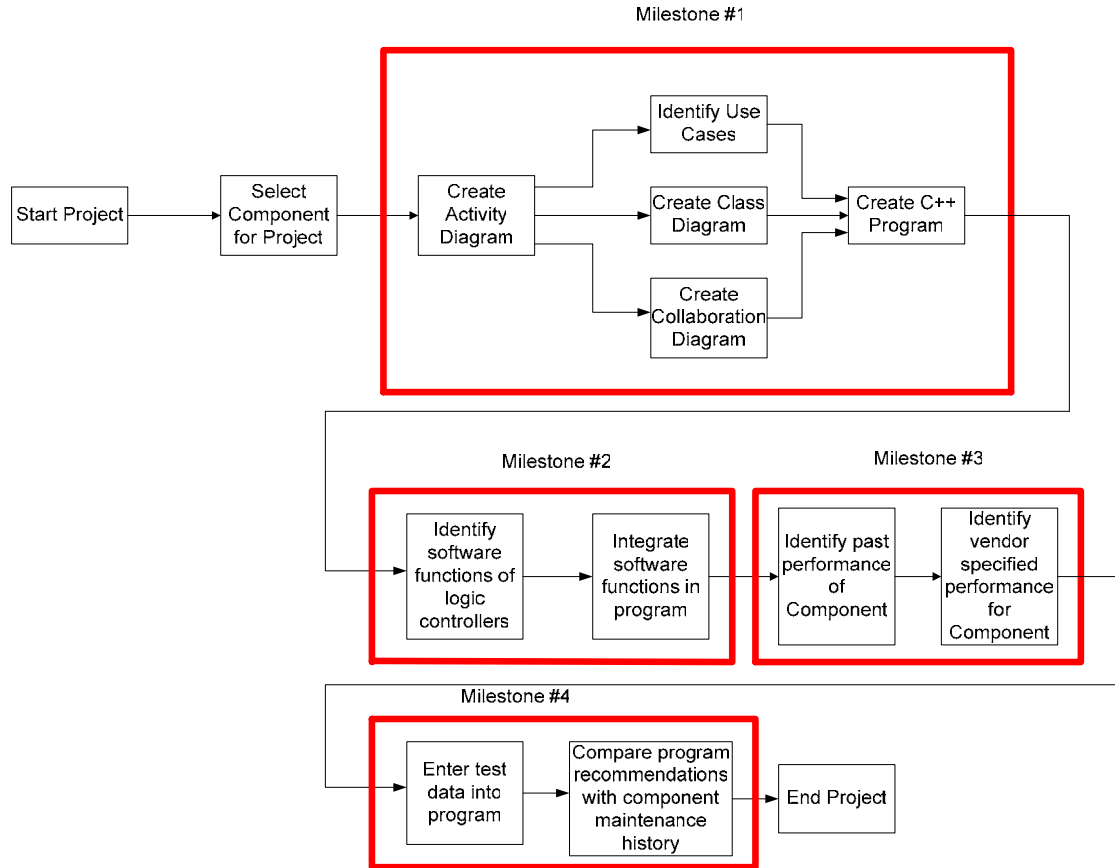
    if(Discharge < NormalD)
        cout << "Low Discharge, Possible Failure\n";

    if(Power > NormalP)
        cout << "High Power, Possible Failure\n";

    if(Vacuum>=NormalV&&Discharge>=NormalD&&Power>=NormalP)
        cout << "Normal Operation\n";
}

```

Diagram 6-Network of Achievements-Monitoring System Development including Milestones



Appendix D-Prototype Database Documentation and Diagrams**Diagram 1-Data Set****PaperTech Data Set**

Craftsman Identification Number	Craftsman Information
Craftsman Name	Craftsman Information
Craftsman Social Security Number	Craftsman Information
Craftsman Date of Hire	Craftsman Information
Craftsman Title	Craftsman Information
Craftsman Assigned Department	Craftsman Information
Vendor Identification Number	Vendor Information
Vendor Name	Vendor Information
Vendor Address	Vendor Information
Vendor Phone Number	Vendor Information
Vendor Since Date	Vendor Information
Equipment Identification Number	Equipment Information
Equipment Name	Equipment Information
Equipment Assigned Department/Location	Equipment Information
Equipment Manufacture Date	Equipment Information
Equipment Installation Date	Equipment Information
Equipment Vendor Supplier	Equipment Information
Part Identification Number	Part Information
Part Name	Part Information
Part(s) in stock	Part Information
Part Vendor Supplier	Part Information
Part Tool Vendor Recommendation	Part Information
Department Identification Number	Department Information
Department Name	Department Information
Department Designation: Production/Support	Department Information
Tool Code	Tool Information
Tool Description	Tool Information

Diagram 2-Six Tables utilized in Database

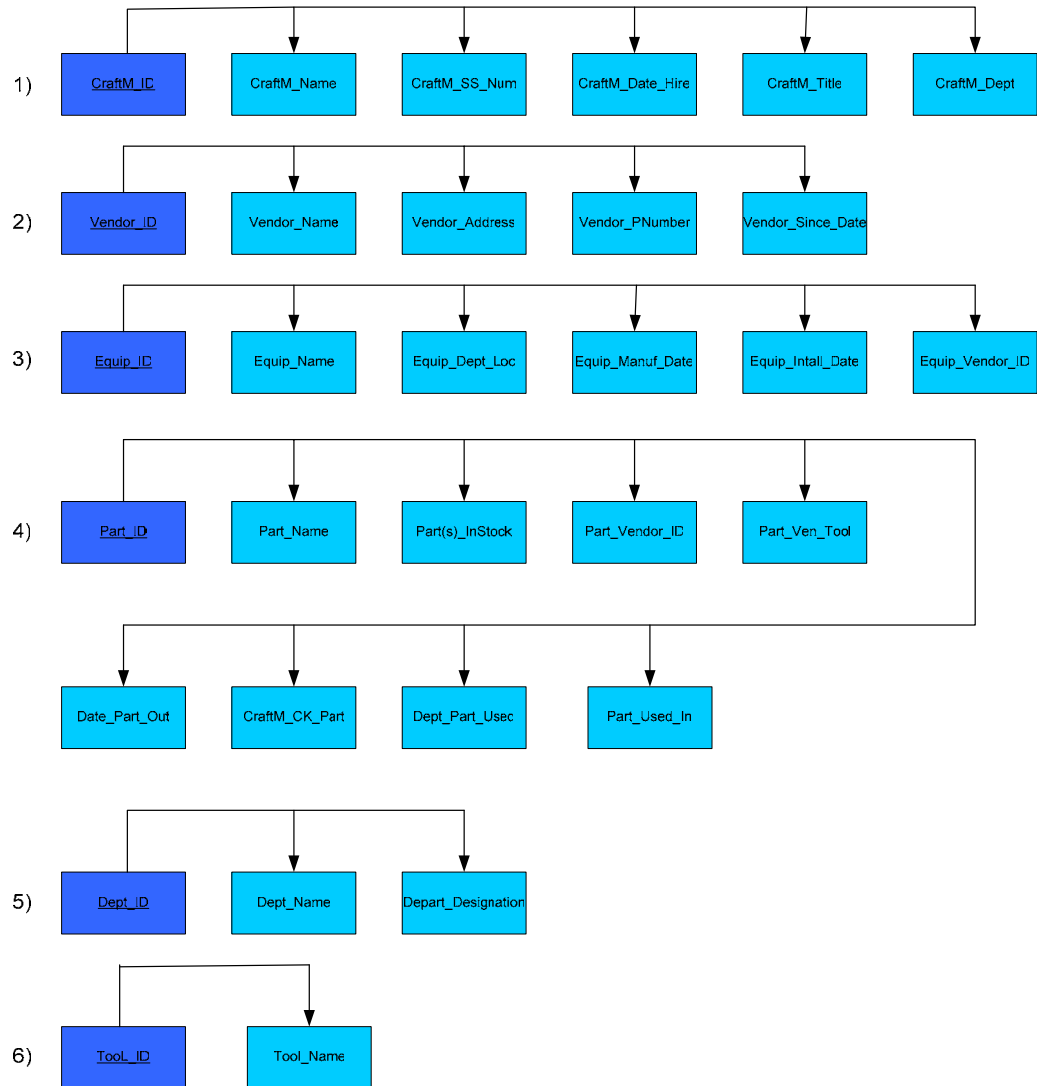
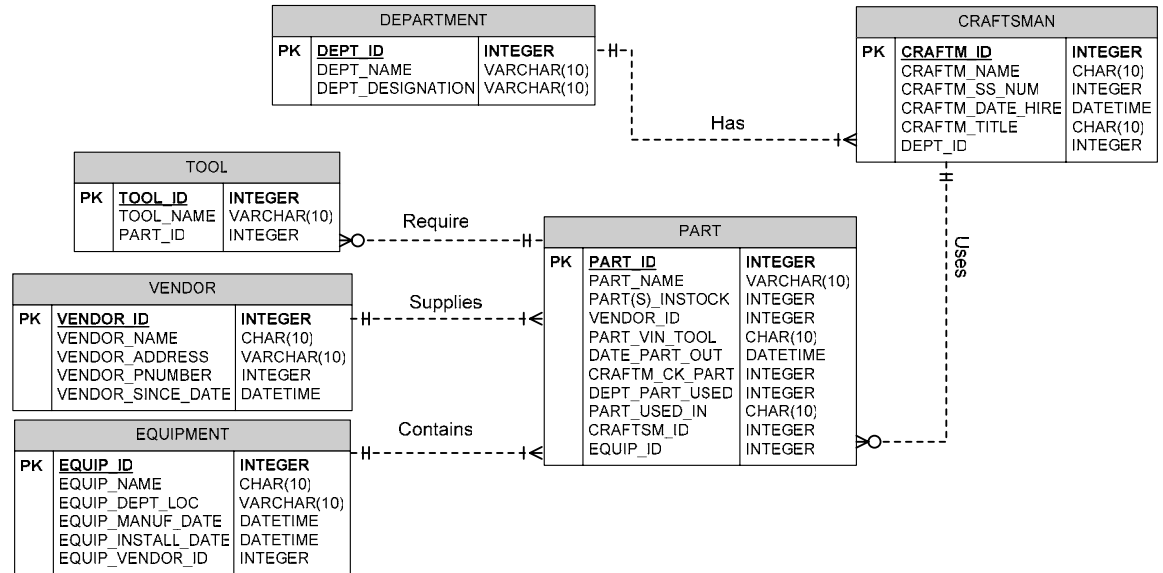


Diagram 3-Entity Relationship Diagram



* Note: The Visio program used to construct the diagram identifies the Primary Keys with a PK designation and a Bold, Underlined font. The Foreign Keys are identified through the location of the connection points between the tables.

The relationships and assumptions made about the data in the above ER Diagram are described below.

- 1) A DEPARTMENT has one or more CRAFTSMAN assigned to it.
- 2) A CRAFTSMAN uses zero or more PART(s).
- 3) A PART requires zero or more TOOL(s) for installation.
- 4) A VENDOR supplies one or more PART(s).
- 5) A piece of EQUIPMENT contains one or more PART(s).

Diagram 4-Data Dictionary for Database

Attribute Name	Column Name	Relation Member	Data Type	Field Length	Constraints	Description
CRAFTM_ID	CRAFTM_ID	CRAFTSMAN	INTEGER	10	NOT NULL PK	Identification number for individual craftsman
CRAFTM_NAME	CRAFTM_NAME	CRAFTSMAN	CHAR	10	NOT NULL	Last name of craftsman
CRAFTM_SS_NUM	CRAFTM_SS_NUM	CRAFTSMAN	INTEGER	10	NOT NULL	Social Security Number
CRAFTM_DATE_HIRE	CRAFTM_DATE_HIRE	CRAFTSMAN	DATETIME	6	NOT NULL	Hire Date
CRAFTM_TITLE	CRAFTM_TITLE	CRAFTSMAN	CHAR	10	NOT NULL	Trade designation
DEPT_ID	DEPT_ID	CRAFTSMAN	INTEGER	10	FK	Foreign Key Constraint to Department DEPT_ID Primary Key
DEPT_ID	DEPT_ID	DEPARTMENT	INTEGER	10	NOT NULL PK	Identification number for individual department
DEPT_NAME	DEPT_NAME	DEPARTMENT	VARCHAR	10	NOT NULL	Name of department
DEPT_DESIGNATION	DEPT_DESIGNATION	DEPARTMENT	VARCHAR	10	NOT NULL	Identifies department designation, production or support
EQUIP_ID	EQUIP_ID	EQUIPMENT	INTEGER	10	NOT NULL PK	Serial number of individual equipment
EQUIP_NAME	EQUIP_NAME	EQUIPMENT	CHAR	10	NOT NULL	Name of individual equipment
EQUIP_DEPT_LOC	EQUIP_DEPT_LOC	EQUIPMENT	VARCHAR	10	NOT NULL	Identifies location of equipment in a department
EQUIP_MANUF_DATE	EQUIP_MANUF_DATE	EQUIPMENT	DATETIME	6	NOT NULL	Identifies date of manufacture for individual equipment
EQUIP_INSTALL_DATE	EQUIP_INSTALL_DATE	EQUIPMENT	DATETIME	6	NOT NULL	Identifies date equipment was installed
EQUIP_VENDOR_ID	EQUIP_VENDOR_ID	EQUIPMENT	INTEGER	10	NOT NULL	Identifies the vendor that supplied the equipment
PART_ID	PART_ID	PART	INTEGER	10	NOT NULL PK	Serial number for part
PART_NAME	PART_NAME	PART	VARCHAR	10	NOT NULL	Name for part

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PART(S)_INSTOCK	PART(S)_INSTOCK	PART	INTEGER	100	NOT NULL	Number of parts currently in stock.
VENDOR_ID	VENDOR_ID	PART	INTEGER	10	NOT NULL FK	Foreign Key Constraint to Vendor VENDOR_ID Primary Key
PART_VIN_TOOL	PART_VIN_TOOL	PART	CHAR	10		Vendor recommended tool(s) for part installation
DATE_PART_OUT	DATE_PART_OUT	PART	DATETIME	6		Date part was checked out
CRAFTM_CK_PART	CRAFTM_CK_PART	PART	INTEGER	10		ID number of craftsman who checked part out.
DEPT_PART_USED	DEPT_PART_USED	PART	INTEGER	10		ID number of department where part was used.
PART_USED_IN	PART_USED_IN	PART	CHAR	10		Name of equipment that part was used in.
CRAFTM_ID	CRAFTM_ID	PART	INTEGER	10	NOT NULL FK	Foreign Key Constraint to Craftsman CRAFTM_ID Primary Key
EQUIP_ID	EQUIP_ID	PART	INTEGER	10	NOT NULL FK	Foreign Key Constraint to Equipment EQUIP_ID Primary Key
TOOL_ID	TOOL_ID	TOOL	INTEGER	10	NOT NULL PK	Serial number for a individual type of tool
TOOL_NAME	TOOL_NAME	TOOL	VARCHAR	10	NOT NULL	Name for an individual type of tool
PART_ID	PART_ID	TOOL	INTEGER	10	NOT NULL FK	Foreign Key Constraint to Part PART_ID Primary Key
VENDOR_ID	VENDOR_ID	VENDOR	INTEGER	10	NOT NULL PK	Identification number for a specific vendor.
VENDOR_NAME	VENDOR_NAME	VENDOR	CHAR	10	NOT NULL	Name for a specific vendor

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VENDOR_ADDRESS	VENDOR_ADDRESS	VENDOR	VARCHAR	10	NOT NULL	Address for a specific vendor
VENDOR_PNUMBER	VENDOR_PNUMBER	VENDOR	INTEGER	10	NOT NULL	Phone number for a specific vendor.
VENDOR_SINCE_DATE	VENDOR_SINCE_DATE	VENDOR	DATETIME	10	NOT NULL	Date a specific vendor began supplying parts.

Diagram 5-DDL used for Logical Design of the Database

```

create table CRAFTSMAN
{
    craftm_id          integer(10)  NOT NULL,
    craftm_name        char(10)     NOT NULL,
    craftm_ss_number   integer(10)  NOT NULL,
    craftm_date_hire   datetime(6)  NOT NULL,
    craftm_title       char(10)     NOT NULL,
    dept_id            integer(10)  NOT NULL,
    CONSTRAINT CRAFTSMAN_craftm_id_pk
    PRIMARY KEY (craftm_id),
    CONSTRAINT CRAFTSMAN_dept_id_fk
    FOREIGN KEY (dept_id) REFERENCES DEPARTMENT (dept_id)
};

```

```

create table DEPARTMENT
{
    dept_id            integer(10)  NOT NULL,
    dept_name          varchar(10)  NOT NULL,
    dept_designation   varchar(10)  NOT NULL,
    CONSTRAINT DEPARTMENT_dept_id_pk
    PRIMARY KEY (dept_id)
};

```

```

create table EQUIPMENT
{
    equip_id           integer(10)  NOT NULL,
    equip_name         char(10)     NOT NULL,
    equip_dept_loc     varchar(10)  NOT NULL,
    equip_manuf_date   datetime(6)  NOT NULL,
    equip_install_date datetime(6)  NOT NULL,
    equip_vendor_id    integer(10)  NOT NULL,
    CONSTRAINT EQUIPMENT_equip_id_pk
    PRIMARY KEY (equip_id)
};

```

```

create table PART
{
    part_id            integer(10)  NOT NULL,
    part_name          varchar(10)  NOT NULL,
    part(s)_instock    integer(10)  NOT NULL,
    vendor_id          integer(10)  NOT NULL,
    part_vin_tool      char(10)     NOT NULL,
    date_part_out      datetime(6)  NOT NULL,
    crafm_ck_part      integer(10)  NOT NULL,
};

```

```

dept_part_used      integer(10)  NOT NULL,
part_used_in       char(10)    NOT NULL,
craftm_id          integer(10)  NOT NULL,
equip_id           integer(10)  NOT NULL,
CONSTRAINT PART_part_id_pk
PRIMARY KEY (part_id),
CONSTRAINT PART_vendor_id_fk
FOREIGN KEY (vendor_id) REFERENCES VENDOR (vendor_id),
CONSTRAINT PART_craftm_id_fk
FOREIGN KEY (craftm_id) REFERENCES CRAFTSMAN
(craftm_id),
CONSTRAINT PART_equip_id_fk
FOREIGN KEY (equip_id) REFERENCES EQUIPMENT (equip_id)
};

```

```

create table TOOL
{
    tool_id          integer(10)  NOT NULL,
    tool_name       varchar(10)  NOT NULL,
    part_id         integer(10)  NOT NULL,
    CONSTRAINT TOOL_tool_id_pk
    PRIMARY KEY (tool_id),
    CONSTRAINT TOOL_tool_id_fk
    FOREIGN KEY (part_id) REFERENCES PART (part_id)
};

```

```

create table VENDOR
{
    vendor_id       integer(10)  NOT NULL,
    vendor_name     char(10)    NOT NULL,
    vendor_address  varchar(10)  NOT NULL,
    vendor_pnumber  integer(10)  NOT NULL,
    vendor_since_date  datetime(6)  NOT NULL,
    CONSTRAINT VENDOR_vendor_id_pk
    PRIMARY KEY (vendor_id)
};

```

```

commit;

```

Diagram 6-DDL used to Populate the Database with Data

```

INSERT INTO CRAFTSMAN (
'662389', 'Persinger', '543987123', '022383', 'Pipefitter', '4');
INSERT INTO CRAFTSMAN (
'546770', 'Smith', '345872947', '052787', 'MillWright', '4');
INSERT INTO CRAFTSMAN (
'345489', 'Morgan', '543890651', '091789', 'Welder', '4');
INSERT INTO CRAFTSMAN (
'322761', 'Stanley', '298345874', '101490', 'Pipefitter', '4');
INSERT INTO CRAFTSMAN (
'568723', 'Wilham', '298675982', '082792', 'Oiler', '4');
INSERT INTO CRAFTSMAN (
'433422', 'Kershner', '223785643', '092488', 'MillWright', '4');
INSERT INTO CRAFTSMAN (
'566423', 'Wright', '321987456', '092283', 'MillWright', '1');
INSERT INTO CRAFTSMAN (
'765232', 'Tolly', '234432556', '072497', 'Pipefitter', '1');
INSERT INTO CRAFTSMAN (
'389634', 'Whitt', '228567559', '120591', 'Welder', '4');
INSERT INTO CRAFTSMAN (
'211346', 'Loan', '298678342', '110393', 'Pipefitter', '1');

INSERT INTO PART VALUES (
'28318039', 'CELL_ASSY', '3', '123');
INSERT INTO PART VALUES (
'28318040', 'CUP_BOARD', '1', '123');
INSERT INTO PART VALUES (
'28318041', 'FILTER_CAL', '2', '231');
INSERT INTO PART VALUES (
'28318042', 'FIL_COM_AM', '1', '231');
INSERT INTO PART VALUES (
'28318043', 'FIL_MEA_AM', '1', '231');
INSERT INTO PART VALUES (
'28318044', 'FIL_REF_AM', '2', '231');
INSERT INTO PART VALUES (
'28318045', 'LOW_NOI_AM', '2', '123');
INSERT INTO PART VALUES (
'08788900', 'V-BELT.MAT', '2', '123');
INSERT INTO PART VALUES (
'83010092', 'BEAR_BABBT', '2', '123');
INSERT INTO PART VALUES (
'83010160', 'TITAN_FILC', '1', '332');

INSERT INTO DEPARTMENT VALUES (
'1', 'PAPER_MACH', 'PRODUCTION');

```

```
INSERT INTO DEPARTMENT VALUES (  
'2', 'POWER_DEPT', 'SUPPORT');  
INSERT INTO DEPARTMENT VALUES (  
'3', 'PULP_MILL', 'PRODUCTION');  
INSERT INTO DEPARTMENT VALUES (  
'4', 'BLEACH_DPT', 'PRODUCTION');
```

```
INSERT INTO EQUIPMENT VALUES (  
'2213453298', 'THSTK_PUMP', '4', '120585', '031999', '123');  
INSERT INTO EQUIPMENT VALUES (  
'3131232455', 'SUMP_PUMP3', '4', '101790', '041802', '123');  
INSERT INTO EQUIPMENT VALUES (  
'2222938299', 'MEASUREX04', '4', '120700', '100502', '231');  
INSERT INTO EQUIPMENT VALUES (  
'3434224567', 'ACCURAY099', '4', '031802', '112903', '231');
```

```
INSERT INTO EQUIPMENT VALUES (  
'6775433234', 'STEAMMIXER', '4', '041294', '032701', '332');  
INSERT INTO EQUIPMENT VALUES (  
'3332242256', 'AGITATER03', '4', '061401', '091203', '332');  
INSERT INTO EQUIPMENT VALUES (  
'4554322332', 'PACK_GLAND', '4', '022295', '010896', '332');  
INSERT INTO EQUIPMENT VALUES (  
'2773284292', 'CHILLER_HS', '4', '042394', '031699', '332');  
INSERT INTO EQUIPMENT VALUES (  
'3324192039', 'CHILLER_LS', '4', '081900', '061602', '332');  
INSERT INTO EQUIPMENT VALUES (  
'4352525699', 'WWPUMP_H2S', '4', '110999', '120500', '332');
```

```
INSERT INTO VENDOR VALUES (  
'332', 'FRISKHORN', '2003COV_VA', '5409782332', '120372');  
INSERT INTO VENDOR VALUES (  
'123', 'FERBIEJOHN', '4002COV_VA', '5409532121', '041781');  
INSERT INTO VENDOR VALUES (  
'231', 'CORETECH', '3221COV_VA', '5408763454', '092285');
```

```
INSERT INTO TOOL VALUES (  
'22313', 'LAS_ALIGNT', '08788900');  
INSERT INTO TOOL VALUES (  
'43256', 'TUBE_TESTR', '83010160');
```

```
commit;
```

Diagram 7-SQL Queries designed to Generate Reports for the Database**REPORT 1**

TITLE CENTER 'Craftsman Requisitions for past thirty days' SKIP 1

COLUMN part_id	HEADING 'Part ID'
COLUMN part_name	HEADING 'Part Name'
COLUMN date_part_out	HEADING 'Date Part Checked Out'
COLUMN craftm_ck_part	HEADING 'Craftsman'
COLUMN craftm_id	HEADING 'Craftsman ID'

```
SELECT PART.part_id, PART.part_name, PART.date_part_out,
PART_craftm_ck_part, CRAFTSMAN_craftm_id
FROM PART, CRAFTSMAN
WHERE (date_part_out > (currentdate-30))
ORDER BY PART.part_id;
```

REPORT 2

TITLE CENTER "Department Part is Used In" SKIP 1

COLUMN part_id	HEADING 'Part Identification Number'
COLUMN part_name	HEADING 'Part Name'
COLUMN equip_id	HEADING 'Equipment Number Part Use In'
COLUMN equip_name	HEADING 'Equipment Name'
COLUMN equip_dept_loc	HEADING 'Department Equipment Located'

```
SELECT PART.part_id, PART.part_name, EQUIPMENT.equip_id,
EQUIPMENT.equip_name, EQUIPMENT.equip_dept_loc
FROM PART, CRAFTSMAN
ORDER BY PART.part_id;
```

REPORT 3

TITLE CENTER 'Total Parts Used During Part 30 Days' SKIP 1

COLUMN part_id	HEADING 'Part ID'
COLUMN part_name	HEADING 'Part Name'
COLUMN date_part_out	HEADING 'Date Part Checked Out'

```
SELECT PART.part_id, PART.part_name, PART.date_part_out
FROM PART
WHERE (date_part_out > (currentdate-30))
```


ORDER BY PART.part_id;

REPORT 4

TITLE CENTER 'Number of Part in Stock' SKIP 1

COLUMN part_id	HEADING 'Part ID'
COLUMN part_name	HEADING 'Part Name'
COLUMN date_part_out	HEADING 'Part in Stock'

```
SELECT PART.part_id, PART.part_name, PART.date_part_out
FROM PART
WHERE (date_part_out = NULL)
ORDER BY PART.part_id;
```

REPORT 5

TITLE CENTER 'Part can be Used in the Following Production Departments' SKIP 1

COLUMN part_id	HEADING 'Part ID'
COLUMN part_name	HEADING 'Part Name'
COLUMN dept_id	HEADING 'Dept. ID'
COLUMN dept_name	HEADING 'Dept. Name'
COLUMN dept_designation	HEADING 'Dept. Designation'

```
SELECT PART.part_id, PART.part_name, DEPARTMENT.dept_id,
DEPARTMENT.dept_id, DEPARTMENT.dept_designation
FROM PART, DEPARTMENT
WHERE DEPARTMENT.dept_designation = Production
ORDER BY PART.part_id;
```

REPORT 6

TITLE CENTER 'Tool Required for Part Installation' SKIP 1

COLUMN part_id	HEADING 'Part ID'
COLUMN part_name	HEADING 'Part Name'
COLUMN part_vin_tool	HEADING 'Vendor Tool Requirement'
COLUMN tool_id	HEADING 'Tool ID'
COLUMN tool_name	HEADING 'Tool Name'

```
SELECT PART.part_id, PART.part_name, PART.part_vin_tool, TOOL.tool_id,  
TOOL.tool_name  
FROM PART, TOOL  
WHERE PART.part_vin_tool != NULL  
ORDER BY PART.part_id;
```

Diagram 8-Network of Achievements-Database System Development including Milestones

