EQUIPMENT AND PROCESS PERFORMANCE IMPROVEMENT USING
AUTOMATED MONITORING SYSTEM

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A project report submitted in partial fulfillment
of the requirements for the award of the degree of
Master of Industrial Engineering (Mechanical Engineering)

FACULTY OF MECHANICAL ENGINEERING
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MAY 2009

To my beloved mother and father

ACKNOWLEDGEMENT

The author wishes to take this opportunity to extend his warmest and sincere gratitude to the supervisor of this project, Assoc. Prof Dr Abd Rahman Abdul Rahim for his invaluable guidance. His encouragement and valued constructive criticisms are very much appreciated. The author is also indebted to the supervisor for spending his precious time reading the thesis draft and offering suggestions for improvement.

Special thanks also goes to the author's parents, and family members for their endless love, encouragement and sacrifice. Also to all those who have been there for the author when needed help and guidance, especially to his colleagues at work and course mates who has been ever willing to provide moral support and help all this while, he would like to express his sincere and heartfelt thanks.

Finally, the author would like to thank the Industrial Engineering panel of the Mechanical Engineering Faculty of Universiti Teknologi Malaysia for enabling him to carry out this project.

ABSTRACT

Factories are faced with many challenges especially with the increased product complexity along with tightened quality, yield and productivity indicators. Engineers working on maintaining, troubleshooting, design/improving equipments and process always lack of efficient tool to help them track equipment state and improve the utilization. The Overall Equipment Effectiveness metric (OEE) is a very powerful tool that can be used to measure productivity at equipment level. Previous research has shown that OEE's along with accurate and consistent equipment state data can be combined with process parameters to give estimates of productivity at the factory level. A factory monitoring tool that facilitates the analysis of a manufacturing system, by integrating KPIV and OEE metrics is studied in this project. Such a system allows factory professionals to analyze system performance by automatically evaluating the productivity metrics of equipment using the tool. This is extended to evaluate the metrics at subsystem level and thereon to the factory level and also to detect the bottleneck elements in the system. This tool paves way for further research on continuous productivity improvement methods development.

ABSTRAK

Kilang-kilang pembuatan banyak melalui cabaran terutamanya dengan penghasilan barang keluaran yang makin rumit, disamping memastikan qualiti, hasil dan daya pengularan sentiasa di paras yang tinggi. Jurutera-jurutera banyak menghadapi kesukaran untuk memelihara, memperbaiki, mencipta atau mempertingkatkan mesin dan proses dengan ketiadaan peralatan untuk membantu mereka mencari and mempertingkatkan pengunaan mesin tersebut. *"Overall Equipment Effectiveness metric (OEE)"* merupakan satu pendekatan yang berkesan untuk menyukat daya pengeluaran sesuatu mesin. Kajian-kajian sebelum ini menunjukan pengunaan OEE dengan data keadaan mesin dan proses yang tepat dapat menafsirkan daya pengeluar sesebuah kilang. Project ini akan meninjau dan menkaji penggunaan suatu peralatan yang mengunakan kaedeh KPIV dan OEE untuk memantau dan menganalisa sistem pembuatan. Dengan adanya peralatan sedemikian, jurutera-juretera dapat menganalisa prestasi daya pengeluarra sesuatu mesin secara automatic. Ia bukan sekadar dapat membantu subsistem tetapi keseluruhan prestasi dengan mengesan kemacetan dalam sistem perkilangan. Kajian ini juga dipercayai dapat membantu penyelidikan untuk penghasilan kaedah prningkatan produktiviti akan datang.

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LIST OF ABBREVIATIONS

CBM   Condition Based Monitoring

CIM   Computer Integrated Manufacturing

CPD   Cost Per Disk

DAQ   Data Acquisition

HMI   Human Machine Interfaces

KPIV   Key Process Input Variables

KPOV   Key Process Output Variables

OEE   Overall Equipment Effectiveness

PLC   Programmable Logic Controller

RAM   Reliability, Availability, and Maintainability

RCFA   Root Cause Failure Analysis

TPM   Total Productive Maintenance

TCP/IP   Ethernet Transmission Control Protocol/ Internet Protocol

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In an increasingly competitive environment, companies must understand how equipment utilization affects profitability and work on its performance improvement. To accomplish these objectives, it is necessary to have proper tool and techniques to monitor, manage and optimize equipment utilization and eventually maximizing throughput, reduce cycle time, improve product quality and manufacturing yields.

Metrics such as overall equipment effectiveness (OEE) have been used as a tool to measure productivity and lean manufacturing initiatives but little focus is given for automated system to efficiently find the root cause of both equipment and process failure. Engineers tend to rely on manually gathered data that is subjective and delayed. Automated data acquisition (DAQ) is a better alternative compared to manual data collection that significantly improves the accuracy of OEE reports and delivers meaningful equipment performance information.

DAQ is a system designed to measure and log important parameters. DAQ system is normally electronics based and comprise of hardware and software. The hardware includes PLCs, sensors, interface components and etc. The software is used to extract data from the hardware and process the signals to generate desired and meaningful information.

Once data has been captured, it is stored for current and future reference. With the stored data, the system could calculate equipment utilization and time spent in nonproductive equipment activities, such as idle and set-up based on E10 guideline.

The SEMI E10 guideline provides a mean of evaluating the operation of equipments. E10-states information contributes to better equipment utilization, and can also be used to respond to developing situations in real time instead of after effect. A detailed study as to how these guidelines can be applied to a manufacturing situation is necessary.

1.2   Problem Statement

Manufacturing industries are faced with many challenges especially with the increased product complexity along with tightened quality, yield and productivity indicators. As engineers work on existing challenges such as maintaining, troubleshooting, design or improving equipments and processes, there is a lack in efficient tool to help them track equipment status and improve the performance. Often people blame equipment for not performing but it could be either an equipment trouble or it is not being fully utilized.

In order to address the multitude of challenges along with this perception, there need to be a methodology, a tool or a technique which would help factories to overcome and make full use of its equipment. This is the very reason why an automated monitoring tool using data aqusition (DAQ) was introduced at the plant. Currently the case study company is operating key equipment without proper monitoring gauges. Some of the issues arise are:

i. The existing system cannot efficiently find the root cause of both equipment and process failure.

ii. Rely on manually gathered data that is subjective and delayed.

iii. Reactive and not proactive approach because most of the information comes many hours or days after the defect is created.

iv. Root-cause on equipment depends on real-time reports and there is insufficient monitoring gauge in all equipment.

v. Reduced yield due to inherent delay in discovering defects

vi. Equipment utilization is redused due to manual interactions before the root-cause is determined

vii. Yield and utilization reports are labor intensive and subjective.

1.3 Objectives

The aim of this project is to develop and implement of a monitoring instrument to deliver real-time equipment state parameter including events, alarms and process control systems from a specified equipment. It will cater three primary functions; namely, a mapping function, a data extraction function and a reporting application function to facilitate the users to view or print reports in textual and graphical formats.

1.4 Scope

This project will focus on the implementation of automated monitoring tool application at MA17 production line, which is part of the new factory expansion. The production line consists of seven main machines which are IS17, MA17, MAD17, MA17 ACD, H17-1, MA17UV, and H17-2.

1.5   Outline of the Project

This report is organized as outlined. Chapter 1 describes the problem statement, objectives and scope of the project. Chapter 2 gives a summary of the literature review and previous research finding relevant to this topic. The background and purpose of overall equipment effectiveness (OEE), and SEMI E10 are also described in this chapter. Chapter 3 illustrates how the project was organized, planned and performed. Chapter 4 presents detailed information about the method of developing a monitoring tool and extracting machine state and process parameters and other information required for OEE metrics calculation. This chapter includes a step by step description of the complete process involving development of the real-time monitoring tool, extraction of relevant information for calculation of the metrics, implementation of the subsystem and factory level metric calculation. Interpretation of the result and discussion is explained in Chapter 5. Chapter 6 described the conclusions and recommendations for this project.

1.6   Summary

This chapter has described the problems faced by practicing manual data acquisition. The objective of the project is to develop a tool to facilitate the analysis of a manufacturing system, by integrating a data acquisition tool and OEE metrics. This tool automates the procedure to analyze the parameters and helps to raise alert by using a user-friendly interface with minimal instructions. Such a system would allow factory professionals to analyze system performance by automatically evaluating the productivity metrics using the tool.

CHAPTER 2

LITERATURE REVIEW

2.1   Introduction

Total Productive Maintenance (TPM) is a lean manufacturing philosophy designed to integrate equipment maintenance into the manufacturing process. The goal of any TPM program is to eliminate losses tied to equipment downtime or in other words, keep equipment producing only good product as fast as possible with no unplanned downtime.

As with any lean initiative, it is critical to measure change. Overall Equipment Effectiveness (OEE) is a metric originally developed to measure the success of TPM programs by associating the six big losses with three measurable which are availability, performance and quality rate. OEE enables organizations to benchmark and monitor their progress with simple, easy to understand metrics. Understanding the true relationship between OEE and TPM can lead to improvements in equipment availability, performance and design. This leads to reduction in maintenance time and service costs.

At most factories, OEE reports are generated by using manual data acquisition and calculation. This has more often than not, resulted in inconsistency and delayed reports. Moreover the interpretation of the report can be subjective from person to person. Thus, the OEE reports are not guaranteed to be accurate. The SEMI E10 guideline provides a mean of evaluating the OEE in a systematic approach.

SEMI E10-92 Guideline for definition and measurement of equipment Reliability, Availability, and Maintainability (RAM) is developed by Semiconductor Equipment and Materials International (SEMI) to establish guidelines for measuring equipment performance. What is required is a system that enables the standard, automatic, accurate and consistent generation of equipment and process performance reports based on the SEMI-E10 Standard metrics [1].

Use of the traditional maintenance concepts of fixed overhaul time, operate to failure maintenance, opportunity maintenance, etc. may not provide an optimum solution, both in terms of quality and cost. Real-time Condition Based Monitoring (CBM) has led to an improvement in the quality of maintenance and to a substantial reduction in maintenance costs.

2.2   Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a major element in lean manufacturing. As lean manufacturing teaches to reduce batch production and lead times, it is critical that machinery operates as intended without failure. The TPM discipline insists that machinery should never or rarely break down and always kept in good condition.

Total Productive Maintenance (TPM) is a process to maximize productivity of equipment for its entire life. TPM fosters an environment where improvement efforts in safety, quality, delivery, cost and creativity are encouraged, through the participation of all employees. OEE is perhaps the most important driver of TPM, and measuring the metric is one of the most challenging tasks involved in implementing TPM [2].

TPM approach comprises of five basic components:

i. Focusing on not just speed, but Overall Equipment Effectiveness

ii. Using a hands-on approach to prevent every type of loss

iii. Involving everyone from top management to shop floor employees where all departments have a role in the productivity improvement process

iv. Conducting zero-loss activities in small groups

v. Performing root cause analysis

TPM is used to drive waste out of the manufacturing process by reducing or eliminating production time lost to machine failures. The goal of any TPM program is to ensure that machinery and equipment is always available to manufacture products for the end customer. By minimizing rework, slow running equipment and downtime, maximum value is added at minimum cost.

As maintenance issues are addressed and total productive maintenance programs implemented, the true value of TPM begins to emerge. Just as lean manufacturing relies on kaizen or continuous improvement the continuous re-evaluation of the maintenance cycle allows for kaizen in maintenance programs. Root cause analysis exposes the underlying issues to be addressed. By addressing issues at the root level, problems can be eliminated.

Maintenance has traditionally been viewed as a separate entity outside of the manufacturing process. As companies began to identify the role of maintenance in the production process a gradual shift in thinking occurred. TPM emerged out of the need to integrate maintenance with manufacturing to improve productivity and asset availability.

2.3   Overall Equipment Effectiveness (OEE)

OEE is a measure of the productivity of manufacturing equipment. Originally developed in Japan as part of total productive maintenance (TPM) to improve overall factory operations, OEE is the efficiency metrics to evaluate how well manufacturing equipment is running compared to the ideal plant.

An OEE of 85% is considered world class. Two main areas to consider when improving OEE is to look at unexpected downtime and unexpected waiting time. Unexpected downtime is when the production facility does not produce because one or more machines are down and halting the entire production. Unexpected waiting time is when a machine is idle waiting for one or more components to be fed to it. OEE is calculated by multiplying three independently measured values. These three measures are:

i. Availability - refers to the probability that the equipment will be retained in or restored to a condition where it can perform its intended function within a specified period of time. (i.e. available time minus any planned downtime)

ii. Performance efficiency - this records the production rate or speed of the production process versus the design or ideal rate

iii. Rate of quality - a measure of the percentage of defects produced by the process

The formula of Overall Equipment Effectiveness is shown in equation 1.1 where A = Availability (%), PE = Performance Efficiency (%) and RQ = Rate of Quality (%).

$$OEE = (A) * (PE) * (RQ) \tag{1.1}$$

Some research on measuring OEE was in the field of semi conductor manufacturing and there are many methods and techniques that are proposed by Naguib (1994), SEMI (1992) and SEMI-E10 (1992).

Naguib (1994) highlighted some problems with metric utilization in semiconductor fabs. It presents some practical solutions, highlighting the Overall Equipment Effectiveness teams at Texas Instruments which have been formed to minimize many of the semiconductor metric problems.

2.4   E10 State

Production lines in the manufacturing industry can be represented as discrete event systems. In a discrete event system the operation is represented by a set of events which transform the system from one state to another. Basic states often used in manufacturing systems are processing, waiting and downtime. These states can be split into several parts. For example, a process can wait for upstream parts to enter or it can wait for downstream resources to accept input. It can also wait for an operator to do some work or wait for a cart to pick up some lots.

The complete set of states in a production line, with several different processes and several parts entering and exiting, will quickly become very complex. It is therefore important to make a system guideline.

In order to develop a consistent set of guidelines, Semiconductor Equipment and Materials International (SEMI - an organization of both semiconductor manufacturers and equipment suppliers) established a task force to develop and achieve consensus concerning these guidelines. This task force created guidelines in 1986, with updates and revisions in 1988, 1990, 1992, and 1993.

One of the most notable SEMI standards products is the SEMI E10-92 Guideline for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM), hereinafter referred to as the "E10 Standard". The primary goal of the E10 Standard is to establish guidelines for measuring equipment performance. The E10 Standard defines six basic equipment states into which all equipment conditions and periods of time must be categorized. The six basic equipment states defined by the E10 Standard include a "productive state," a "standby state," an "engineering state," a "scheduled downtime state," an "unscheduled downtime state," and a "nonscheduled state" [4].

Productive state designates a period of time during which the equipment is performing its intended function and includes regular production, including product loading and unloading, work for third parties, rework, production tests and engineering runs performed in conjunction with production.

Standby state designates a period of time, other than nonscheduled time, during which the equipment is in a condition to perform its intended function, but is not operating, and includes such equipment states as no operator available, no product available, no support tools or awaiting results of production tests.

Engineering state designates a period of time during which the equipment is in a condition to perform its intended function, but is instead operated to conduct engineering experiments and includes process engineering and equipment engineering.

Scheduled downtime state designates a period of time during which the equipment is not available to perform its intended function due to planned downtime events, such as scheduled maintenance.

Unscheduled downtime state designates a period of time during which the equipment is not in a condition to perform its intended functions due to unplanned downtime events, such as unscheduled maintenance.

Finally, nonscheduled state designates a period of time during which the equipment is not scheduled to be utilized in production, such as unworked shifts, weekends and holidays, including shutdown and start-up. Figure 2.1 illustrates the E10 state model.
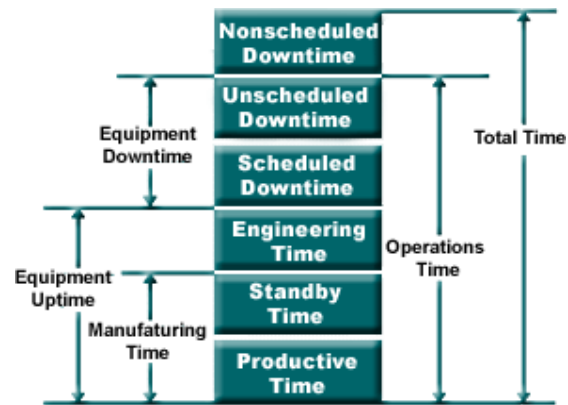
Figure 2.1: E10 state model

2.5 Condition Based Monitoring (CBM)

Condition Based Monitoring (CBM) is a maintenance process where the condition of equipment is monitored for early signs of impending failure. This can be done automatically with the use of instrumentation such as DAQ or manual monitoring. In automated CBM when any monitored and predefined condition limit is exceeded, a signal or output is turned on to generate a work order.

CBM assumes that all equipment will deteriorate and that partial or complete loss of function will occur. CBM monitors the condition or performance of plant equipment through various technologies. The data is collected, analyzed, trended, and used to project equipment failures. Once the timing of equipment failure is known, action can be taken to prevent or delay failure. In this way, the reliability of the equipment can remain high.

CBM uses various process parameters (e.g. pressure, temperature, vibration, flow) to monitor conditions. With these parameters, condition based maintenance obtains indications of system and equipment health, performance, integrity and provides information for scheduling timely corrective action.

For this project, all selections of parameters are defined and incorporated into the proposed monitoring tool for effective condition based monitoring, which is part of the plant's equipment optimization program.

Until recently, middle and corporate level management have ignored the impact of maintenance on product quality, production costs and more importantly on bottom line profit. The developments of computer based instrumentation that can be used to monitor the operating condition of plant equipment have provided the means to reduce or eliminate unnecessary repairs, prevent catastrophic machine failures and reduce the negative impact of the maintenance operation on the profitability of manufacturing and production plants.

Plants that have implemented successful condition based maintenance methods indicate substantial improvements in reliability, availability and operating costs. Major improvements can be achieved in maintenance costs, unscheduled machine failures, repair downtime, spare parts inventory, and both direct and in-direct overtime premiums.

2.6   Previous Studies

Exploring equipment state and process data of manufacturing systems has been a wide topic of research and the technology that is available today is highly sophisticated. A study of previous works gives adequate information to work on managing a real time data acquisition in a better way.

Trybula and Pratt (1994) have applied SEMI E10 guideline to present a method of evaluating equipment. By providing a migration path for increasingly complex modeling efforts, this methodology establishes a means of developing models that can be directly correlated to previously validated models. The initial modeling effort provided the results that yielded failed, busy, or idle state. Consequently, the effort applied to earlier models can be reused to assist in developing more complex models. The information presented is not intended to be complete but as a starting point for future developments [1].

LAWS and CUBES method is proposed by Konopka and Trybula (1995). In this method, the production and equipment state data was collected and used to determine where factory bottleneck tools are. Although they did not explain the data collection method, it clearly defines how critical equipment and process data are in improving factory bottleneck tool. Further investigation of this data with a productivity analysis framework called CUBES identify and prioritize productivity inefficiencies with their accompanying tool. This analysis, when implemented across the manufacturing line, should increase factory capacity [5]. It is a very challenging task to generate accurate and consistent data as they occur in modern factories that consist of highly complex manufacturing systems.

Wang, *et.al,* (1998) developed measurement of reliability, availability and maintainability (RAM) of manufacturing equipment and, enables automatic, accurate and consistent generation of equipment performance report based on the E10 standard metric. Equipment performance reporting, via E10 metrics, is an important instrument in enabling technicians, engineers and managers to understand the overall effectiveness of their tools, and to communicate this information to the management [6].

Pomorski (1997) focused on the use of OEE and major equipment loss analysis to optimize the performance of constraint tools at Fairchild Semicounductor, South Portland, Maine. The proposal defined OEE in terms consistent with SEMI E10-96, whenever possible. OEE management has proven to be an effective tool to improve manufacturing performance. Successful implementation of OEE management requires a micro factory modeling process that defines workstation capabilities and tool theoretical outputs. Also required is a factory capacity model, linked to the business plan that projects the required OEE by toolset, which supports the business objectives of the operation [7].

2.7 Summary

This chapter provides a summary of literature review and research finding relevant to the topic. The background and purpose of TPM, OEE, E10 state and CBM are also described.

Most of the literature available on Overall Equipment Effectiveness, currently, attempt at measuring OEE only at equipment level. It is a very challenging task to understand networks of equipment as they occur in modern factories that consist of highly complex manufacturing systems.

This project will develop and implement a data acquisition tool which can determine the factory metrics in the manufacturing line based on lean manufacturing and TPM. This method employs two important components namely OEE and Key Process Input Variable (KPIV) and a computer software that analyzes the performance of the production systems based on these metrics. This tool should be able to identify areas that can be improved in the current system in order to increase productivity.

CHAPTER 3

METHODOLOGY

3.1   Introduction

This chapter will describe how the project is carried out. Throughout the project, discussions and brainstorming on the problem identification, development and implementation of the system has been held with the Equipment, Process, Operation and Industrial Engineering department in order to get a good understanding, information, and new ideas. The equipment and software vendors also have put their expertise into the project through discussions.

For the planning of the project Gantt chart in Microsoft Excel was used. There were also regular project meetings with the supervisor to make sure that everything went on as planned and any problem was dealt with immediately

Table 3.1 shows the planning of the project. During the project, different phases overlapped each other much more. During Project Part 1, feasibility study was planned, and it was carried out during the following twenty weeks before the documentation and writing of the project.

Table 3.1 : Project time table

Part 1	
Week 1~4	Preliminary meetings
	Literature studies
	Background theory
	Previous studies
Week 5~6	Planning
	Problem formulation
	Objective and scope
Week 7~9	Review on project methodology, tools and techniques
	Identify and select case study
	Begin project implementation
Week 10~14	Prepare draft 1
	Part 1 presentation
Part 2	
Week 15~25	Project completion and fine tuning
	Data collection and analysis
	Prepare draft 2
Week 26~35	Interpretation of results
	Discussion and conclusion
	Suggestion for future work
	Final draft
Week 36~40	Project report completion
	Final presentation

3.2   Literature Studies

The literature studies covered in this project include DAQ, TPM, OEE, E-10 state implementation and cross-functional teams. The information was found from articles and books at Universiti Teknologi Malaysia eLibrary and internet. Past projects were also studied.

3.3   Data Collection

To gain better knowledge of the equipment and process at the pilot line, existing data sheets which had been collected since March 2008 was analyzed. The process and equipment engineers answer and discuss questions regarding the operations and processes of the machines.

The collected data has been analyzed based on methods from literature review. OEE was used to improve data collection, and arrange and start up the meetings. The monitoring tool was put into practice when working in eliminating major losses and improving the largest problem area of the machines. It was also an important tool when making Root Cause Failure Analysis (RCFA).

All information obtained was used to perform an analysis of the current situation. The analysis is based on the theories and data collection from machine performance. From the analysis a number of recommendations for the monitoring tool were developed.

3.4   Experiment Area

3.4.1 Introduction

The equipment development department at the case study factory has over the past two years been in a reactive rather than proactive mode with respect to equipment reliability. Therefore the team was engaged in a project to study different areas which urgently need improvement. Implementation of equipment monitoring and reporting tool was one important area that must be improved.

The area chosen as a pilot area for the improvement project was MA17 production line, which is part of the new factory expansion. The process of this line is identical to other existing production lines although some of the machines are different and more advance.

The project was implemented with cross functional meetings from all departments involved in the tooling, production, maintenance, and engineering. The collection of production data was improved with the integration and automated system.

The production department should continue working on the tool and propagating it to other production lines. To do this they need to find a new driving force, educate users about the tool and OEE and focus on the collection of accurate production data.

Much can be done with increased knowledge about manufacturing processes, but the focus of the project is the search for increased Overall Equipment Effectiveness (OEE). OEE is a benchmark based on machine availability, performance and quality. This approach will result in a better benchmark than using uptime and throughput.
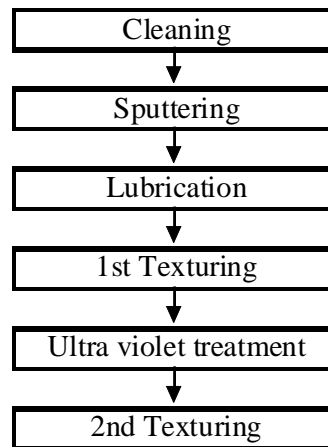
The first part of the project focused on logging of events in a production line. The data can be analyzed to figure out where unnecessary time is wasted. With figures and numbers it is easier to make decisions on what problems should be prioritized and if investments in improvements will be cost effective.

The second part of the project focused on improving process quality. Increased process quality is important to reduce scrap and to improve the product by reducing the amount of defects and to get a better finish.

Without a focus on integrating information collection and knowledge about processes at MA17, the benefits from thinking lean will be reduced. Lean manufacturing needs a well defined feedback from the production system to show its full potential. This is a key principle in lean manufacturing and a necessity to increase the amount of tasks done at MA17 which can be automated.

3.4.2 Production Line Structure

At MA17 the integration of information was one area of focus when the new production line was constructed in 2008. The production line consists of seven main machines. These are IS17, MA17, MAD17, MA17 ACD, H17-1, MA17UV and H17-2. Figure 3.1 illustrates the main manufacturing process.

```
┌─────────────────────────┐
│        Cleaning         │
└─────────────────────────┘
             ↓
┌─────────────────────────┐
│       Sputtering        │
└─────────────────────────┘
             ↓
┌─────────────────────────┐
│       Lubrication       │
└─────────────────────────┘
             ↓
┌─────────────────────────┐
│      1st Texturing      │
└─────────────────────────┘
             ↓
┌─────────────────────────┐
│  Ultra violet treatment │
└─────────────────────────┘
             ↓
┌─────────────────────────┐
│      2nd Texturing      │
└─────────────────────────┘
```

Figure 3.1: MA17 main processes

Figure 3.2 shows the MA17 design principle for the information network. The main goal for this information network was to gather equipment and production data, so that it can be analyzed. From the MA17 manufacturing line, the Key Process Input Variables (KPIV) and SEMI E10 information is gathered for each machine, so that it is possible to relate types of failures with relevant machine. This makes it possible to focus on stations where improvements have to be made.
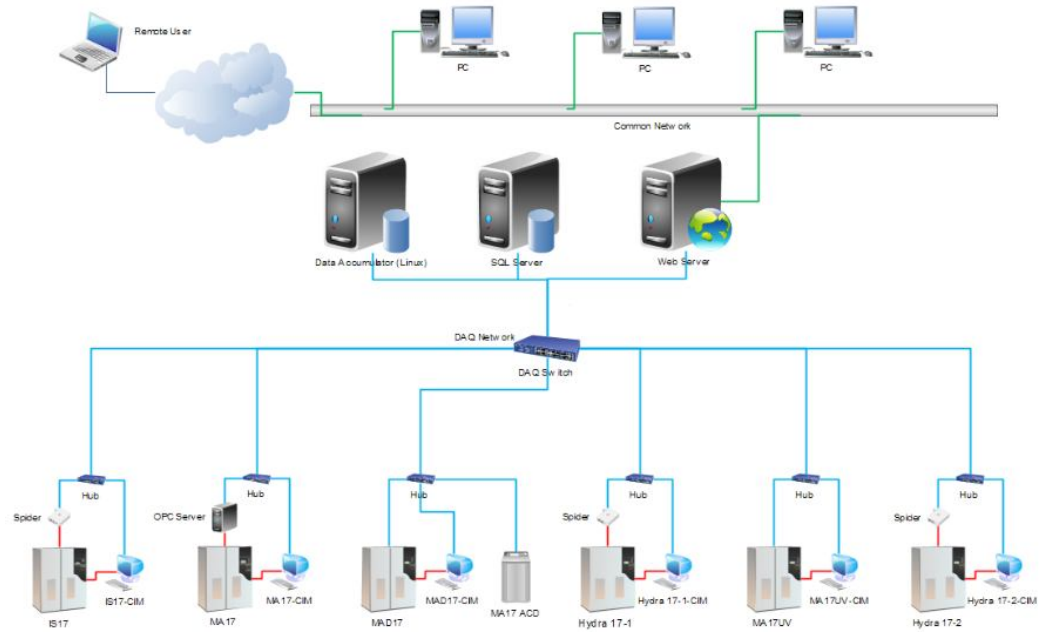
Figure 3.2: MA17 production line DAQ architecture

After the production line was operational, it was analyzed to find areas which could be improved to increase total output. People who work in production line had some ideas of how some processes could be improved, but no one knew exactly how the ideas would affect the output. To find the improvement potential of different ideas, the data collection system was analyzed. It was then discovered that the information level of detail was too low, and it was almost impossible to improve it. Bypassing manual data collection system and obtaining data directly from the PLCs made it possible to get data with sufficient level of detail.

The data collection system is also configured to create shift-reports where number of parts and quality is recorded. This system works well on a day-to-day basis, but it is still human dependent.

3.4.3   Experiment Methodology

Information collected from MA17 production system can be stored and analyzed on three levels.

The first level is the data level. Raw data can be collected from a large variety of sensors, and there are several methods for importing and storing these data onto a server to make them available.

Raw data alone are of no use, as a large set of numbers do not tell anything. Data has to be transformed to information. Information is data set into system. The data needs metadata which describes what the data represents, and how to interpret them. Other useful metadata is how the data was captured and who did it. Creating metadata is very important, as it has to describe the data so well that no information which cannot be recreated later is lost.

When the information is secured, it can be transformed to the third level which is knowledge. The information has to be analyzed to find out what they tell us about a system, and what conclusions can be drawn from them.

After information is secured and transformed into knowledge it is important to feed the knowledge back into the manufacturing system. This is the tough part, since the manufacturing system will never be as flexible and intelligent as human.

3.5   Summary

This chapter described how the project was organized, planned and executed. Information was obtained from literature, observations and discussions. There was already existing research on data acquisition and OEE.

CHAPTER 4

SYSTEM IMPLEMENTATION

4.1   Introduction

In this chapter the need for computation, network interconnection and data exchange to fulfill the needs of a monitoring tool at the production plant will be discussed.

4.2   DAQ Infrastructure

Data Acquisition (DAQ) presents the method of automatically generating reports for use in assessing reliability, availability and performance of a plurality of pieces of equipment in the trial line – MA17. The method comprises:

i.   Accumulating database events occurring in connection with the equipment;

ii.   Responsive to a data request having user selectable event restriction criteria, said event restriction criteria including a date range and a characteristic indicative of related ones of the equipment and

iii.   Mapping each event complying with said event restriction criteria to one of a plurality of predefined equipment states and accumulating time associated with the event in one of a plurality of time bins, each time bin associated with the predefined equipment states.

4.3   Hardware

4.3.1   Programmable Logic Controller (PLC)

A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of electromechanical processes. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. PLCs have built in communications ports usually 9-Pin RS232, and optionally for RS485 and Ethernet. [8]. At MA17, all equipment except for Texture 1 and Texture 2 is using Mitsubishi Q-series PLC and the Ethernet port is used for communication. Texture 1 and Texture 2 use TCP/IP protocol.

4.3.2   Human Machine Interfaces (HMI)

PLCs and other advanced production controllers are small black boxes with LEDs to show operation status. In order to make it possible for operators without knowledge on programming to understand what is going on, complex Human Machine Interfaces (HMI) have been developed. HMI is a computer program with a visual representation of the production cell on screen. The visual representation is often color-coded to show the parts of the production cell which is working, and the parts which need intervention. An intervention might be to refill a feeder, or fix a machine that has stopped. HMI also shows some statistics about current production, and have the possibility for some simple interaction with the production cell, start/stop, select current product and other functions. Computer Integrated Manufacturing (CIM) stations are available at all machines at the factory. The HMI software is loaded at MA17 CIM stations for users to view and input data.

4.3.3   Servers

The most important thing when collecting data is to store them for later use. If detailed data for a large production cell is to be collected and stored, it will very quickly accumulate very large amount of data. With a dataset as described above the complete information about what a production system does should be available. Often it will be enough with a smaller dataset, but with a complete dataset it is possible to calculate precisely how much time the production system has spent in different states, and where it is possible to improve the system. After the MA17 production system has operated and the performance indicators which describe the system status are known, they can be calculated on a regular basis thereby shrinking the size of the dataset.

4.3.4   Communication Link

The most common network topology for Ethernet is the star where many different computers connect through one main hub. This hub can again be connected to other hubs. Modern hubs, called switches, have intelligence and know which computers are connected on different ports, and they can handle much more data per second internally than the network speed. So if 4 computers are connected to a switch, computer 1 and 2 can communicate without disturbance at the same time as computer 3 and 4 can communicate. Dedicated network line is provided for MA17 DAQ purpose.

4.4   Software

4.4.1   Software Development

Software programs acquire data by interfacing with data acquisition hardware, either plug-in cards or standalone systems compatible with the data acquisition hardware, or a bridge must be used. The steps required to select a data acquisition software program are:

  i.   Determine the features and performance necessary to accomplish the task at hand;

  ii. Determine the available resources of time, money and expertise; and

  iii. Select the tools to perform the task.

After considering important aspect as shown in Table 4.1, outsourced programmer is engaged to develop the software. The software design and specification is developed constructed by the internal functional team.

Table 4.1 : Software development comparison

Attribute	Write own software	Outsource
Resources	Required	Not Required
Experience	Not available	Experienced
Lead time	Long	Short
Initial cost	Low	High
Risk of unstable program	High	Low

4.4.2   Software Design

The first step is to determine what data needs to be collected and what type of analysis and presentation is required for the data. Options range from simple plotting of an analog variable versus time to extremely sophisticated mathematical analysis of multiple analog and discrete values. Data analysis techniques can be divided into three main areas as shown in Table 4.2.

Table 4.2: Primary data analysis techniques

FEATURE	DESCRIPTION
Process monitoring	Analog and discrete data are collected and displayed in a graphical format. Data is usually displayed on a graph versus time, or another variable
Mathematical manipulation	Data is analyzed using various high-level mathematical techniques such as fast Fourier transform (FFT), curve fitting, filtering, etc.
Statistical analysis	Data is analyzed using various statistical techniques including X-bar and R-bar charts, frequency histograms, Chi-square analysis, etc.

For this project, process monitoring is used and typical application examples include:

i.   Monitoring the set point, the output, and the process variable versus time to aid in PID loop tuning;

ii.   Plotting one analog variable versus a second analog variable;

iii. Alarming variables when alarm points are reached, or when a variable exhibits certain behaviors such as rapid change in value;

iv.   Filtering variables to eliminate noise problems;

v.   Plotting historical data, including overlaying current data on historical data for analysis; and,

vi.   Comparing sets of measured variables to desired results (whether manually entered or automatically generated).

4.5 **Reporting and Charting**

Once data has been acquired, there is often a need to store it for current and future references. The dashboard provides a format for logging event and time data during a manufacturing period defined by an equipment engineer. Setting up dashboard input is the key to success in using the automatic Generic Equipment Model, GEM-generated method of equipment utilization logging. Basically, the dashboard must be configured to match the process state model of a specific piece of equipment being measured, or a group of equipment in the same class.

Analysis will enable equipment engineer to determine the amount of activity to store defined data by start and stop times, specified amount of production, shift, day or week. For example, an ad hoc page could filter each transition from execute to idle, terminating data collection at a given time or date.

With the stored data, the system calculates equipment utilization and time spent in nonproductive equipment activities, such as idle and set-up time. The calculation results can be displayed in pie charts, stacked bar charts, Pareto analyses, or other metrics of interest.

Engineers can use these output to determine equipment utilization in percentage emphasizing the percent of time spent in nonproductive equipment states. This determines where process or factory engineering work can be shifted for a higher percentage of productive or process-execute time. While pie charts are intuitively helpful, results could also be the output in a Pareto analysis to determine the sources and priorities of problems, or a stacked bar chart that shows how equipment utilization changes or improves over time.

4.5.1 Downtime Calculation

Machines will typically suffer short stoppages of just a few seconds when operating normally and long stoppages of minutes or hours when major disturbances occur. Downtime monitoring records every machine stoppage (equipment error, idle etc.), no matter how short, as an individual event. This allows every downtime event to be analyzed and offers a high level of detailed and specific information not always available in manual systems.

Each downtime event can be assigned a cause and also a comment. In practice a time allowance is set for each machine to differentiate between a short and long stoppage. When a machine has been stopped longer than the preset time a reason must be assigned to the event. For example, if equipment was idling for more than 30 mins, the reason for the idling should be assigned. A machine interlock can be used to prevent the machine from being restarted until a downtime reason is entered. This ensures that the operator enters the reason for the stoppage at the time it occurs and not at the end of the shift when they may have forgotten or feel tempted to alter it. For this project, existing CIM stations was used to block machine operation if there is no assigned reason. Over-rides are allowed for changeover, maintenance and setup periods.

Short stoppage time is often viewed as negligible but when it is recorded accurately it could be large and is frequently found to be a major factor in lost production. Reducing short duration stops not only increases efficiency but also eases the burden on operators resulting in improved man-machines ratio.

Downtime reasons are multi-layered allowing any upper level reason to have multiple sub options. For example upper level of idle can be caused by no inventory, break, awaiting result etc. Multiple reasons can be assigned to a stoppage if the reason for the downtime changes during the stoppage. Comments can be added to

downtime events, either when the stoppage occurs or at a later time. These can provide specific information about a stoppage to aid fault identification, diagnosis and repair etc.

Example of second level downtime cause are no inventory, break or idle can be selected from pull down lists on the terminal display or keyed in as a short code. Where possible downtime reasons are also captured automatically from PLC's and associated control equipment.

Each machine has unlimited user defined downtime causes stored and edited from the central PC. This makes it easy to manage downtime causes and any changes made appear instantly on relevant production terminals. This allows flexibility to continuously improve machine efficiency.

4.5.2　OEE Calculation

Utilizing OEE requires timely access to relevant data to enable an organization to measure its OEE score by drawing and analyzing data in real-time (or close to real-time) from production equipment, and presenting the data to plant operators and manufacturing management in a format that enables the data to be understood. This generally involves the implementation of an OEE solution in the form of software that draws and analyzes data from the production process, and presents it in an easy-to-use manner.

The formula associated with the method of calculating OEE include planned maintenance (scheduled downtime) and nonscheduled time. All equipment states data are obtained using the method as stated in the SEMI E10 guidelines.

The E10 standard which was used defined metrics for six basic equipment time bins: productive, standby, engineering, scheduled downtime, unscheduled downtime, and nonscheduled time as shown in Figure 4.1. The equipment itself, via GEM default activity messages, only knows whether it is in standby, productive, or unscheduled downtime because of a fault. For other time bins, the equipment does not know how to define its state or condition. In these cases, either the equipment operator or the factory host computer must define the correct time bin to be filled.
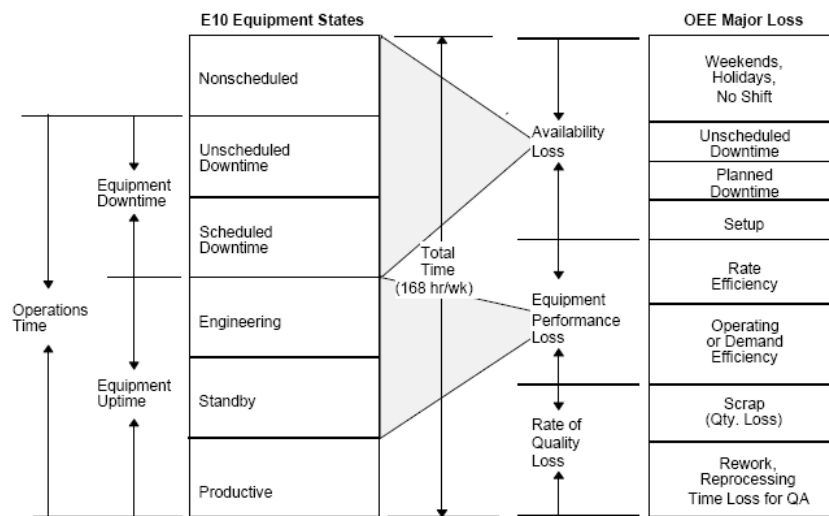
Figure 4.1: E10 States and OEE correlation [8]

The proposed tool uses automatic feeds to monitor machine start/stop, fault signals and product waste with additional input from the operator to provide meaningful information about the cause of stoppage. Some details like planned production time and theoretical cycle time have to be entered into the system, but the rest of the data is collected from the production equipment.

Figure 4.2 shows details the measures factored into the OEE metric, breakdown of the six major losses and formula.

Equipment
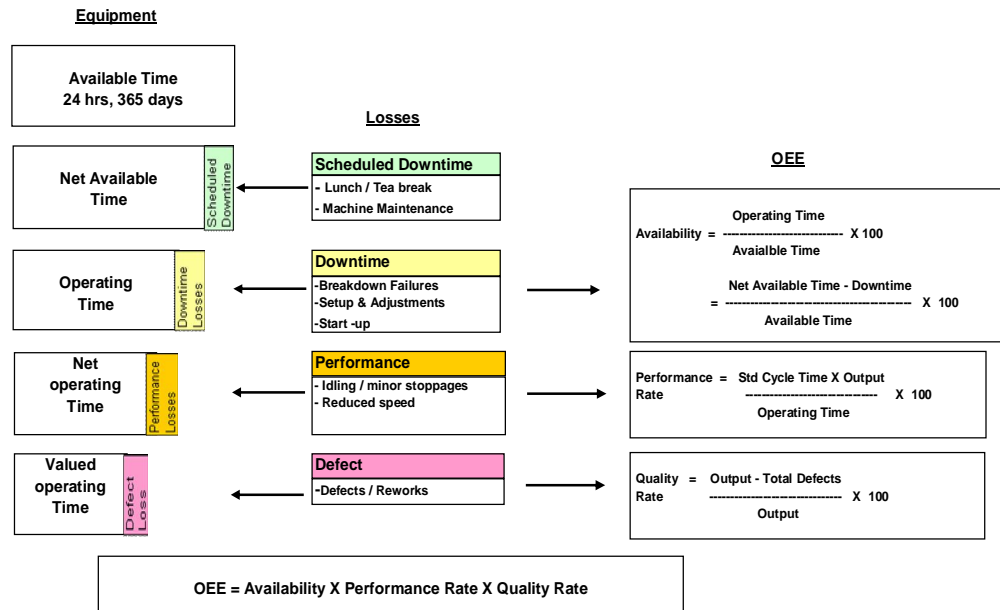
Figure 4.2: OEE breakdown and formula

For example B shift in the factory operates for 8 hrs / day with one tea break for 10 mins only. A cleaning machine in the line is on scheduled maintenance for 10 mins. Due to stringent quality standard, only 8 lots were found to be defective. The machine encountered one breakdown for 20 mins and only one conversion was carried out within 40 mins. Total output at the end of the shift includ defective lots was 400. Ideal cycle time of the machine is 0.5 mins / lot. Figure 4.3 illustrates how OEE is calculated for the given example. Assume all information except for quality loss is automatically obtained from the equipment. The quality loss is entered by the user using HMI.

Availability, A		
A Available Time		480
B Scheduled downtime		20
C Net Available Time	(A-B)	460
D Downtime Losses		60
E Operating Time	(C-D)	400
F Availability	(E/A)	83.33%
Performance Rate, P		
G Output		400
H Ideal Cycle Time		0.5
I Performance Rate	(H*G) /E	50.00%
Quality Rate, Q		
J Total Defects		8
K Quality Rate	(G-J) /G	98.00%
L **OEE = A * P * Q**		**40.83%**

Figure 4.3: OEE calculation example

4.6   Summary

This chapter describes the method and system of automatically and accurately generated reports based on a given set of parameters. Automatic downtime capturing methodology and OEE formulation based on SEMI E10 guidelines has also been explained.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This project has been carried out at production department and the decisions and recommendations made are to be implemented, evaluated and documented for future use.

The actual project duration was longer than planned. The main reason was due to delay in getting people to understand the importance of the project. The production volume was also reduced due to economic slowdown and project line MA17 was not fully utilized. MA17 was on planned shutdown most of the time and this has affected data collection. As a consequence, direct improvement from the project implementation could not be justified. From data simulation, benefits and return of investment is discussed in this chapter.

5.2   Benefits of the Project

5.2.1   Easy Access

System information can be viewed wherever needed, throughout the plant or remotely over any distance. This allows performance of MA17 line to be accessed by the head office in US, overseas division or even from home PC. User passwords and privileges ensure secure access with all actions recorded by the system.

The key to running a factory is obtaining up-to-the-minute information about the operation. The monitoring tool provides a method to rapidly view data relevant to the user's interest. The user can readily access data from any time period with or without an alarm event.

The tool automatically monitors, displays and saves critical process parameters from the integrated MA17 machines. The real time monitoring reduces time and effort in manual data collection and compilation and helps operation, process engineering and maintenance managers.

Table 5.1 summarizes the data that can be accessed from the tool. Sections 5.2.2 will describe what data and how it can be accessed.

Table 5.1: Top level selection

Top Level selection	Description
Administration	Configuration/parameter setting page. For authorized personnel only
Executive dashboard	Provide quick glance of production line/equipment performance and status
Operations	Provide detail equipment and process data
Report	Provide operation report
Ad Hoc Query	Able to perform query based on selection
Documentation	User guide and technical information

5.2.2 Escalation and Notifications

The tool provides alarm capabilities to designated users based on out of range data from equipment and process parameters. The server can be configured to send out email or paging notification whenever alarm conditions are met. Email addresses or pager number provided during the initial setup by the user will be used to send alarm notifications to the respective user.

The notification sent by the server contains basic description of the alarm condition, the machine on which the alarm condition triggered and a link to the screen that will contain details of the parametric data that triggered the alarm message.

As an example, Figure 5.1 shows the alarm email notification obtained from IS17 due to Tank 2 flow rate is above normal. Detail information on the alarm can be viewed from the path given or alternatively by accessing the monitoring tool. The instantaneous notification helps the engineer and technician to attend to the problem immediately and thus reduce the process error or equipment downtime. Before this, they have to wait for manual triggering by the equipment operator which is usually slow and gives inaccurate description of the problem.

Escalation of alarms will be sent to higher management in the organization if the alarm is not acknowledged within a preset time interval. The tool also provides additional facilities for improved maintenance efficiency by automatic alert when maintenance is due.

FactoryLOOK Process Alarm Notification

Following parameters generated process alarms:

Tank 2 : Tank 2 Flow Rate - Above Normal

To access FactoryLOOK, click here http://172.23.50.191/FactoryLOOK/
Select: Machine
Select: Alarm List tab
Select: Alarm Description link from list

PLEASE DO NOT REPLY TO THIS MESSAGE.
THIS IS A SYSTEM GENERATED MESSAGE AND THIS MAILBOX IS NOT MONITORED.

Figure 5.1: Example of alarm email notification

5.2.3   Real Time Equipment Event Monitoring

A user can view the causes of equipment downtime in various methods. Figure 5.2 illustrates the decision tree to show the structure of choosing machine state related data. Users can start from a higher level dashboard and focus to the operation or machine level to conduct more detailed analyses.
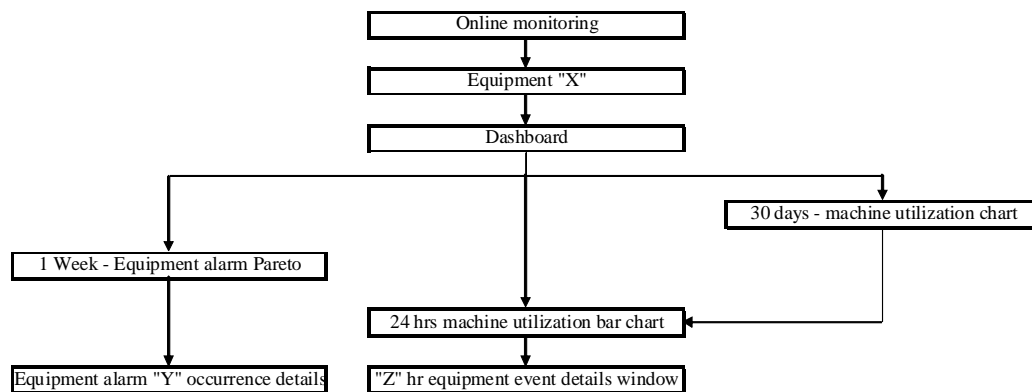
Figure 5.2: Decision tree of equipment event monitoring

Figure 5.3 shows an example of dashboard IS17. The 24-hours machine summary chart represents the equipment state for the most recent 24 hours. Each bar represent 1 hour summary of the equipment state by colour code (green-production mode, red-equipment breakdown, blue- equipment idling, yellow-under maintenance or engineering and grey- DAQ not available). The 30 Days – machine utilization chart on the other hand represents the summary of IS17 utilization for the past 30 days.
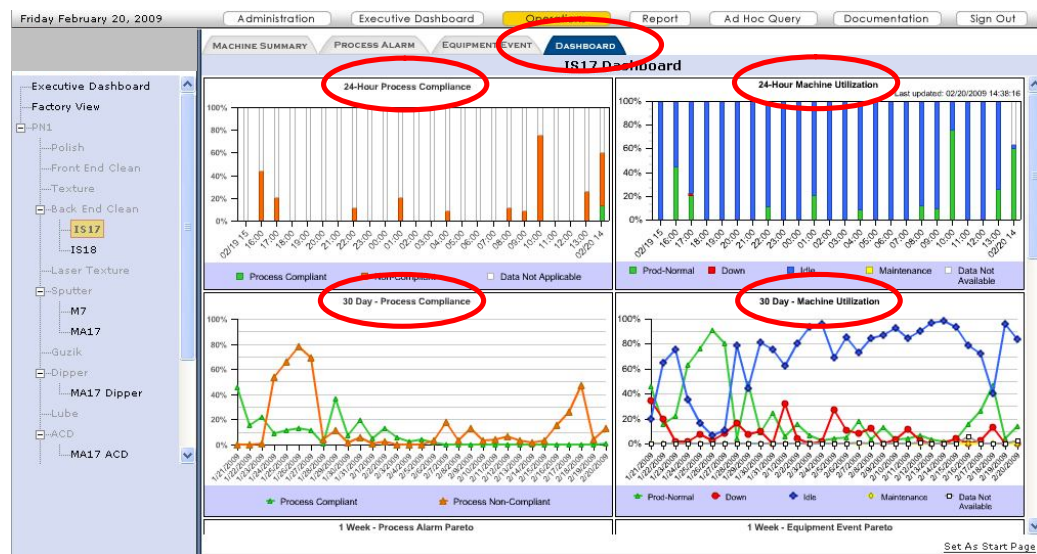
Figure 5.3: Equipment dashboard

For details of equipment state, the tool provides a list of downtime causing events for the time period of interest. Clicking the bar chart in the 24-Hr machine utilization chart on the dashboard will bring forth a pop-up page containing a list of equipment event as shown in Figure 5.4. The example demonstrates one hour of IS17 equipment state from 5 pm to 6 pm on 19 February 2009. The downtime events correspond to the specific one hour stated at the bottom of the screen. Such detail helps to identify production loss, hidden potential problem in a machine and deliver additional throughput by improving the overall performance of an equipment.
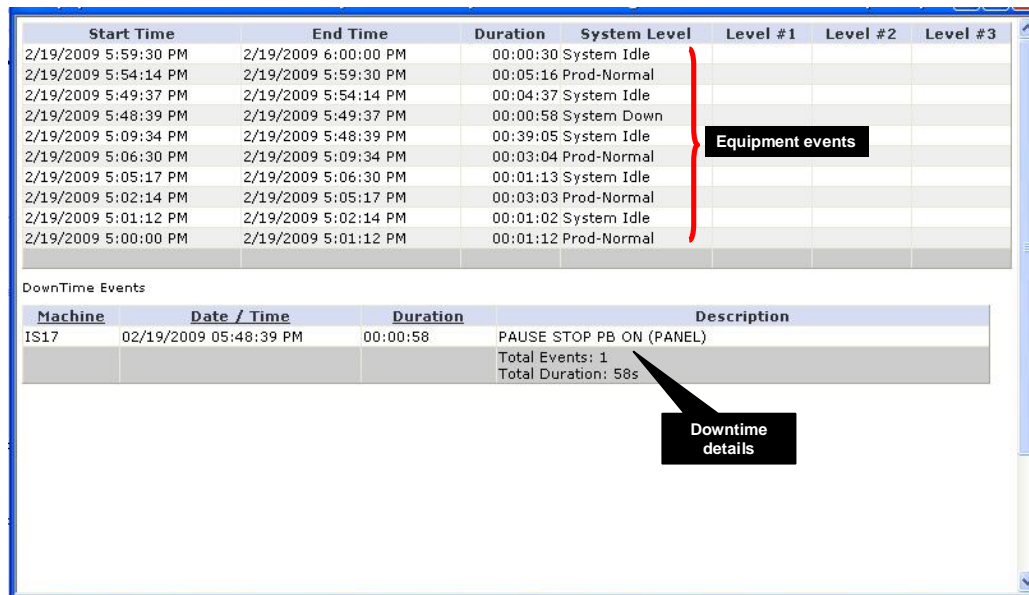
Figure 5.4 : Equipment event details window

To view the equipment events for a time period prior to the most recent day, the 30-day machine utilization chart used. Clicking on a red data point (triangle) on the line chart will bring forth a pop-up with the 24-hr machine utilization chart for that particular day. For example Figure 5.5 shows the 24hrs machine utilization chart of IS17 for 02 February 2009 once it was chosen from the 30-day chart.
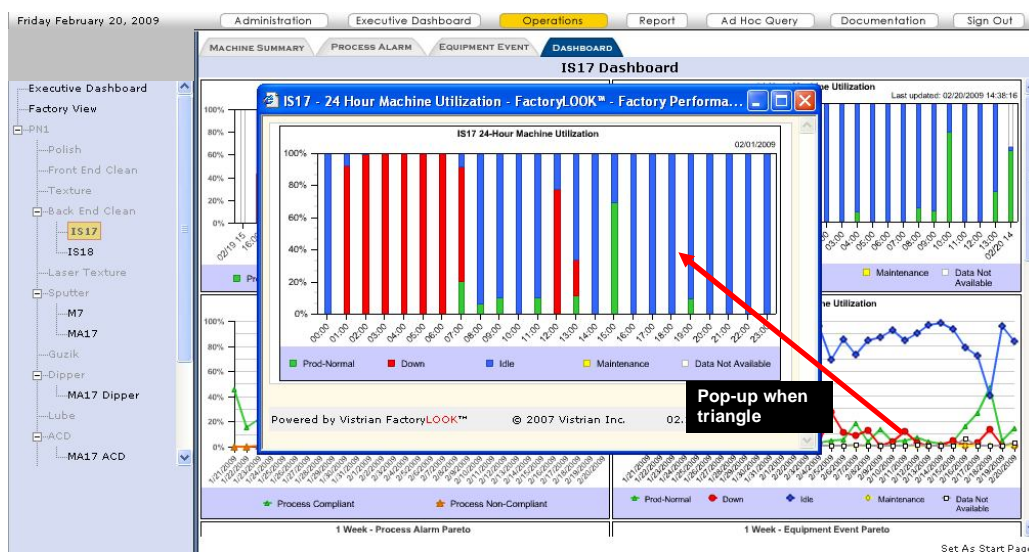
Figure 5.5: 24 hours machine utilization chart

By clicking on a 1 hr column on this pop-up, equipment events window will appear (Figure 5.4) and shows data and charts for that specific day.

The 1 week-equipment event Pareto chart on dashboard (Figure 5.6) shows the errors and its occurrences for the past 1 week. Clicking on the chart will show a pop-up with a detailed breakdown of all incidents in the prior week. Figure 5.7 shows the example of IS17 auto-run condition alarm occurrence for the past 1 week. It helps the engineers to focus on the most frequent error and resolve it to obtain better utilization.
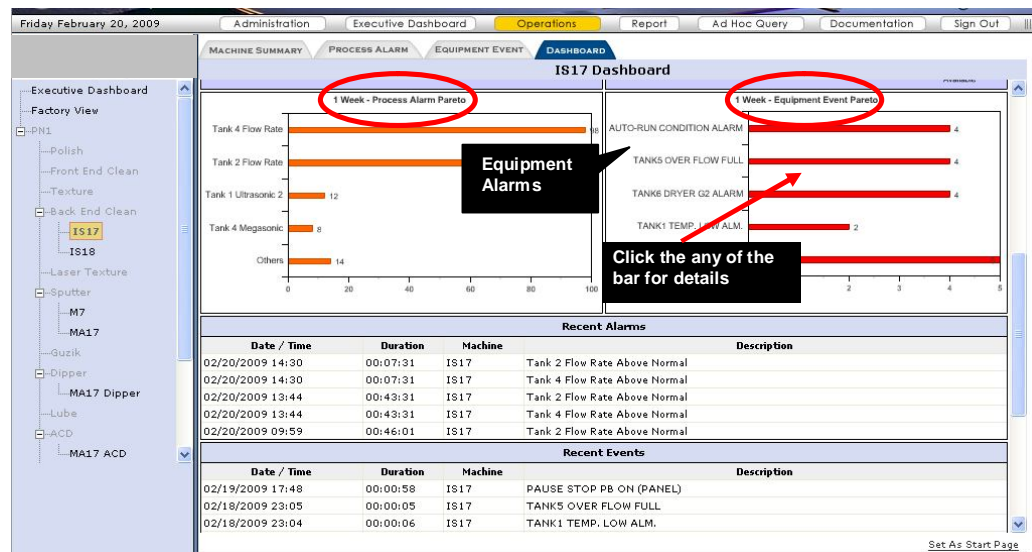
Figure 5.6: 1 week – equipment event Pareto
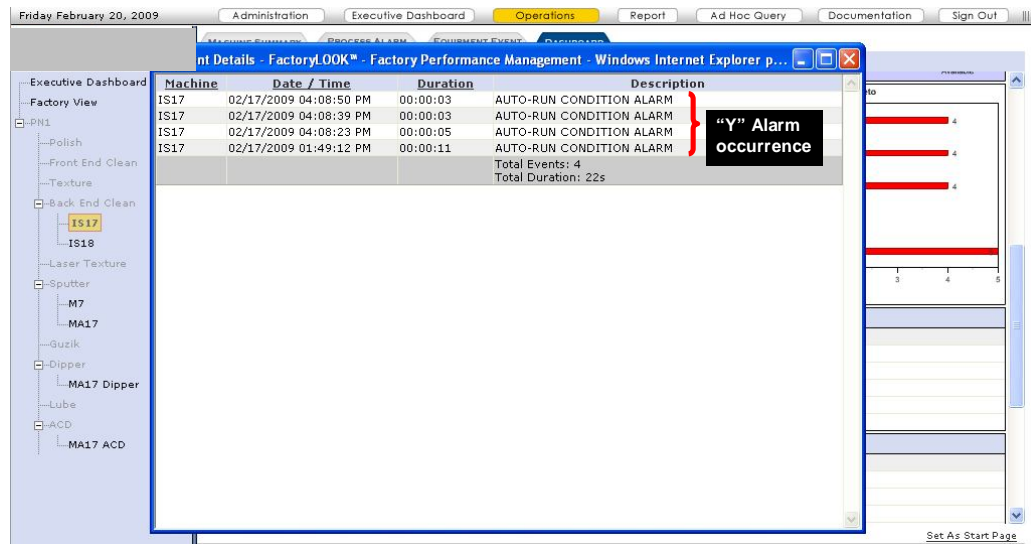
Figure 5.7: Specific equipment error occurrence details

5.2.4   Real Time Key Process Input Variables (KPIV) Monitoring

The dashboard also provides KPIV and process compliance monitoring. Figure 5.8 illustrates the decision tree to show the structure of choosing machine process related data. The behavior is similar to what was explained in Section 5.2.3, with process alarms instead of equipment events.
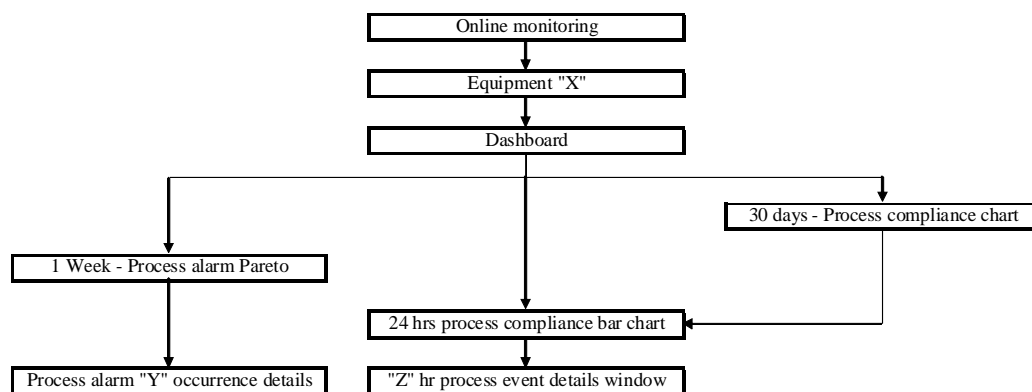
Figure 5.8: Decision tree of process event monitoring

5.2.5 Recent Equipment Alarm Details

Figure 5.9 illustrates the decision tree to show the structure of viewing equipment alarms list. From the equipment event page for a specific machine of interest, the user can view the equipment alarm data. Figure 5.10 shows the equipment alarms of IS17 for the specified period.
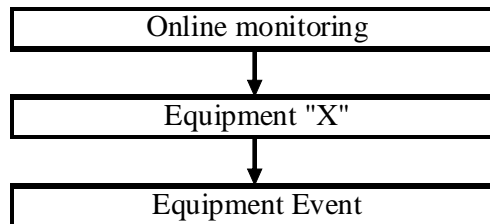
Figure 5.9: Decision tree of equipment alarm event list

Figure 5.10: Equipment event alarm list

5.2.6   Recent Process Alarm Details

Figure 5.11 shows the decision tree of the structure of viewing process alarms. From the process alarm page for a specific machine of interest, the user can view the process parameter data that triggered a specific alarm.

```
┌─────────────────────────────────┐
│       Online monitoring         │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│         Equipment "X"           │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│         Process alarm           │
└─────────────────────────────────┘
```
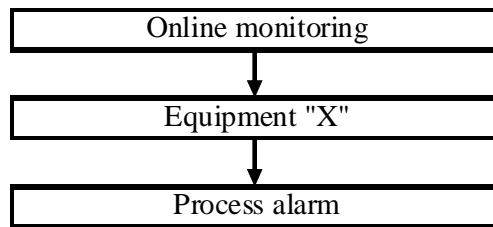
Figure 5.11: Decision tree of process alarm event list

Figure 5.12 shows 1 week process alarms of IS17 from 13 February 2009. Click on the description line of the alarm listing on this page will pop-up a window containing the relevant process parameter chart from the time period. Figure 5.13 shows an example of IS17 tank 2 flow rate out of specification. The green area represents within specification data while the data in red is of process non compliance. For this particular case, the process engineer manages to detect and correct the problem immediately and prevent production of bad lots.
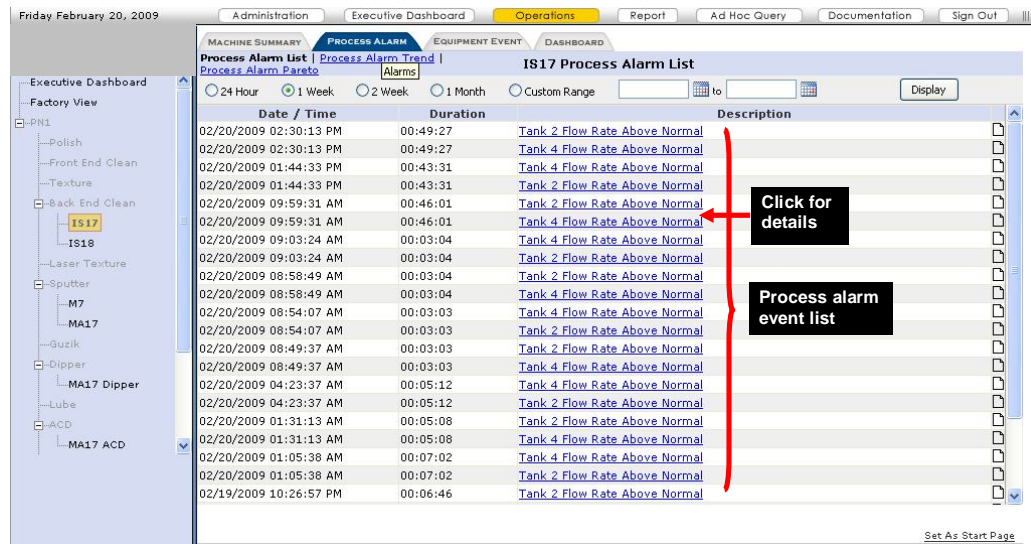
Figure 5.12: Equipment process alarm list

Figure 5.13: Process parameter chart

5.2.7 Historical and Live Process Data

The tool also provides the user with the capability to view process parameter data in the form of real time value or charts. Figure 5.14 illustrates the decision tree to show the structure of viewing live and historical data or charts. Charts are accessible from the machine summary screen of the selected machine by clicking on the button labeled "Live" or "Recent". The controls allow the user to set the refresh interval to suit his or her needs.
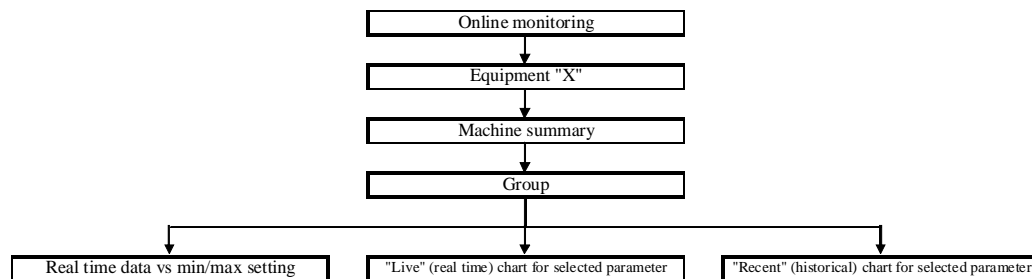
Figure 5.14: Decision tree for viewing real time and historical data or chart

The data are categorized in groups for easier viewing. The page shows minimum and maximum set point with association with the actual value. For example Figure 5.15 shows data of IS17 Tank 1 flow rate. The minimum is set at 130 lpm, maximum as 170 lpm and the actual value obtain from the machine is 148.7 lpm. This shows that the parameter is within process specification. Figure 5.16 shows the value of the flow rate in chart form when the live button is clicked.
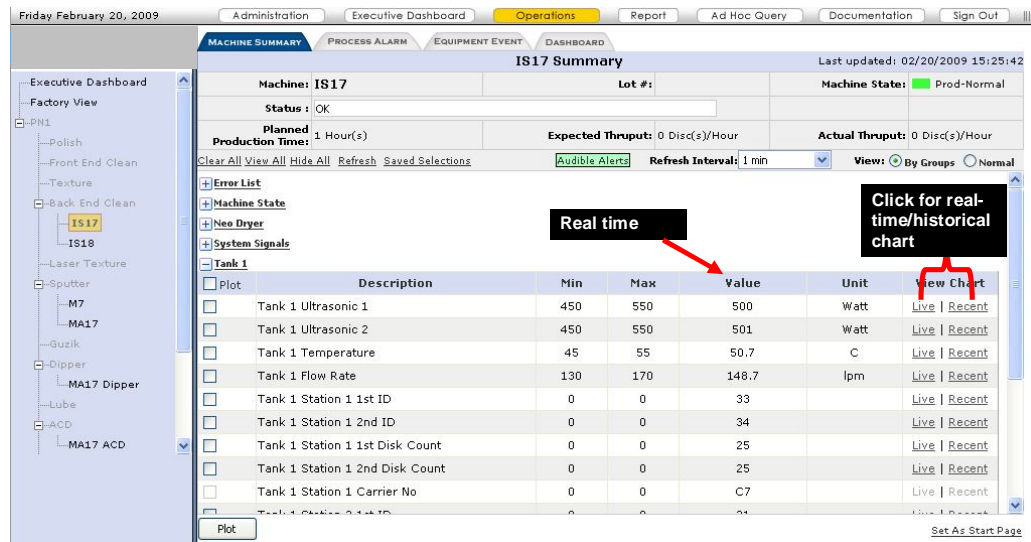
Figure 5.15: Machine summary page
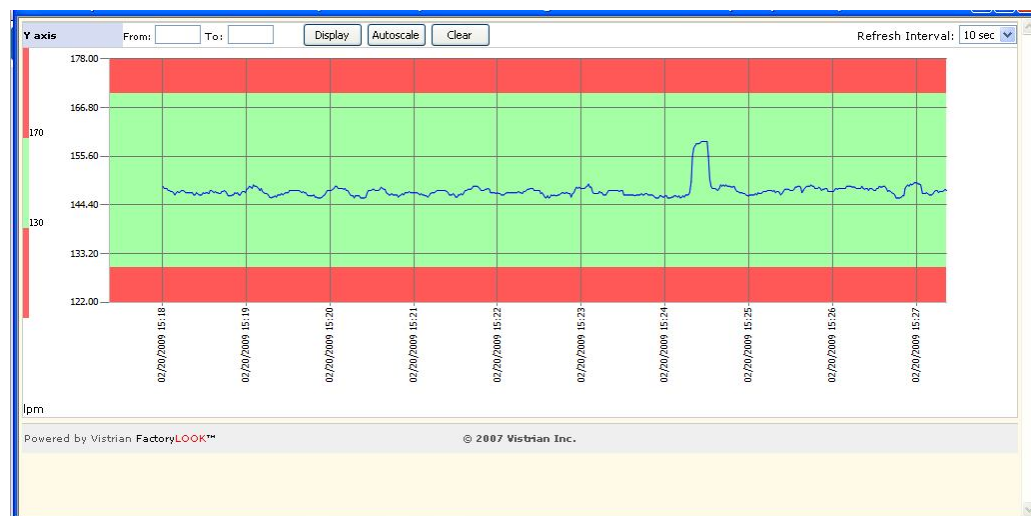
Figure 5.16: Real-time or historical chart

If the user is interested in historical data and to provide more options for chart manipulation, the "Recent" button can be clicked. Process data is displayed in a pop-up window. The navigation button can be used to locate the data segment of interest. Alternately, the date and time of interest can be entered to retrieve the data from the specified time period for display. Additionally, the cursor can be moved to the region of the data point and use the mouse click to zoom into a region of interest.

Figure 5.17 shows IS17 Tank 1 flow rate in historical chart form and how the abnormal pattern of the flow rate can be enlarged.
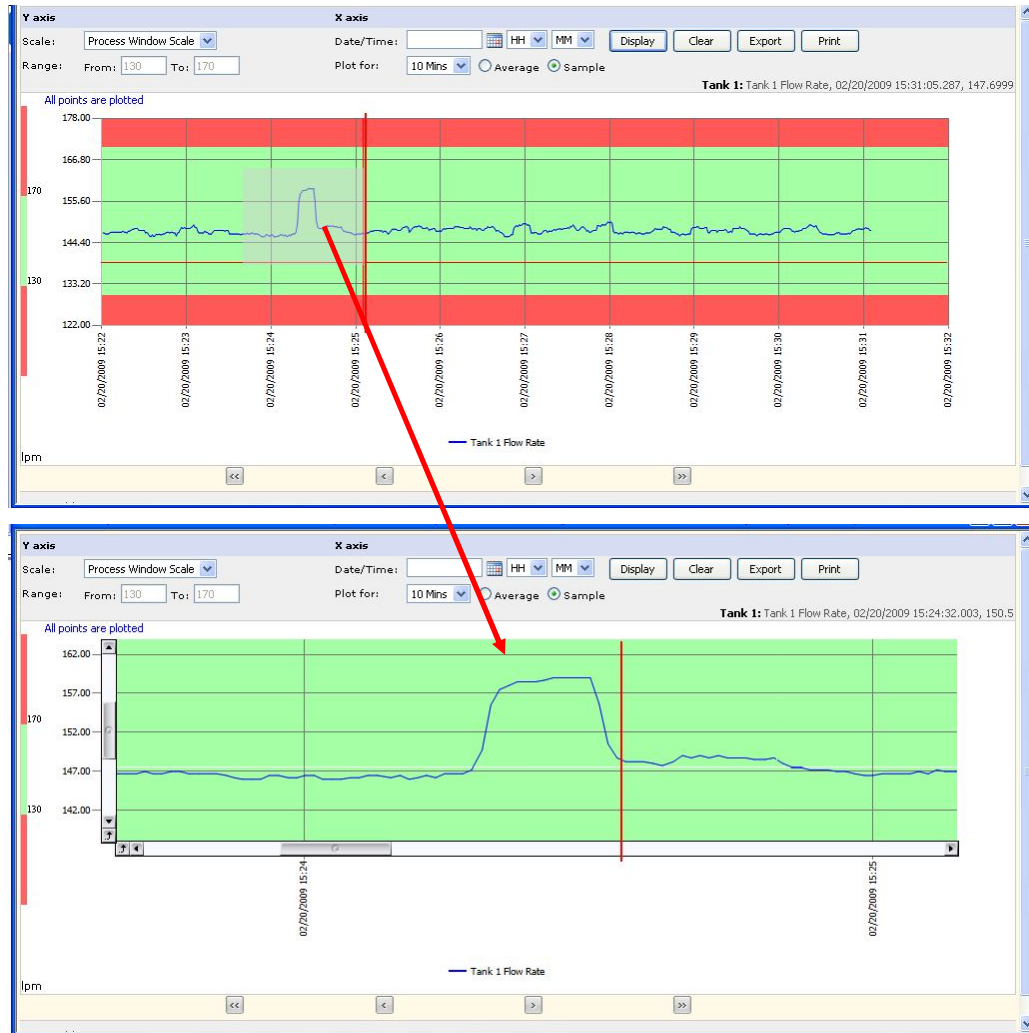
Figure 5.17: Historical chart with zooming features

5.2.7.1 Viewing Multiple Parameters in One View

The tool supports two methods of viewing multiple process parameters in the same screen as below:

i.   Single chart with as many as 4 parameters plotted in a line chart form

ii.   Multiple charts (up to 4 charts) with as many as 3 parameters each, plotted in a line chart form.

Figure 5.18 shows single chart with multiple IS17 parameters. Tank1 ultrasonic 1, ultrasonic 2 and temperature can be viewed in one chart for evaluation. Before this there was no such tool for engineers to assist them in their assessment.
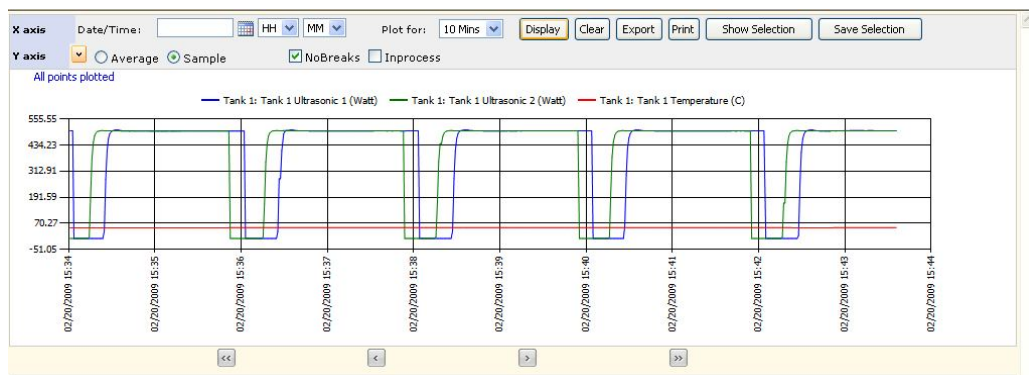
Figure 5.18: Single chart with multiple parameters

Figure 5.19 shows multiple charts of dissimilar parameters with different units of measure. For demonstration purpose, some parameters from IS17 machine summary are selected and the screen is shown in Figure 5.19. The selections can also be saved by clicking the "Save Selection" button.

.
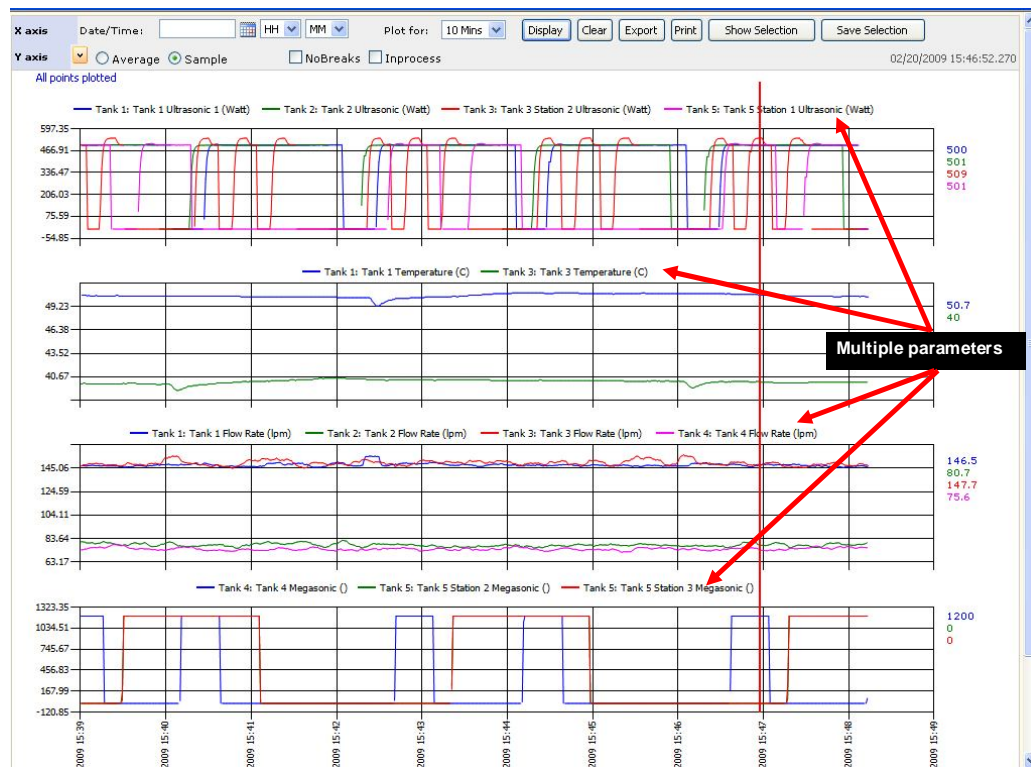
Figure 5.19: Multiple chart with dissimilar parameters

5.2.8 Customized Operation and Equipment Report

Downtime or production reports across machines, shifts, production lines, products, operators, reject rates etc. are available instantly. Fully customized reports can combine text, graphics and trends and cover any time period, shift, day, month etc. They can be produced on demand or at preset times and can be sent to a printer, email, fax and even published in the internet.

Figure 5.20 shows the example of IS17 report. User can select the machine, date or preferred shift for reporting. A click on the view details button will show the detail events for the chosen period of time. For example Figure 5.21 shows the detail event report for IS17.
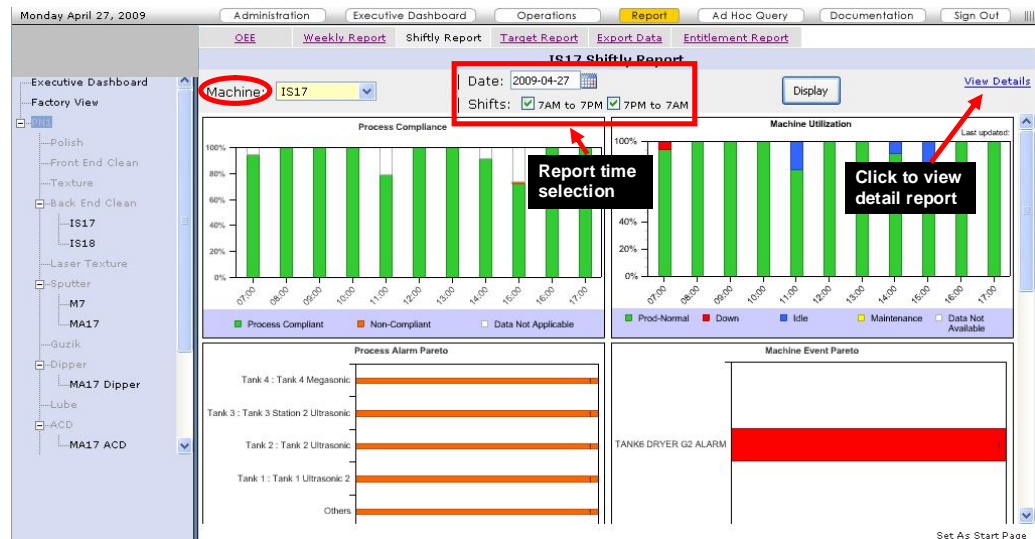
Figure 5.20: Main report page

Figure 5.21: Detail event report page

5.2.9 Overall Equipment Effectiveness (OEE) Report

The formula associated with the method of calculating OEE include planned maintenance (scheduled downtime) and nonscheduled time. All equipment data are obtained using the method stated in SEMI E10 guidelines. Some details like planned production time and theoretical cycle time have to be entered into the system, but the rest of the data is collected from the production equipment.

Availability calculation is based on E10-states nonscheduled, unscheduled and scheduled downtime. Nonscheduled downtime is set using the entitlement page at administrator window. Figure 5.22 show the example of IS17 entitlements. The schedule downtime is obtained by HMI. For example, once user selects maintenance in IS17 HMI (Figure 5.23), the selection will map with the E10 setting of IS17 (Figure 5.24) and formulate the scheduled downtime. The unscheduled downtime is obtained directly from the equipment when is goes into alarm. Figure 5.25 shows an example of the system downtime signal obtained from IS17.

Figure 5.22: Entitlement configuration page for nonscheduled calculation

Figure 5.23: Human machine interface (HMI) window

Figure 5.24: Equipment to E10 state mapping

Figure 5.25 : System signal showing real time equipment state

The performance calculation is based on E10-states of standby (idle) and engineering. Similar to unscheduled down time method, the idle state is also obtained automatically from the machine. The engineering time is again formulated using the HMI.

Since the factory does not rework defective product, the quality rate is purely based on number of lots scrapped. This information requires user input. User needs to key-in the loss data (quality rate) in the HMI as shown in Figure 5.26.
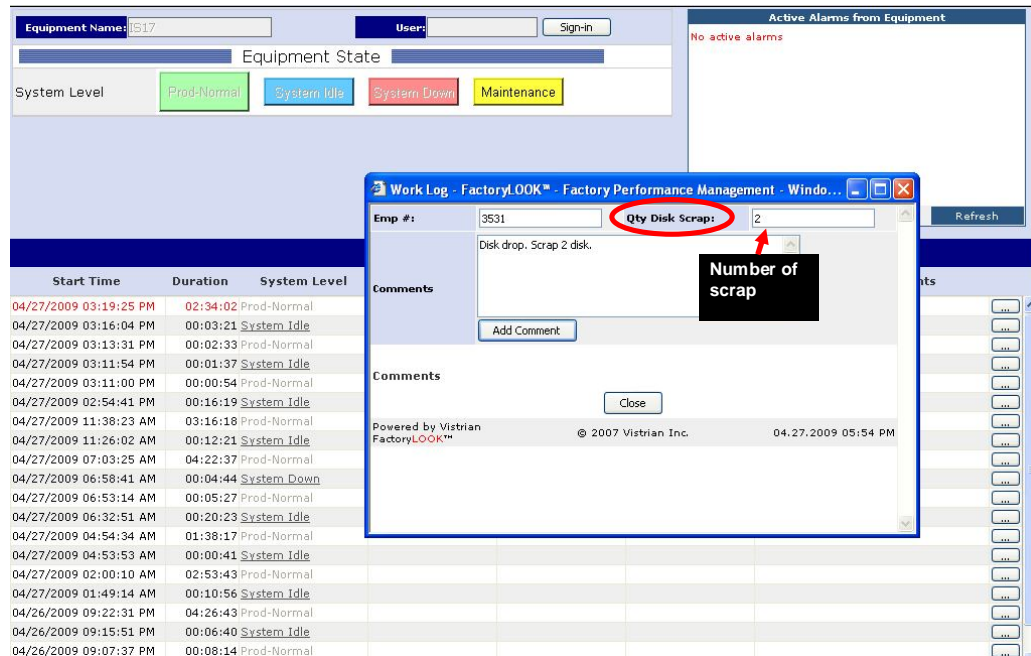
Figure 5.26: Human machine interface (HMI) comment window

All OEE components are calculated based on E10 state and published in the operation dashboard as well as in the report dashboard. Figure 5.27 shows an example of OEE pie chart in IS17 operation dashboard and Figure 5.28 shows OEE pie chart together with E10 chart in the report dashboard.
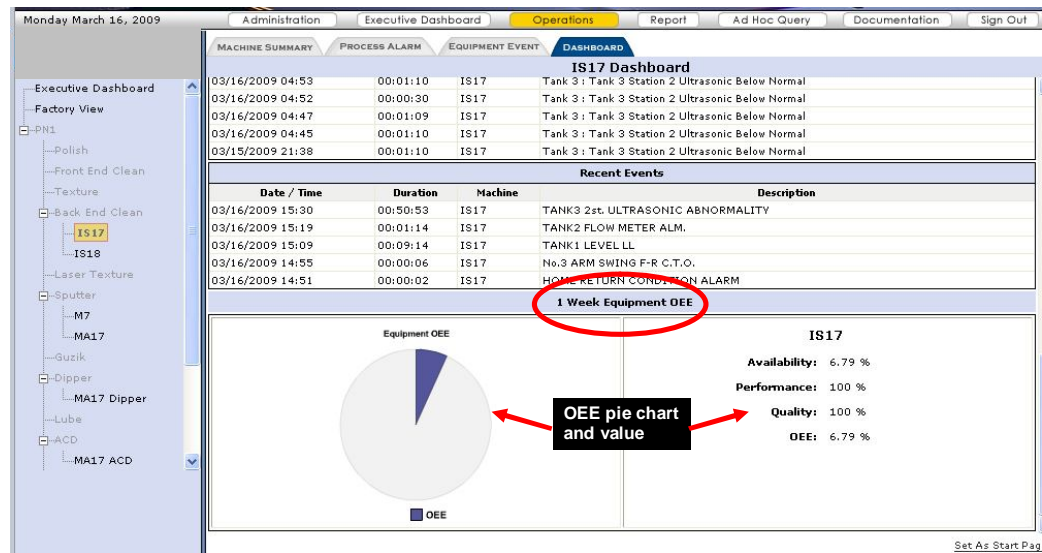
Figure 5.27: OEE report at operation dashboard
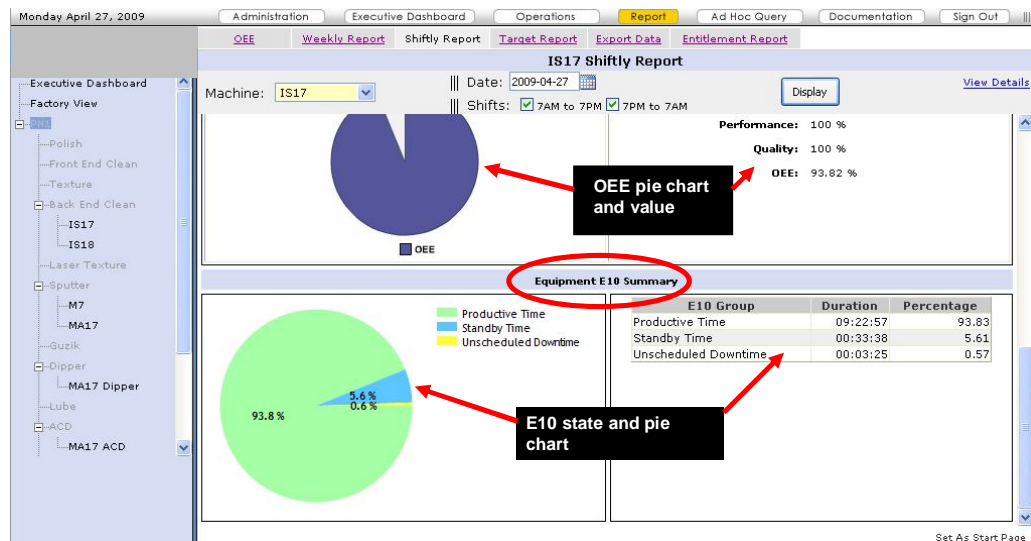
Figure 5.28: OEE report at report dashboard

5.3   Return of Investment (ROI)

From the information of product performance, cost performance and cost of implementation, the return on investment (ROI) can be estimated. In this case, the implementation costs would include equipment and other costs incurred by the company. This ROI technique is repeated for each MA17 equipment to provide insight into which improvements will provide the largest returns.

Table in Appendix A is used as a template to calculate the project ROI for individual machines. The throughput and actual cost of the equipment and product is provided. The labor cost for maintenance, operations and engineering are formulated based on average values as it varies for each employee. Spares, consumable cost and equipment life is assumed based on previous experience. The improvement of the tool is entered in the columns in yellow and the spreadsheet will automatically calculate and express the payback in months. Table 5.2 shows the summary of each equipment's ROI. The detailed calculation is attached in the Appendix B to M.

Table 5.2: ROI summary

Equipment	Pay back (month)
IS17	0.7
MA17	1.9
MAD17	0.2
MA17 ACD	0.5
H17-1	0.3
MA17UV	0.8
H17-22	0.3

With a system typically costing just a fraction of the value of the machines it monitors, implementation makes real financial sense with fast return on investment. Capital expenditure on new equipment can often be eliminated by increasing the

utilization of existing assets. It offers short payback periods, typically within a few months.

5.4 Discussion

From the project result, the tool obviously demonstrates huge benefits but no actual significant utilization improvement could be measured at present. The assessment was conducted during global economic crisis and the prototype line MA17 was not fully utilized. All findings from this evaluation are only to demonstrate the workings of the system.

Much effort was spent on sorting and preparing collected data for analysis and to develop the system for creating graphs to visualize OEE. It is difficult to create an on-line automated system to detect quality rate for OEE computation.

User interfaces was created for all production setups. For prototype line MA17 the database and user interface gave a good insight on how the production line functioned.

When designing the tool for MA17 production line, it was important to know the complete processes in a line, so that the features of the processes can be used to create a stable and flexible system. A cleaning process which is very fast should not be joined together with a slower, more stable process. The cleaning process should be able to build up a small buffer, which is large enough for the sputter process to feed from when the clean line has to be maintained.

5.5   Summary

This chapter has described the implementation and results achieved in the project. It explained the features and capability of the monitoring tool and described how automated OEE report is generated. Finally return on investment (ROI) analysis of the project was explained.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1   Conclusion

The objective of the project is to develop and implement of a monitoring instrument to deliver real-time equipment state, parameter including events, alarms and process control systems from a specified equipment. The tool helped to provide an easy-to-use interface solution for real-time equipment and process parameter monitoring. This work has the potential to be used for all production lines to minimize machine downtime.

With the proposed system a lot of information from the production line is available to engineers and operators. It is also possible to summarize and aggregate data and make it usable by other personnel involved in production system and at different stages of the production systems life-cycle.

The data gathered from the production system is of use to different parties of the production system. The information needs can vary between personnel, but they all can get the information from the base data collected.

The project focuses on optimizing the utilization of the production line. The basis of the work done is based on the idea that a defined system can be in 4 states. It can either be processing (production), wait for parts to enter the system or wait for a downstream process to accept input (idling), or there can be an internal downtime (system down or maintenance). Using this basis it is possible to define a system boundary and to define whether a system is a bottleneck, upstream of a bottleneck, or downstream of a bottleneck.

The proposed data collection will quickly give information about the stability and performance for the production system, so that potential problems can be identified early on. Problems need to be identified early so that changes required are easy to implement and do not require major change in the system setup.

6.2   Recommendations for Future Works

The results from data logging are very promising although the results from the tool can't completely be used at this moment due to low demand and uncertainty in production planning. Some results such as average cycle time, and the duration of different states was utilized by the engineers. With these data it was easy for them to determine where more emphasis is needed to optimize the production line.

The results in this project shows great potential and several more functions could be incorporated within the system. Future recommendations include creating an automated system to detect quality rate for OEE computation. Although it is difficult to eliminate human interface, minimizing manual data input will lead to more accurate and reliable data.

There is a plan to correlate the KPIV and KPOV for lot traceability. This will help engineers to detect issues by lot using one system rather then drawing data from few different systems. Some methods to do this have been tested, but there are still many others that could be considered.

In the rollout phase auto shutdown features should be included. This can be done by integrating test result and sending signal to automatically shutdown equipment when the rules are met. It will help to prevent operation from continue producing bad parts.

Other recommendation is to integrate all manual tasks into the system. For example, checklist could be made online and manage systematically. Triggers could be set to remind filling in the checklist at the same time eliminate the use of papers.

REFERENCES

1. W.J. Trybula, and Margaret Pratt. (1994). Applying SEMI El0 Guidelines to Manufacturing. *Proceedings 1994 IEMT Symposium., Sixteenth IEEE/CPMT International.* 12-14 Sep 1994. La Jolla, CA, USA, 309-310

2. Nakajima, S. (1988), *Introduction to TPM*, Productivity Press, Cambridge, MA.

3. Naguib and Schlueter. (1994) Conflicting Goals or Increasing Opportunities. *Semiconductor Manufacturing Conference and Workshop*, 1994. IEEE/SEMI, Volume , Issue , 23-25 Sep 1994, 55 – 60

4. Semiconductor Equipment and Materials International (SEMI). (1986). *SEMI E10 Guidelines*. San Jose, USA : SEMI

5. John Konopka and Walt Trybula. (1995). Utilizing Production Data to Increase Factory Capacity. *IEEE/CPMT Int'l Electronics Manufacturing Technology Symposium*. Sept. Montopolis Drive, Austin, 292-294

6. Wang, Qingsu, Zvonar, John, Simpson, and Mike. (1998). *United States Paten No. 574,0429* Washington DC: U.S. Patent and Trademark Office.

7. Sheta, A. F. and De Jong, K. (1996). Parameter Estimation of Nonlinear Systems in Noisy Environments Using Genetic Algorithms. *Proceedings of the 1996 IEEE International Symposium on Intelligent Control*. 15-18 September. Dearborn, Michigan: IEEE, 360 - 365.

8. Tom Pomorski. (1997). Managing Overall Equipment Effectiveness (OEE) to Optimize Factory Performance. *Semiconductor Manufacturing Conference Proceedings, 1997 IEEE International Symposium.* 6-8 Oct 1997. South Portland, Maine, USA : IEEE, A33 - A36

9. V. A. Ames, Jerry Gililland, John Konopka, and Rich Schnabl. (1995) *Overall Equipment Effectiveness (OEE) Guidebook*. SEMATECH

10. Laura Peters. (2004). Tighter Equipment Tracking for efficient Fabs. *Semiconductor International*, 2004

11. Konopka, J.M. (1995). Components, Packaging, and Manufacturing Technology*, Part A, IEEE Transactions*, Sep 1995. 484 - 491

12. Yuri Karzhavin. (2000). Productivity Improvement Focus at White Oak Semiconductor. *IEEE*, 2000

13. K. M. N. Muthiah and S. H. Huang. (2007) *Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection*. International Journal of Production Research. 2007

APPENDIX A

ROI calculation template

Return Of Investment (ROI) Calculation (USD)			
COST			
1	Equipment Cost ($)		
2	Product Cost ($/Unit)		
3	Throughput (units / hr)		
4	Maintenance Labor Cost / Hr ($)		
5	Operations Labor Cost / Hr ($)		
6	Engineering Labor Cost / Hr ($)		
7	Spares & Consumables Cost / Year ($)		
8	Equipment Life in Years		
EQUIPMENT PRODUCTIVITY BENEFITS			$0
	Utilization Improvement of and Spares Reduction		
	Utilization Improvement (%)		
	Equipment Cost Savings / Year		
	Spares Reduction (%)		
	Spares Savings ($)		
	TOTAL EQUIPMENT SAVINGS		
LABOR PRODUCTIVITY BENEFITS			$0
	Maintenance Labor Reduction / wk (hrs)		
	Operation Labor Reduction / wk (hrs)		
	Engineering Labor Reduction / wk (hrs)		
	TOTAL LABOR SAVINGS		
SAVINGS FROM QUALITY IMPROVEMENTS			$0
	Yield Improvement Conservatively		
	Yield Improvement (%)		
	TOTAL YIELD RELATED SAVINGS		
MARGIN FROM ADDITIONAL REVENUE			$0
	Additional revenue opportunity from increased utilization		
	Additional Throughput from Equipment Utilization (units/hr)		
	Additional Revenue from above		
	Additional Margin from above (20%)		
TOTAL BENEFIT / YR			$0
PROJECT COST			
Payback Period (months)			**#DIV/0!**

APPENDIX B

IS17 ROI pre-calculation

Assumptions

Maintenance technician (MT) = 7 for 3 systems with average cost of RM2200/month

Maintenance Engineer (ME) = 1 for 8 systems with average cost of RM3500/month

Operator (O) = 1 for each system with average cost of RM1500/month

Engineers (E) = 3 for 3 systems with average cost of RM3500/month

RM1 = USD0.2726

Pre-Calculation

Maintenance labour cost / Hr $= \dfrac{\Sigma MT * AC}{System*Days*Hours} + \dfrac{\Sigma ME * AC}{System*Days*Hours}$

$= \dfrac{7*2200}{3*30*24} + \dfrac{1*3500}{8*30*24}$

$=$ 7.13 $+$ 0.61

$=$ RM7.74

$\sim$ USD2.10

Operations labour cost / Hr $= \dfrac{\Sigma O * AC}{System*Days*Hours}$

$= \dfrac{1*1500}{1*30*24}$

$=$ RM2.08

$\sim$ USD0.57

Engineering labour cost / Hr $= \dfrac{\Sigma E * AC}{System*Days*Hours}$

$= \dfrac{3*3500}{3*30*24}$

$=$ RM4.86

$\sim$ USD1.33

APPENDIX C

IS17 ROI calculation table

Return Of Investment (ROI) Calculation (USD)		
COST		
1 Equipment Cost ($)	1,860,000	
2 Product Cost ($/Unit)	5.00	
3 Throughput (units / hr)	1500	
4 Maintenance Labor Cost / Hr ($)	2.10	
5 Operations Labor Cost / Hr ($)	0.57	
6 Engineering Labor Cost / Hr ($)	1.33	
7 Spares & Consumables Cost / Year ($)	16,740	
8 Equipment Life in Years	8	
EQUIPMENT PRODUCTIVITY BENEFITS		**$7,477**
Utilization Improvement of 3% and Spares Reduction by 3%		
Utilization Improvement (%)	3.0%	
Equipment Cost Savings / Year	6,975	
Spares Reduction (%)	3.0%	
Spares Savings ($)	502	
TOTAL EQUIPMENT SAVINGS	7,477	
LABOR PRODUCTIVITY BENEFITS		**$2,424**
Maintenance Labor Reduction / wk (hrs)	7	
Operation Labor Reduction / wk (hrs)	7	
Engineering Labor Reduction / wk (hrs)	21	
TOTAL LABOR SAVINGS	2,424	
SAVINGS FROM QUALITY IMPROVEMENTS		**$65,700**
Yield Improvement Conservatively at 1%		
Yield Improvement (%)	0.1%	
TOTAL YIELD RELATED SAVINGS	65,700	
MARGIN FROM ADDITIONAL REVENUE		**$394,200**
Additional revenue opportunity from increased utilization		
Additional Throughput from Equipment Utilization (units/hr)	45	
Additional Revenue from above	1,971,000	
Additional Margin from above (20%)	394,200	
TOTAL BENEFIT / YR		**$469,801**
PROJECT COST		**$27,000**
Payback Period (months)		**0.7**

APPENDIX D

MA17 ROI pre-calculation

Assumptions

Maintenance technician (MT) = 14 for 2 system with average cost of RM2200/month

Maintenance Engineer (ME) = 2 for 2 systems with average cost of RM3500/month

Operator (O)= 1 for each systems with average cost of RM1500/month

Engineers (E) = 3 for 18 systems with average cost of RM3500/month

RM1 = USD0.2726

Pre-Calculation

$$\text{Maintenance labour cost / Hr} = \frac{\Sigma MT * AC}{System*Days*Hours} + \frac{\Sigma ME * AC}{System*Days*Hours}$$

$$= \frac{14*2200}{2*30*24} + \frac{2*3500}{2*30*24}$$

$$= 21.39 + 4.86$$

$$= RM26.25$$
$$\sim USD7.16$$

$$\text{Operations labour cost / Hr} = \frac{\Sigma O * AC}{System*Days*Hours}$$

$$= \frac{1*1500}{1*30*24}$$

$$= RM2.08$$
$$\sim USD0.57$$

$$\text{Engineering labour cost / Hr} = \frac{\Sigma E * AC}{System*Days*Hours}$$

$$= \frac{3*3500}{18*30*24}$$

$$= RM0.81$$
$$\sim USD0.22$$

APPENDIX E

MA17 ROI calculation table

Return Of Investment (ROI) Calculation (USD)			
COST			
1	Equipment Cost ($)	6,100,000	
2	Product Cost ($/Unit)	5.00	
3	Throughput (units / hr)	1380	
4	Maintenance Labor Cost / Hr ($)	7.16	
5	Operations Labor Cost / Hr ($)	0.57	
6	Engineering Labor Cost / Hr ($)	0.22	
7	Spares & Consumables Cost / Year ($)	54,900	
8	Equipment Life in Years	8	
EQUIPMENT PRODUCTIVITY BENEFITS			**$7,900**
	Utilization Improvement of 1% and Spares Reduction by 0.5%		
	Utilization Improvement (%)	1.0%	
	Equipment Cost Savings / Year	7,625	
	Spares Reduction (%)	0.5%	
	Spares Savings ($)	275	
	TOTAL EQUIPMENT SAVINGS	7,900	
LABOR PRODUCTIVITY BENEFITS			**$3,054**
	Maintenance Labor Reduction / wk (hrs)	7	
	Operation Labor Reduction / wk (hrs)	7	
	Engineering Labor Reduction / wk (hrs)	21	
	TOTAL LABOR SAVINGS	3,054	
SAVINGS FROM QUALITY IMPROVEMENTS			**$60,444**
	Yield Improvement Conservatively at 0.1%		
	Yield Improvement (%)	0.1%	
	TOTAL YIELD RELATED SAVINGS	60,444	
MARGIN FROM ADDITIONAL REVENUE			**$120,888**
	Additional revenue opportunity from increased utilization		
	Additional Throughput from Equipment Utilization (units/hr)	13.8	
	Additional Revenue from above	604,440	
	Additional Margin from above (20%)	120,888	
TOTAL BENEFIT / YR			**$192,285**
PROJECT COST			**$30,700**
Payback Period (months)			**1.9**

APPENDIX F

MAD17 ROI pre-calculation

Assumptions

Maintenance technician (MT) = 13 for 8 system with average cost of RM2200/month

Maintenance Engineer (ME) = 1 for 8 systems with average cost of RM3500/month

Operator (O) = 1 for each systems with average cost of RM1500/month

Engineers (E) = 2 for 8 systems with average cost of RM3500/month

RM1 = USD0.2726

Pre-Calculation

$$\text{Maintenance labour cost / Hr} = \frac{\Sigma MT * AC}{System*Days*Hours} + \frac{\Sigma ME * AC}{System*Days*Hours}$$

$$= \frac{13*2200}{8*30*24} + \frac{1*3500}{8*30*24}$$

$$= 4.97 + 0.61$$

$$= RM5.58$$
$$\sim USD1.52$$

$$\text{Operations labour cost / Hr} = \frac{\Sigma O * AC}{System*Days*Hours}$$

$$= \frac{1*1500}{1*30*24}$$

$$= RM2.08$$
$$\sim USD0.57$$

$$\text{Engineering labour cost / Hr} = \frac{\Sigma E * AC}{System*Days*Hours}$$

$$= \frac{2*3500}{8*30*24}$$

$$= RM1.22$$
$$\sim USD0.33$$

APPENDIX G

MAD17 ROI calculation table

Return Of Investment (ROI) Calculation (USD)			
COST			
1	Equipment Cost ($)	180,000	
2	Product Cost ($/Unit)	5.00	
3	Throughput (units / hr)	1824	
4	Maintenance Labor Cost / Hr ($)	1.52	
5	Operations Labor Cost / Hr ($)	0.57	
6	Engineering Labor Cost / Hr ($)	0.33	
7	Spares & Consumables Cost / Year ($)	1,620	
8	Equipment Life in Years	8	
EQUIPMENT PRODUCTIVITY BENEFITS			**$691**
	Utilization Improvement of 3% and Spares Reduction by 1%		
	Utilization Improvement (%)	3.0%	
	Equipment Cost Savings / Year	675	
	Spares Reduction (%)	1.0%	
	Spares Savings ($)	16	
	TOTAL EQUIPMENT SAVINGS	691	
LABOR PRODUCTIVITY BENEFITS			**$1,121**
	Maintenance Labor Reduction / wk (hrs)	7	
	Operation Labor Reduction / wk (hrs)	7	
	Engineering Labor Reduction / wk (hrs)	21	
	TOTAL LABOR SAVINGS	1,121	
SAVINGS FROM QUALITY IMPROVEMENTS			**$399,456**
	Yield Improvement Conservatively at 0.5%		
	Yield Improvement (%)	0.5%	
	TOTAL YIELD RELATED SAVINGS	399,456	
MARGIN FROM ADDITIONAL REVENUE			**$479,347**
	Additional revenue opportunity from increased utilization		
	Additional Throughput from Equipment Utilization (units/hr)	54.72	
	Additional Revenue from above	2,396,736	
	Additional Margin from above (20%)	479,347	
TOTAL BENEFIT / YR			**$880,616**
PROJECT COST			**$15,350**
Payback Period (months)			**0.2**

APPENDIX H

MA17 ACD ROI pre-calculation

Assumptions

Maintenance technician (MT) = 6 for 8 system with average cost of RM2200/month

Maintenance Engineer (ME) = 1 for 8 systems with average cost of RM3500/month

Operator (O) = 1 for each system with average cost of RM1500/month

Engineers (E) = 1 for 8 systems with average cost of RM3500/month

RM1 = USD0.2726

Pre-Calculation

$$\text{Maintenance labour cost / Hr} = \frac{\Sigma MT * AC}{System*Days*Hours} + \frac{\Sigma ME * AC}{System*Days*Hours}$$

$$= \frac{6*2200}{8*30*24} + \frac{1*3500}{8*30*24}$$

$$= 2.29 + 0.61$$

$$= RM2.90$$
$$\sim USD0.79$$

$$\text{Operations labour cost / Hr} = \frac{\Sigma O * AC}{System*Days*Hours}$$

$$= \frac{1*1500}{1*30*24}$$

$$= RM2.08$$
$$\sim USD0.57$$

$$\text{Engineering labour cost / Hr} = \frac{\Sigma E * AC}{System*Days*Hours}$$

$$= \frac{1*3500}{8*30*24}$$

$$= RM0.61$$
$$\sim USD0.17$$

APPENDIX I

MA17 ACD ROI calculation table

Return Of Investment (ROI) Calculation (USD)		
COST		
1	Equipment Cost ($)	103,000	
2	Product Cost ($/Unit)	5.00	
3	Throughput (units / hr)	2000	
4	Maintenance Labor Cost / Hr ($)	0.79	
5	Operations Labor Cost / Hr ($)	0.57	
6	Engineering Labor Cost / Hr ($)	0.17	
7	Spares & Consumables Cost / Year ($)	927	
8	Equipment Life in Years	8	
EQUIPMENT PRODUCTIVITY BENEFITS			**$396**
	Utilization Improvement of 3% and Spares Reduction by 1%		
	Utilization Improvement (%)	3.0%	
	Equipment Cost Savings / Year	386	
	Spares Reduction (%)	1.0%	
	Spares Savings ($)	9	
	TOTAL EQUIPMENT SAVINGS	396	
LABOR PRODUCTIVITY BENEFITS			**$681**
	Maintenance Labor Reduction / wk (hrs)	7	
	Operation Labor Reduction / wk (hrs)	7	
	Engineering Labor Reduction / wk (hrs)	21	
	TOTAL LABOR SAVINGS	681	
SAVINGS FROM QUALITY IMPROVEMENTS			**$87,600**
	Yield Improvement Conservatively at 0.1%		
	Yield Improvement (%)	0.1%	
	TOTAL YIELD RELATED SAVINGS	87,600	
MARGIN FROM ADDITIONAL REVENUE			**$525,600**
	Additional revenue opportunity from increased utilization		
	Additional Throughput from Equipment Utilization (units/hr)	60	
	Additional Revenue from above	2,628,000	
	Additional Margin from above (20%)	525,600	
TOTAL BENEFIT / YR			**$614,276**
PROJECT COST			**$27,000**
Payback Period (months)			**0.5**

APPENDIX J

H17-1 and H17-2 ROI pre-calculation

Assumptions

Maintenance technician (MT) = 14 for 8 system with average cost of RM2200/month

Maintenance Engineer (ME) = 1 for 8 systems with average cost of RM3500/month

Operator (O) = 1 for each system with average cost of RM1500/month

Engineers (E) = 1 for 8 systems with average cost of RM3500/month

RM1 = USD0.2726

Pre-Calculation

$$\text{Maintenance labour cost / Hr} = \frac{\Sigma MT * AC}{System*Days*Hours} + \frac{\Sigma ME * AC}{System*Days*Hours}$$

$$= \frac{14*2200}{8*30*24} + \frac{1*3500}{8*30*24}$$

$$= 5.35 + 0.61$$

$$= RM5.96$$
$$\sim USD1.62$$

$$\text{Operations labour cost / Hr} = \frac{\Sigma O * AC}{System*Days*Hours}$$

$$= \frac{1*1500}{1*30*24}$$

$$= RM2.08$$
$$\sim USD0.57$$

$$\text{Engineering labour cost / Hr} = \frac{\Sigma E * AC}{System*Days*Hours}$$

$$= \frac{1*3500}{8*30*24}$$

$$= RM0.61$$
$$\sim USD0.17$$

APPENDIX K

H17-1 and H17-2 ROI calculation table

Return Of Investment (ROI) Calculation (USD)		
COST		
1 Equipment Cost ($)	586,116	
2 Product Cost ($/Unit)	5.00	
3 Throughput (units / hr)	1400	
4 Maintenance Labor Cost / Hr ($)	1.62	
5 Operations Labor Cost / Hr ($)	0.57	
6 Engineering Labor Cost / Hr ($)	0.17	
7 Spares & Consumables Cost / Year ($)	5,275	
8 Equipment Life in Years	8	
EQUIPMENT PRODUCTIVITY BENEFITS		**$2,303**
Utilization Improvement of 3% and Spares Reduction by 2%		
Utilization Improvement (%)	3.0%	
Equipment Cost Savings / Year	2,198	
Spares Reduction (%)	2.0%	
Spares Savings ($)	106	
TOTAL EQUIPMENT SAVINGS	2,303	
LABOR PRODUCTIVITY BENEFITS		**$983**
Maintenance Labor Reduction / wk (hrs)	7	
Operation Labor Reduction / wk (hrs)	7	
Engineering Labor Reduction / wk (hrs)	21	
TOTAL LABOR SAVINGS	983	
SAVINGS FROM QUALITY IMPROVEMENTS		**$183,960**
Yield Improvement Conservatively at 0.3%		
Yield Improvement (%)	0.3%	
TOTAL YIELD RELATED SAVINGS	183,960	
MARGIN FROM ADDITIONAL REVENUE		**$367,920**
Additional revenue opportunity from increased utilization		
Additional Throughput from Equipment Utilization (units/hr)	42	
Additional Revenue from above	1,839,600	
Additional Margin from above (20%)	367,920	
TOTAL BENEFIT / YR		**$555,166**
PROJECT COST		**$15,900**
Payback Period (months)		**0.3**

APPENDIX L

MA17UV ROI pre-calculation

Assumptions

Maintenance technician (MT) = 14 for 8 system with average cost of RM2200/month

Maintenance Engineer (ME) = 1 for 8 systems with average cost of RM3500/month

Operator (O) = 1 for each system with average cost of RM1500/month

Engineers (E) = 1 for 8 systems with average cost of RM3500/month

RM1 = USD0.2726

Pre-Calculation

$$\text{Maintenance labour cost / Hr} = \frac{\Sigma MT * AC}{System*Days*Hours} + \frac{\Sigma ME * AC}{System*Days*Hours}$$

$$= \frac{14*2200}{8*30*24} + \frac{1*3500}{8*30*24}$$

$$= 5.35 + 0.61$$

$$= RM5.96$$
$$\sim USD1.62$$

$$\text{Operations labour cost / Hr} = \frac{\Sigma O * AC}{System*Days*Hours}$$

$$= \frac{1*1500}{1*30*24}$$

$$= RM2.08$$
$$\sim USD0.57$$

$$\text{Engineering labour cost / Hr} = \frac{\Sigma E * AC}{System*Days*Hours}$$

$$= \frac{1*3500}{8*30*24}$$

$$= RM0.61$$
$$\sim USD0.17$$

APPENDIX M

MA17UV ROI calculation table

Return Of Investment (ROI) Calculation (USD)		
COST		
1 Equipment Cost ($)	300,000	
2 Product Cost ($/Unit)	5.00	
3 Throughput (units / hr)	1385	
4 Maintenance Labor Cost / Hr ($)	1.62	
5 Operations Labor Cost / Hr ($)	0.57	
6 Engineering Labor Cost / Hr ($)	0.17	
7 Spares & Consumables Cost / Year ($)	2,700	
8 Equipment Life in Years	8	
EQUIPMENT PRODUCTIVITY BENEFITS		**$777**
Utilization Improvement of 2% and Spares Reduction by 1%		
Utilization Improvement (%)	2.0%	
Equipment Cost Savings / Year	750	
Spares Reduction (%)	1.0%	
Spares Savings ($)	27	
TOTAL EQUIPMENT SAVINGS	777	
LABOR PRODUCTIVITY BENEFITS		**$983**
Maintenance Labor Reduction / wk (hrs)	7	
Operation Labor Reduction / wk (hrs)	7	
Engineering Labor Reduction / wk (hrs)	21	
TOTAL LABOR SAVINGS	983	
SAVINGS FROM QUALITY IMPROVEMENTS		**$181,989**
Yield Improvement Conservatively at 0.3%		
Yield Improvement (%)	0.3%	
TOTAL YIELD RELATED SAVINGS	181,989	
MARGIN FROM ADDITIONAL REVENUE		**$242,652**
Additional revenue opportunity from increased utilization		
Additional Throughput from Equipment Utilization (units/hr)	27.7	
Additional Revenue from above	1,213,260	
Additional Margin from above (20%)	242,652	
TOTAL BENEFIT / YR		**$426,401**
PROJECT COST		**$27,000**
Payback Period (months)		**0.8**