# FUNCTIONAL SPECIFICATION OF A MANUFACTURING EXECUTION SYSTEM

by

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B.S. Electrical Engineering, Manhattan College (1997)

Submitted to the Department of Electrical Engineering and Computer Science and the Sloan School of Management in partial fulfillment of the requirements for the degrees of

Master of Science in Electrical Engineering and Computer Science
and
Master of Business Administration

at the
Massachusetts Institute of Technology
June 2003





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# ABSTRACT

With increasingly demanding customers, shortened product lifecycles and toughening competition, manufacturers must develop more efficient production processes and closer integrate the shop floor to the enterprise. A Manufacturing Execution System (MES) is a factory floor information and communication system that, in addition to feeding shop floor information to enterprise applications, integrates real-time data from the shop floor to enable efficient production and manages manufacturing processes.

This thesis examines the standard functionality, industry and future of Manufacturing Execution Systems. The industry (capabilities and deficiencies) and the standard functionality of Manufacturing Execution Systems are examined in enough detail as to give the sponsor company a firm foundation for entering this market. We suggest ways that a Manufacturing Execution System can be used as a catalyst and enabler for certain process improvement methods. Specifically, we look at the integration of an MES with Lean principles and Six Sigma methodologies.

As a result of this effort, a number of strategic recommendations are presented to the company that sponsored this research, as well as key learnings, and opportunities for future work.

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# ACKNOWLEDGEMENTS

The research presented in this thesis was performed under the auspices of the MIT Leaders for Manufacturing Program, a partnership between MIT and a number of major global manufacturing companies.

I thank my wife Arlene for indulging me with her encouragement and patience these past two years – I could never have done this without you. I would like to thank my mother Hyacinth Sargeant and the rest of my family and friends for their continued love and support during my graduate education.

I am extremely gracious to Dr. Donald Rosenfield and the Leaders for Manufacturing Program for making this opportunity to learn and grow as an individual possible. I would like to thank the staff of the LFM program for their assistance during my participation in the program. I would like extend my appreciation to my colleagues at MIT in the LFM Class of 2003 and Sloan School of Management Class of 2003 for their friendship and camaraderie.

Thanks to ABB Limited for its support of my internship and this paper. In particular, Mika Kuhmonen, Rafael de Jesús, Mark Shaw and Juhani Pylkkanen for their able supervision and helping me to shape this work and make my internship a success. Many people in the Advanced Manufacturing and Engineering team played an important role in making my experience at Corporate Research a very rewarding one. In particular, two key individuals provided much appreciated time and assistance during my internship: Ulla Peltoniemi and Nina Saarimaa.

I would like to thank my thesis advisors Dr. Debbie Nightingale at MIT and Dr. Kwanghui Lim at the National University of Singapore for their invaluable advice and capable supervision of this research and editing of this thesis.

I thank the Humphrey (who prove that Bajans are everywhere) and Shaw families of Vaasa for their remarkable kindness and hospitality throughout my stay in Vaasa.

Special thanks to the Intel Corporation for their financial support of my course of study. It is truly appreciated.

Finally, I would like to dedicate this effort to my grandmother Erlene Sargeant who taught me humility, quiet confidence and to always put my best foot forward.

*"Things which matter most must never be at the mercy of things which matter least"* – Goethe

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# CHAPTER 1: INTRODUCTION

## 1.1 Objective

A Manufacturing Execution System (MES) is a factory floor information and communication system. Its primary goal is to integrate real-time data from the shop floor to enable efficient production, manage manufacturing processes, and feed shop floor information back to enterprise applications. This thesis details the essential functions of an MES system and explains its application in the area of discrete manufacturing. Additionally, this paper outlines the emerging trends in MES technology and the ever evolving MES market, and shows the integration of MES with Lean and Six Sigma manufacturing process improvement principles.

With increasingly demanding customers, shortened product lifecycles and toughening competition, manufacturers must develop more efficient production processes and closer integrate the shop floor to the enterprise. The need for capable and proficient MES applications has never been stronger. Customers demand to know where their order is at all times, shareholders demand that companies maintain control of their inventories, and production workers demand better tools with which to work. To succeed, manufacturers must make their production processes flexible and visible enough to provide information across the enterprise upon request.

A MES meets these needs by integrating the data on the shop floor and providing it to other manufacturing information systems. MES serves as a critical link in pulling information from the equipment and control layers and delivering it to enterprise systems. "The MES is at the center of the enterprise's entire fulfillment cycle....As such, the MES can provide the greatest benefit for the organization through its potential to link with the critical pieces in the enterprise."[1]

However, the implementation of an MES alone will not allow a firm to reach the ultimate level of efficiency. Enterprises that integrate lean business process improvements and workforce performance enhancements with technology-enabled MES' will move to that ultimate level of efficient manufacturing.

The objective of this thesis is thus to define the functions of an MES in the Discrete Manufacturing environment, and the use of such to enhance the implementation of good manufacturing principles. Specifically, the aims are to:

- *Provide an evaluation of the MES industry*
- *Specify the critical MES functions*
- *Define a framework for future Manufacturing Information System (MIS) projects*
- *Define the concept of an MES integrated with good manufacturing principles*
- *Implement and verify these concepts in an actual plant*

## 1.2 Background

ABB is a leader in power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact. The ABB Group of companies operates in around 100 countries, employs around 139,000 people and in 2002 had revenues over $US 18 billion.

The project came under the supervision of the Finland Corporate Research Center which in turn is a part of the larger Corporate Research and Group Processes organization. The Research groups go across the entire organization and consult to all product groups and divisions. In Corporate Research there are eight research centers in Finland, Germany, Norway, Switzerland, Poland, Sweden, India and the USA. Each has groups within them that support various areas of the business but only one leads the reasearch effort for each area. In the Finnish Research Center, the main focus areas are Lean manufacturing, Production scheduling principles, Supply Chain Management and Supporting IT systems.

One of the groups in the Finnish Research Center is the Advanced Manufacturing Engineering (AME) team. The purpose of the AME team is to identify advances in manufacturing and supply chain technologies and improve the operations of ABB plants using these technologies. One of the sub-teams of AME is focused on IT systems in manufacturing environments and it was under this sub-team that the the work performed for this thesis was undertaken.

Over the last several years, ABB made a number of major acquisitions in the Automation Industry. Given the increasing number of control systems and hardware platforms gained by mergers, ABB faces the challenge of both remaining committed to customer support while avoiding significant investments in developing and evolving separate systems.

Through the acquisition of key software capabilities, ABB has been able to migrate towards a single, common platform. This platform, Aspect Integrator Platform forms the foundation of ABB's Industrial

IT vision. With the advancement of Industrial IT, ABB found that they not only deliver value at the device level but could also tap into enterprise management areas as well.

However, the results of a previous LFM internship found that significant potential exists for ABB by utilizing Industrial IT at the Shop Floor Control and Manufacturing Execution level. This market place is significantly larger and is growing at a faster pace than ABB's current focus. Furthermore, a market leader has yet to be established at this layer unlike the ERP (SAP, Baan) and Device (ABB, Allen Bradley) layers. Although many companies are targeting this position, dominance requires a firm foundation in automation technologies that ABB has a long history of providing. The previous project resulted in the start of a pilot project in Ratingen, Germany utilizing Industrial IT technologies in a SFC / MES a pplication. There is a lso t he need to i dentify a dditional a reas o f research n eeded f or a pplying Industrial IT in shop floor and manufacturing execution control systems. This work involves specification of MES functionality and the integration of good manufacturing principles.

Though the industry is somewhat saturated with MES products, ABB has decided to acquire or develop this capability internally to move onto the same playing field as its main competitors (Invensys, Honeywell, GE) who have all moved quickly to acquire this capability. Given the current automation capability and large installed base, it is logical for ABB to build on this and develop an MES product internally.

However, it is not enough for ABB, hereafter r eferred to as t he sponsor company, to enter the MES market with a "me too" MES product. The market is saturated with several products with very similar product offerings. Most products meet the basic requirements of an MES but do little (if anything at all) to incorporate good manufacturing principles such as Lean and Six Sigma. A key MES differentiator would be to integrate these principles into the software work flow or in a way such that it supports the implementation of such principles.

## 1.3 Technology Overview

Within the world of manufacturing software, the functional boundaries among programs are very blurred. For example, ERP systems are constantly incorporating functions that could be considered part of a Supply Chain Management application or other process-specific application. The situation is the same for MES software with different vendors offering different levels of functionality. However, the Manufacturing Enterprise Solutions Association (MESA) has developed a detailed model of the basic functionality of any MES solution. [2] The table below provides descriptions of all eleven MES modules, as defined by MESA. It is within this framework that the detailed functionality of an MES was specified.

**Table 1.1: MES functionality as Defined by MESA**

| MES Function | Description |
|---|---|
| 1. Resource Allocation and Status | This module manages resources including machines, tools, labor skills, documents and other materials. |
| 2. Operations/Detailed Scheduling | This module sequences and times activities for optimized plant performance based on finite capacities of the resources and attributes of specific production units. |
| 3. Dispatching Production Units | This module manages the flow of production units in the form of jobs, orders, batches, lots and work orders by giving commands to send materials or orders to parts of the plant to begin a process or step. |
| 4. Document Control | This module manages and distributes records or forms on products, processes, designs, or orders. |
| 5. Data Collection | This module monitors, gathers, and organizes data about processes, materials, and operations from people, machines, or controls. |
| 6. Labor Management | This module monitors the status of operations personnel based on qualifications, work patterns and business needs. |
| 7. Quality Management | This module records, tracks, and analyzes the performance of product parameters to engineering specifications. |
| 8. Process Management | This module directs the flow of work in the plant based on planned and actual production activities. |
| 9. Maintenance Management | This module coordinates activities that allow plant equipment to function continuously. |
| 10. Product Tracking and Genealogy | This module monitors the progress of units, batches, or lots of output to create a full product history. |
| 11. Performance Analysis | This module evaluates actual plant performance against goals and historical performance. |

## 1.4 Integration to Other Systems

Manufacturing Execution Systems provide full benefit when integrated with other manufacturing information systems. A MES provides information on actual production status, as well as a host of other resources, to systems such as:

- Enterprise Resource Planning (ERP) Systems
- Supply Chain Management (SCM) Systems
- Product Data Management (PDM) Systems
- Customer Relationship Management (CRM) and other Sales/Service Systems
- Control and Automation

It passes costs, cycle times, throughput and other performance data to the ERP system; order status, shift-to-shift constraints, production capacities and capabilities to the SCM system; quoting and delivery-reliant data to sales and service systems; product yield and quality data to engineering systems; and instructions and recipes to controls. Conversely, it gets ERP plans and routings for its work dispatch; master plans and schedules from SCM, configurations and quotes from sales and service; work instructions and operational parameters from engineering; and data on actual performance and operating conditions from controls. [3]

As the strategic value and influence of MES applications increase, they will move from being a plant centric application to one that affects the entire enterprise, customers and suppliers. The boundaries between MES and other manufacturing information systems will continue to blur and total collaboration will become a reality. MES applications will see improved functionality in decision support, interactive graphical work instructions, machine-to-machine integration, multi-site synchronization and more complex execution workflow. As these changes occur, collaborative MES applications will enhance enterprise integration, production agility and scalability, and drive recognition inside the corporation of results that can be gained from MES systems.

## 1.5 Industry Overview

According to ARC Advisory Group's Global Outlook for Discrete Manufacturing, the overall market for production management systems (i.e. MES for Discrete Manufacturing) will grow from over $400 million in 2001 to just over $800 million in 2006. [4] They base these figures on growth in the semiconductor industry and strong growth in the electronics, aerospace and automotive industries. These figures were recently downgraded from over one billion by 2005, based on recent economic developments.

This growth will only come by passing significant hurdles; limited understanding of discrete MES benefits, high cost of solutions to smaller companies, and slow implementation times inhibit market expansion. In some industries, the value of implementing an MES is not well understood and calculating paybacks is often ambiguous. Additionally, decision makers in the upper levels of a corporation are hardly familiar with the benefits to the users at the plant level. In many cases, small customers cannot afford the software fees, implementation fees, and miscellaneous recurring upgrade/modification fees associated with deploying solutions. The challenge to MES providers is to reduce the costs to procure, deploy and maintain their solutions. The typical extended implementation timeline also hinders sales. This complicates the ROI calculation and makes it more difficult for those who need the solutions to sell them to key decision makers. Despite these hurdles however, the outlook is reasonably optimistic.

Per AMR Research, in 2002, the competitive landscape for all MES applications was split between process automation and equipment vendors, Strategic Business Units of large automation companies, pure-play MES companies and specialized MES vendors. [5] The customer industries in the market are lead by Semiconductors, Pharma/Life Sciences, Electronics, Food/CPG, Aerospace & Defense and Automotive/Auto Parts.

The industry has recently seen a bout of partnering and consolidation between large automation OEM's and small software vendors. Analysts are forecasting that this trend will continue through the end of 2002. Not only is this partly driven by the recent economic downturn but also by MES vendors trying to expand functionality and become adaptable to a wider range of vertical markets. Table 1.2 below contains a list of some dominant MES vendors.

**Table 1.2: List of Dominant MES Vendors (2002)**

| | | |
|---|---|---|
| Applied Materials | CIMNET | Honeywell |
| Apriso | CIMx | iBaset |
| AspenTech | DataSweep | IFS (Intercim) |
| Brooks (PRI Automation) | Emerson (Intellution) | Invensys (Baan, Wonderware) |
| Camstar | GE Fanuc (CIMPLICITY) | Lilly Software |

An indepth analysis of the MES market revealed that several large competitors are moving into the area of ERP, Shop Floor Control, Asset Management, Manufacturing Execution System arena. Large companies like Invensys, Rockwell and Honeywell have developed or are in the process of creating their own solutions. The analysis show that they have already entered this potential market and ABB will have to increase its speed to market with Industrial IT solutions if it is to be a successful player in this market. This is supported by research at the AMR Research Group (See Figure 1.1 below) which showed that majority of MES vendors are divisions of large companies or complements to process automation and equipment vendors. [4]

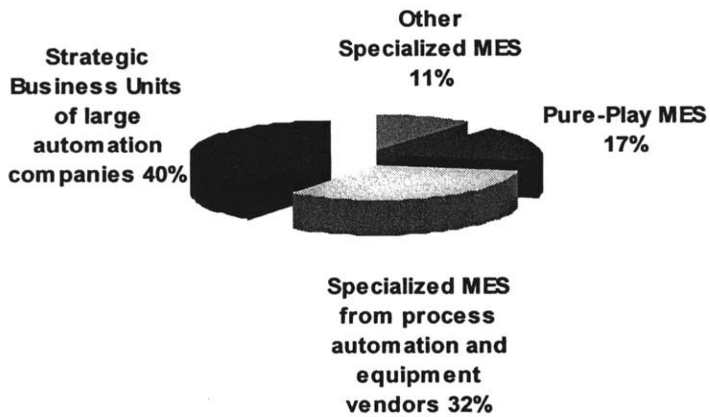


**Figure 1.1: 2002 MES vendor segments**

What set ABB apart from its competitors and as a current and future leader is its long history of manufacturing technologies developed in the automation segment. While this market is not new to ABB, it is still critical to continue to develop it and to increase its expertise in order to maintain ABB's leadership status.

## 1.6 Approach and Research Methodology

This thesis is a continuation of the work done at the sponsor company by Michael Hoag during his LFM internship. Michael showed the application of Industrial IT to discrete manufacturing by demonstrating potential applications. Building on this foundation, we framed the project around an MES product, analyzed the competitive market, specified the detailed functionality of each of the MES modules and specified the integration of lean and six sigma principles with an MES.

The methodology used may be categorized into five phases:

1. Develop an understanding of the software platform and the Industrial IT initiative
2. Investigate the general scope of Manufacturing Information Systems and MES in particular
3. Research the MES market
4. Combine knowledge of MES market and requirements to specify a product
5. Use knowledge of MES and good manufacturing principles to define a future MES

In Phase One, I worked with a project team implementing an MES application in one of the sponsor company's plants. This included authoring several project documents and writing some of the initial code for the application. It also allowed me first-hand interaction with production associates whose valuable insight showed the customer requirements for such an application. The work done at the plant in Germany and other projects within the sponsor company provided a foundation for defining the product for this thesis.

In Phase Two, research on the entire scope of manufacturing information systems with a focus on manufacturing execution systems allowed a critical understanding the integration between an MES and other manufacturing systems. Key outputs from this phase were the draft of a detailed MES specification and a lesser detailed whitepaper. This allows the sponsor company to pinpoint how current and future projects fit within the MES framework.

In Phase Three, critical information about the MES industry was gathered. The purpose of this was mainly to understand some of the key trends in the industry, the capability and deficiencies of the available products and who the benchmark vendors were. The main sources used were:

- Industry and vendor web pages
- Research groups (Forrester, AMR, Gartner)
- Industry whitepapers, trade journals and vendor brochures
- Academic case studies
- Demos and interviews at industry conventions

In Phase Four, through the use of a Quality Function Deployment, a comprehensive comparison of MES vendors and a listing of the key deficiencies in the products were completed. This market and product information can be used to create commercialization and go-to-market strategy.

Using the knowledge from Phase Four, it was concluded that most MES did not address or incorporate manufacturing principles. Thus, the definition of the functionality in a Next Generation MES was completed in Phase Five. In addition to integrating good manufacturing principles into MES functionality, the use of emerging technologies enhance MES functionality is shown.

## 1.7 Thesis Overview

This thesis is organized into four main chapters.

Chapter 2 provides a detailed look at MES functionality and the requirements of a manufacturing execution system. This chapter answers the question "What does a discrete MES do?" and identifies typical MES architecture and integration to other systems.

Chapter 3 analyzes the MES market in its entirety. It looks at the vendors and their products and makes clear the competitive landscape. An overview of discrete MES customers is presented and some key market trends are identified. At the end of this chapter, a QFD is used to rank the vendors and determine the market capabilities and deficiencies.

Chapter 4 builds on Chapter 3 by addressing the deficiencies identified in the QFD. The "Principled MES" shows how emerging technologies can be used to enhance MES functionality and the integration of good manufacturing principles with MES functionality.

Chapter 5 presents a set of strategic recommendations to the sponsor company, key learnings that have been drawn as a result of this research and opportunities for future work.

# CHAPTER 2: MES INDUSTRY ANALYSIS

## 2.1 Chapter Overview

This chapter describes the ever evolving MES industry. We start by describing an overview of the current market and MES customers in discrete industries - a comparison of discrete and process industries is included to clarify the differences. Next, we analyze the vendor landscapes in the MES industry and some dominant trends. Finally we present a patent analysis of the industry.

During this information-gathering process, available time and resources were optimized by using an expand-and-focus strategy. [6] The methods used included:

- Lead user interviews – of the client group at a sponsor plant
- Expert consultation – both internal and external groups
- Patent searches – based primarily on an internally generated patent report
- Literature searches – business cases, product brochures and trade whitepapers
- Competitive benchmarking – through research groups and industry conferences

After expanding the scope of the search, the scope was focused on the most promising directions.

## 2.2 Market Overview

According to ARC Advisory Group's Global Outlook for Discrete Manufacturing, the overall market for production management systems (i.e. MES for Discrete Manufacturing) will grow from over $400 million in 2001 to just over $800 million in 2006. [4] They base these figures on growth in the semiconductor industry and strong growth in the electronics, aerospace and automotive industries. These figures were recently downgraded from over one billion by 2005, based on recent developments in the economy.

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## 2.3 MES Customers

**Discrete vs. Process**

In discrete industries, products can be sold as units or multiples of a unit; in process industries, products can be divided into any lot size by adjusting container size. Examples of discrete industries include the aerospace, automotive and semiconductor industries while the chemicals, paper, oil refining and mill products are considered process industries. In some cases, the line between process and discrete manufacturing is blurred. In the food industry, many products use continuous processes but the packaging of the end product may be discrete. In the apparel industry, production of raw materials is process while production of the final units of clothing is discrete.


**Figure 2.1: Example of Discrete and Process Industries**

Manufacturing Execution Systems for discrete manufacturing address diagnostic, maintenance, and productivity challenges associated with personnel and machines used in volume manufacturing. The operator interfaces typically provide machine control, diagnostic/production instructions, fault logs, product flow, material management, and operator guidance. The biggest challenge facing discrete manufacturers is how to integrate and leverage real-time information from multiple sources to get a product out the door. The effort is focused on integrating data from individual parts of the process – from product specifications and parts inventory, to assembly, instructions, QA testing, receiving and shipping.

Manufacturing Execution Systems for process manufacturing address diagnostics, maintenance, statistical process control, recipe management and productivity challenges associated with batch processes. The operator interfaces typically provide machine control, diagnostic messages, temperature bar graphs, flow meters, pressure monitors, and recipe editors. The challenge facing process manufacturers is capturing real-time information from several points in a single integrated process to get a product of exacting quality out the door. Not only does the production process involve a continuous flow that cannot be interrupted, but also the individual production processes are so closely linked to each other that it's impossible to view or manage any of them in isolation.

Though MES applications exist for both the discrete and process industries, there are significant differences in the way they are used. The table below shows traditional functions that are available in MES applications in both industries and some that apply to both but are used differently in each.

**Table 2.1: Traditional Functions in Discrete and Process MES**

| DISCRETE | BOTH | PROCESS |
|---|---|---|
| Product Tracking | Quality Management | Flow Monitoring |
| Production Dispatch | Maintenance Management | Recipe Management |
| Resource Allocation | Document Control | Alarm Management |
| Scheduling & Planning | Labor Management | Process Management |
| Workflow Management | Performance Analysis | |

As stated previously, the focus of this work is Manufacturing Execution Systems used in discrete environments so the remainder of this thesis centers its attention here.

## 2.4 MES Benefits

So what exactly does an MES contribute to the production environment? First, an MES captures plant floor information – production methods, procedures, knowledge and experience - in a digitized manner, then delivers this information to humans and various manufacturing information systems so that production activities can be optimized.

As such, an MES provides a foundation for continuous quality improvement, cycle time reduction and lowering of production costs. The primary benefits from implementing an MES in a production environment can be categorized as:

- Providing plant floor visibility
- Communication real-time information to other information systems to facilitate better decision making
- Identifying opportunities for inventory reduction
- Increasing production capacity through better resource management
- Reducing length needed for process changes
- Increasing production quality through workflow automation
- Increasing production quality through identification and reduction of defects
- Ensuring compliance to regulatory standards

**Plant Floor Visibility** – By integrating an MES into a plant, supervisors or management can 'see' into the process. By knowing machine status, employee location, and material location, management has better control and knowledge of the operating conditions. This information is used to create a database of timely and accurate operational information, which in turn allows accurate performance measurement. This benefit is not limited solely to the manufacturing organization, having the capability to track orders through the plant gives sales and thus customers a better estimate of when orders will be delivered.

**Connection to other Information Systems** – However, the value of an MES increases significantly with integration to other systems. The data gathered from the shop floor, when passed to the ERP, PDM or CRM systems, increases their value to the organization. For example, the inventory visibility that the MES provides to the ERP system allows the ERP to provide better estimates of delivery dates to customers. This same connection allows changes in customer order priority to be efficiently communicated to the shop floor allowing dynamic prioritization. Integration to Product Design Management systems allows design engineers to make specification changes and distribute them to the shop floor as soon as possible after approval. When production associates have queries about the assembly instructions or product assembly parameters they can check notes on the assembly work instructions or alert the appropriate engineer automatically. Integration to SPC systems allows these same product parameters to be captured and analyzed for root cause and trend analysis. Real measured cycle times can be used to set accurate standards and calculate production costs in financial systems, and instructions and recipes can be passed automatically to the machine controls. A short listing of example data transferred between MES and other systems is shown in Table 2.2.

**Table 2.2: Sample Data Types Transferred between MES and Other Systems**

| | DATA TO/FROM | SYSTEM |
|---|---|---|
| MES | →<br>• Costs<br>• Cycle times and throughput<br>• Lot consumptions per part number<br>• WIP and FG Inventory visibility<br>• Production Posting | ERP |
| | ←<br>• Issue Work Order Numbers<br>• Plans and routings<br>• Bills of Materials<br>• Material lot information | |
| | →<br>• Order status<br>• Time spent on rework<br>• Production capacities and capabilities | SCM |
| | ←<br>• Master plans and schedules<br>• Supplier information | |
| | →<br>• Product yield and quality<br>• Maintenance records | PDM |
| | ←<br>• Work instructions<br>• Operational parameters | |
| | →<br>• Availability and delivery<br>• On-hand inventory levels | CRM |
| | ←<br>• Configurations<br>• Special Instructions | |

| | | |
|---|---|---|
| | →<br>• Instructions and recipes<br>• Operating parameters<br>←<br>• Operating conditions<br>• Alarms & events | **Controls** |

**Inventory Management** – Technologies such as barcode labels and RFID tags provide the capability for material to be tracked across the production line and their approximate locations to be known. Tracking of Work-In-Progress and Finished Goods inventory allows focused actions targeting inventory reduction to be taken. By seeing the current level of inventory, the plant manager can set targets and define alarms when preset inventory levels are exceeded. In fact, this allows 'lowering of the water around the iceberg' and further problems are illuminated.

**Resource Management** – An MES provides visibility into the current condition of resources such as people and machines. Ideally, production capacity can be increased through minimization of resource delays. Productivity metrics can be calculated based on equipment uptime, employee order completion times and product quality.

For maintenance purposes, the creation, scheduling, assignment and completion of maintenance tasks result in more efficient usage of expensive equipment. Furthermore, the faults and downtime of equipment can be correlated to product quality to identify possible root causes or trends in product performance.

**Quality Improvement through Workflow Automation** – An MES enables reduction of paper handling processes on the shop floor. The goal is not only to reduce paper (external to BOM) on the shop floor but to reduce non-value added activities such as manual data entry and provide simple and fast access to vital information. The reduction of manual data entry is accomplished by connecting equipment directly to the MES. For example, if a critical dimension is required for a part, the operator would typically record the measurement on a paper log or spreadsheet or other database. With integration to an MES, the measuring equipment could be connected to the database and the measuring process controlled by the MES. This reduces the possibility of error in capturing the data and formats it so that it can be readily manipulated.

By incorporating digital workflow, the production associate is provided only the needed information to work on a particular work order. As soon as the MES detects the product type, it can display the related information – BOM, drawings, specifications. In this way, the operator no longer needs to scan through reams of information to get to the parts he/she needs. Additionally, the information can be displayed in a much more visual and consolidated manner than typical. A secondary effect of making the production associate more productive is an increase in satisfaction and a boost in morale.

**Quality Improvement through Identification and Reduction of Defects** – As data is captured more efficiently from the production floor and in a format that is easily manipulated, it becomes easier to perform root cause and trend analyses. The MES can transfer this data to Statistical Process Control (SPC) systems where process anomalies can be identified and annotated right on control charts. In sum, tracking of key quality metrics will allow for easier reporting, control charting, statistical process control, root cause analysis and eventually improvement.

**Compliance to Regulatory Standards** – The capturing of product genealogy allows factories to develop and maintain quality assurance by analyzing product history to continuously update and improve quality objectives. In highly regulated industries like the medical or aerospace industry, this allows access to audit trails and device history records.

**Reduced Effect of Process Changes** – The length of disruptions in the production process due to employee changes and product structure changes can be minimized due to documentation of processes and links to other systems. When a new employee needs to be trained on a process, the learning curve can be shortened due to product knowledge being documented and readily available. Typically, the knowledge is stored in the previous employee's head or in documents away from the workstation. By integrating these documents into the workflow, and at the workstation, the new operator can be brought up to speed quicker than in a typical situation.

Product Bills-Of-Material (BOM's) are usually captured in the factory's Product Data Management system. Integration of this system to the MES allows changes in the BOM or other pre-defined assembly parameters to be transferred directly to the workstation and integrated with the workflow with minimal disruption to the process. The production associate can then configure the product by selecting the appropriate routing and process parameters.

These benefits can be better understood by comparing various hypothetical situations in the production process with and without an MES. In Table 2.3 below, several such situations are described.

**Table 2.3: Description of situations with and without MES**

| Situation | Before MES | With MES |
|---|---|---|
| A rarely ordered part needs to be assembled. | The Production Associate (PA) searches through a stack of assembly instructions for the required one | The MES detects the part (through scanner or RFID tag) and automatically displays the required assembly instructions. |
| The PA has a question on assembly parameter | The PA spends time looking for supervisor or engineer. | The PA clicks button on screen that immediately pages the appropriate person. |
| The amount of inventory needed for an assembly is insufficient at the workstation. | The level is detected when the Production Associate starts to assembly the part. | Using RFID or other, the inventory level is tracked by the MES. As the part required to be built is scanned, the PA is alerted to the insufficient level and can manually order more from stores. |
| Manager needs to know where a specific order is in the assembly process. | The manager walks to the shop floor and asks a series of PA's and/or supervisors for the location of the part. The supervisors in turn then go looking for the part. | The manager searches the MES database (through some interface) to locate the part. |
| Customer places rush order and the salesperson needs to know if they can meet the delivery date. | The salesperson calls manufacturing scheduler or other to find out how loaded the shop is when the order can be added. | The MES provides a list of current orders being assembled. When compared to the ERP list of orders, the salesperson now knows which of the current orders can be moved. |
| A design engineer makes a change to an assembly drawing. | The engineer holds a meeting the relevant assemblers and informs them of the change then the paper is copied to all the necessary workstations. | The engineer modifies all the documents that need to be updated and sets an alert for the first time the affected assemblies are next used. |
| Annual assembly standards need to be set. | An engineer walks around to assembly personnel and gets | The MES captures start and end times for each assembly cycle. |

| | | |
|---|---|---|
| | estimates of assembly cycle times usually using a stop watch. | An average is then used for the standard. |
| Measurements from an assembly are to be recorded for regulatory purposes. | Transcription errors occur when transferring to a spreadsheet or written list. | The data from digital gauges or other measurement equipment is transferred automatically to the MES. |
| Some complex parts need to be assembled. | Similar parts are assembled incorrectly because they look alike. | After scanning, the MES alerts the assembler if the parts are incorrect. |
| The customer has special requirements for an order. | The salesperson annotates notes to the order and then instructions are given to the PA. | Special requirements are highlighted in the MES and lets the PA know from a visual signal. |
| A product fails at a customer and the root cause must be determined. | Some information is missing and the root cause can not be determined. | All events around the product – assembler, date of assembly, machine faults – are captured and can be analyzed for root cause. |

## 2.5 MES Vendors

A competitive analysis of the Shop Floor Control, Real-Time Enterprise Data, Human Machine Interface and Manufacturing Execution System market segments was undertaken. This analysis focused on companies and products that integrated these segments and allowed customers to access real-time data, have a single user interface and provided real-time asset management. Market sources such as ARCweb, Thomas Register, McKinsey Quarterly and Dun and Bradstreet were used. A complete list of the market sources used can be found in Appendix A.

The criteria used to evaluate each company were:

- Revenues
- Employees
- Geographic Presence
- Sources of Competitive Advantage
- Target Industries
- Key Customers
- Competing Product(s) Description

Using this information, detailed company and product profiles were compiled for each company in the study from which summaries were created. An example of a company summary is shown below in Figure 2.2.

**Figure 2.2: Example Company Profile Summary**

| COMPANY PROFILE | COMPETITIVE PRODUCT(S) |
|---|---|
| **Revenues**: £7231M<br><br>**Employees**: 93519, Product A division - 800<br><br>**Geographic Location**: Global<br><br>**Target Industries**: Automotive. Chemical. Food processing and packaging. Pharmaceutical. Oil and gas. Machine tools. Textiles. Pulp and paper. Mining. Electronics. Utilities. Consumer goods. Transportation<br><br>**Key Customers**: Caterpillar. Delta Motor, Tektronix, Miller Brewing, Eastman Kodak, Baxter Healthcare, Chevron, Mobil, Lockheed, Nasa<br><br>**Sources of Competitive Advantage**: Unique position in both supply and demand sectors. Large installed base - already in 60,000 buildings worldwide and over 20,000 power systems project installations. Sector expertise e.g. retail, food, healthcare, pharmaceuticals. Automation Systems, Control Systems, Power Systems, Software Systems | **Product: Product A – Application 1, Application 2**<br><br>**Description**: Visualization software that lets you see the process and production information in real time and develop new applications. Open, Windows NT™-based control software that connects to whatever devices you want to. A real-time factory database provides a common point of access for plant floor and business system data. A web server add-on is included for remote viewing over the Internet or company Intranet. Also has a specialized application software for batch management and resource tracking.<br><br>**Assessment**: ***DIRECT COMPETITOR*** |

As part of the assessment of each company, a classification of Direct Competitor, Same Industry but Non-Competitive, Latent Competitor, Business Partner, Outside of Industry or Internal Group was assigned. The first three of these assessments are summarized in the competitive landscape shown below.

**Table 2.4: Competitive Landscape**

| Direct Competitors | Same Industry, Non-Competitive | Latent Competitors |
|---|---|---|
| • Applied Materials | • Schneider | • Business Objects |
| • Apriso | • Siemens | • GE Fanuc |
| • AspenTech | • Emerson | • IBM |
| • Camstar | • Alstom | • Valdero |
| • CIMNET | | |
| • CIMx | | |
| • Datasweep | | |
| • GenRad | | |
| • Honeywell | | |
| • iBASEt | | |
| • Industrial and Financial | | |

| | | |
|---|---|---|
| Systems (IFS)<br>• InterCIM<br>• Invensys<br>• Lilly Software<br>• nMetric<br>• PRI Automation<br>• ProfitKey<br>• Rockwell<br>• Technomatix | | |

The 19 Direct Competitors identified above were ranked measured against the criteria shown below in Table 2.5. It is important to note that the criteria measure the product more so than the company.

**Table 2.5: List of Vendor Rating Criteria**

| Criteria | Description |
|---|---|
| Historical Data | Historical data analysis is available |
| Widely Available Platform | Development platform is widely available |
| Data Collection | Functionality is included in product |
| Dispatch Production Units | Functionality is included in product |
| Document Control | Functionality is included in product |
| Labor Management | Functionality is included in product |
| Maintenance Management | Functionality is included in product |
| Performance | Functionality is included in product |
| Process Management | Functionality is included in product |
| Product Genealogy | Functionality is included in product |
| Quality Management | Functionality is included in product |
| Resource Allocation | Functionality is included in product |
| Scheduling | Functionality is included in product |
| Integration with Manufacturing Principles | Integration with Lean, Theory of Constraints, Six Sigma, etc. |
| Real-time data | Does the MES provide real-time information |
| Automated Test and Inspection | Connection to integrate inspection devices |
| Web-based interface | Graphical user interfaces are internet-enabled |

Though interviews, product demonstrations, company brochures and websites, and analyses by research groups and trade journals, each competitive product was analyzed against the criteria presented above. A summary of this evaluation is shown in Appendix B.

Appendix B illuminates two thoughts. Firstly, no MES vendor today provides a solution that offers complete MES functionality and secondly, few consider the incorporation of good manufacturing principles in the structure of the product.

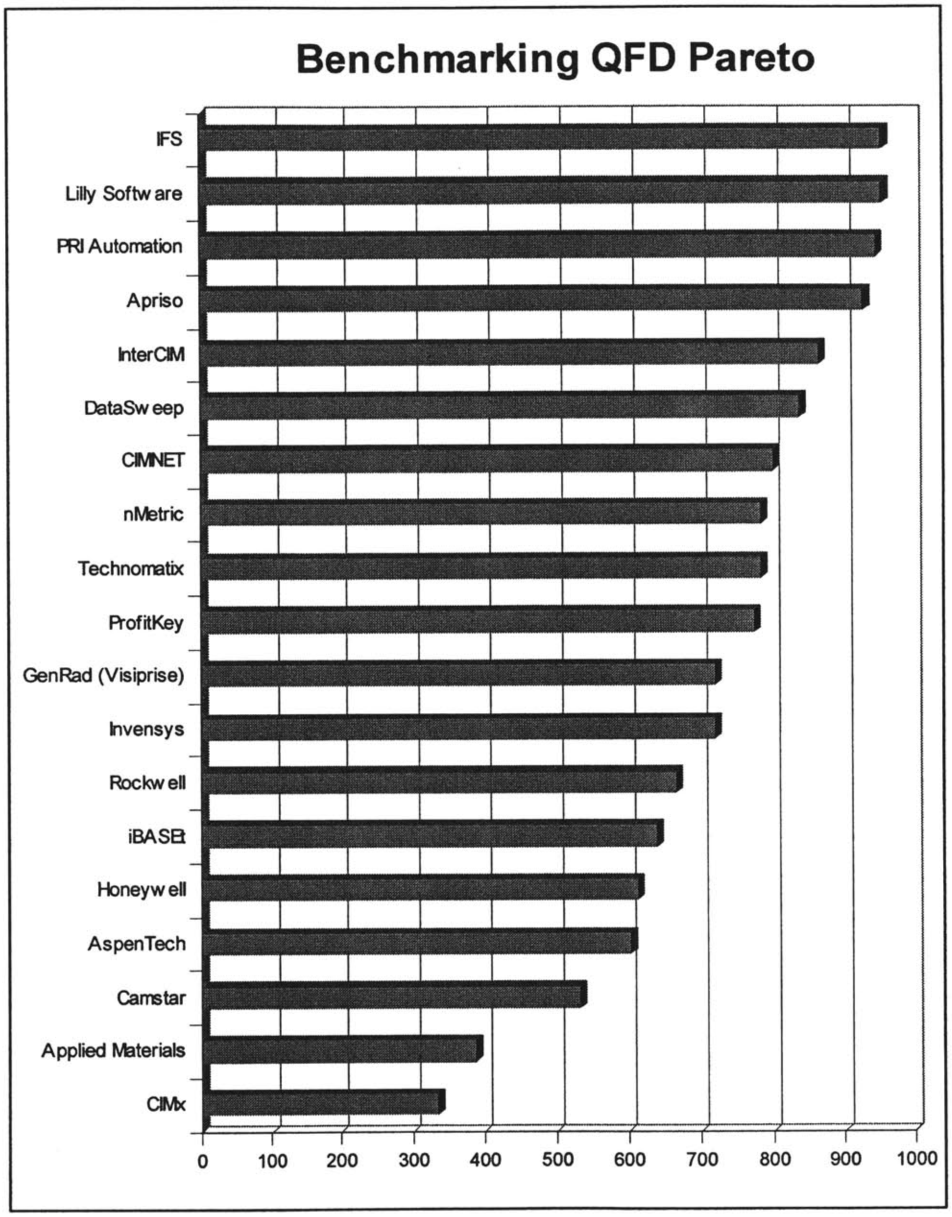
A more comprehensive evaluation would have been to obtain important rankings for each of the criteria and rate each vendor on the level of meeting each (Quality Function Deployment –like analysis). However, due to the various trains of thought in the industry, this would be at best difficult and complete thoroughly. Instead, a rough QFD analysis was performed and the sorted results displayed below in Figure 2.3. In the QFD, each criterion was given an importance rating. The MES modules were all given 9's while the others somewhat less. An "H" was then placed in each cell to represent that the product met the criterion. For each "H", the product of the importance of the respective criterion and the value 9 was added to the total for that vendor. The totals for each criterion are also captured on the right of the figure.

**Figure 2.3: Snapshot of QFD Results**

| MES CRITERIA | Importance | IFS | Lilly Software | PRI Automation | Apriso | InterCIM | DataSweep | CIMNET | nMetric | Technomatix | ProfitKey | GenRad (Visiprise) | Invensys | Rockwell | iBASEt | Honeywell | AspenTech | Camstar | Applied Materials | CIMx | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data Collection | 9 | H | H | H | H | H | H | H | H | H | H | H | H | H | | | H | | | | | 1134 |
| Dispatch Production Units | 9 | H | H | H | H | H | H | | | | H | | | | H | | H | H | H | | | 891 |
| Document Control | 9 | H | H | H | | H | | | | H | H | H | H | | | H | | | | H | | 810 |
| Labor Management | 9 | H | H | | H | H | | H | | | | H | | | | | | | | | | 486 |
| Maintenance Management | 9 | H | H | H | H | | | | H | | H | | H | | H | | | | | | | 648 |
| Performance Management | 9 | | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | | | | 1296 |
| Process Management | 9 | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | | 1539 |
| Product Genealogy | 9 | | H | | H | | H | H | H | H | | H | H | | H | H | H | | H | | | 972 |
| Quality Management | 9 | H | H | H | H | H | H | H | H | H | H | H | | H | H | H | | H | H | H | | 1377 |
| Resource Allocation | 9 | H | H | H | H | H | H | H | | H | | | H | H | | H | | H | | | | 972 |
| Scheduling | 9 | H | H | H | H | | H | H | H | | H | | | H | | | H | | | | | 810 |
| Lean Principles | 7 | H | | | | H | | | H | | | | | H | | | | | | H | | 315 |
| Real-time data | 7 | H | | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | H | | | 1071 |
| Six Sigma | 7 | | | | | H | | | | | | | | | H | | | | | | | 126 |
| Theory of Constraints | 7 | H | H | H | | | | | | H | | | | | | | | | | | | 252 |
| Automated Test and Inspection | 4 | H | | | | | H | | | | H | | | | | | | | | | | 108 |
| Web-based interface | 4 | | | H | | | H | H | H | H | | H | H | | | H | | H | | | | 324 |
| Historical Data | 3 | | | H | H | H | H | H | H | H | | H | H | H | H | | H | | | | | 324 |
| Widely Available Platform | 3 | | | H | H | | H | H | H | H | H | H | H | H | | H | H | H | | H | | 378 |
| | | | | | | | | | | | | | | | | | | | | | | |
| Total | | 954 | 954 | 945 | 927 | 864 | 837 | 801 | 783 | 783 | 774 | 720 | 720 | 666 | 639 | 612 | 603 | 531 | 387 | 333 | | |

The two figures below show the results of this "rough" QFD analysis. In Figure 2.4, the chart shows that IFS meets the criteria specified to the largest extent while CIMx the least.

**Figure 2.4: Sorted Pareto of "rough" QFD results**




Furthermore by combining this evaluation with Figure 2.5 below, we now have an idea of what vendors provide the most competition should the sponsor company decide to enter this market. Figure 2.5 shows the perception of Boston-based AMR Research Group of the market served by several MES vendors. On the far left, the vendors who target the discrete market segment are shown. These include Brooks/PRI Automation, iBASEt, DataSweep, CIMNET, Intercim, nMetric, Apriso, Applied Materials, Casco and

Synquest. Casco and Synquest were found to be focusing on very narrow MES areas so were eliminated from further analysis.

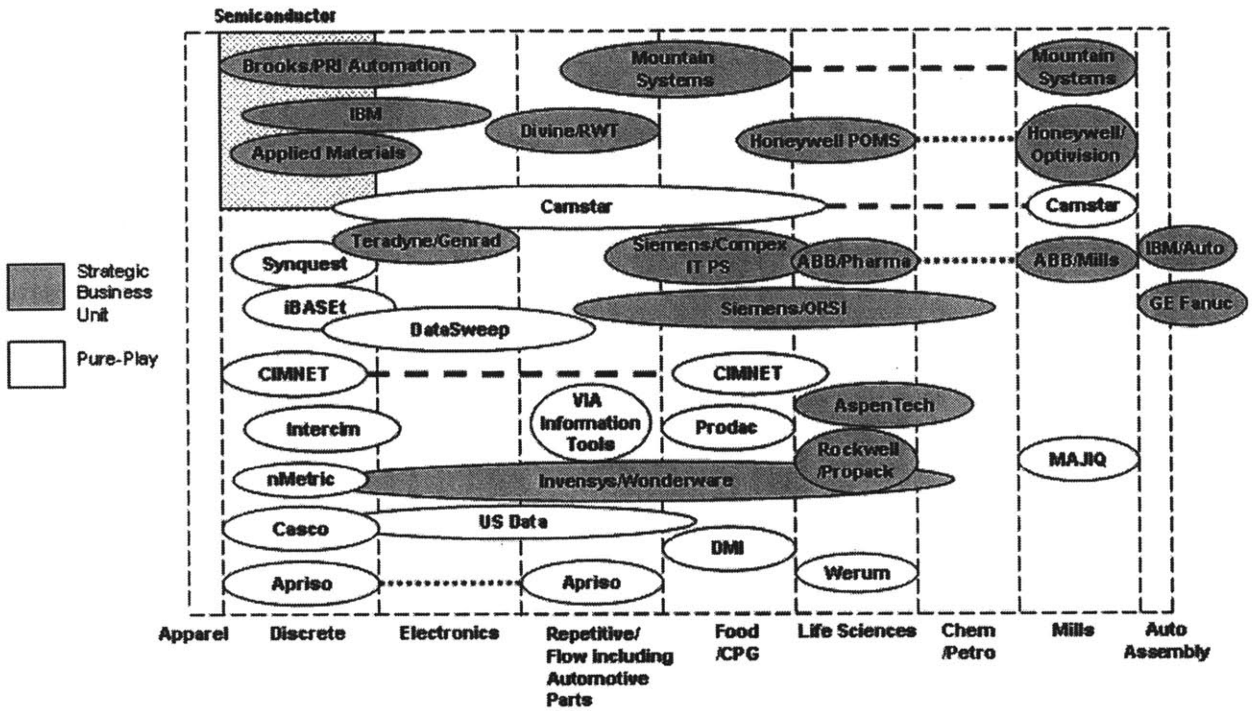



**Figure 2.5: Perception of markets served by MES vendors**

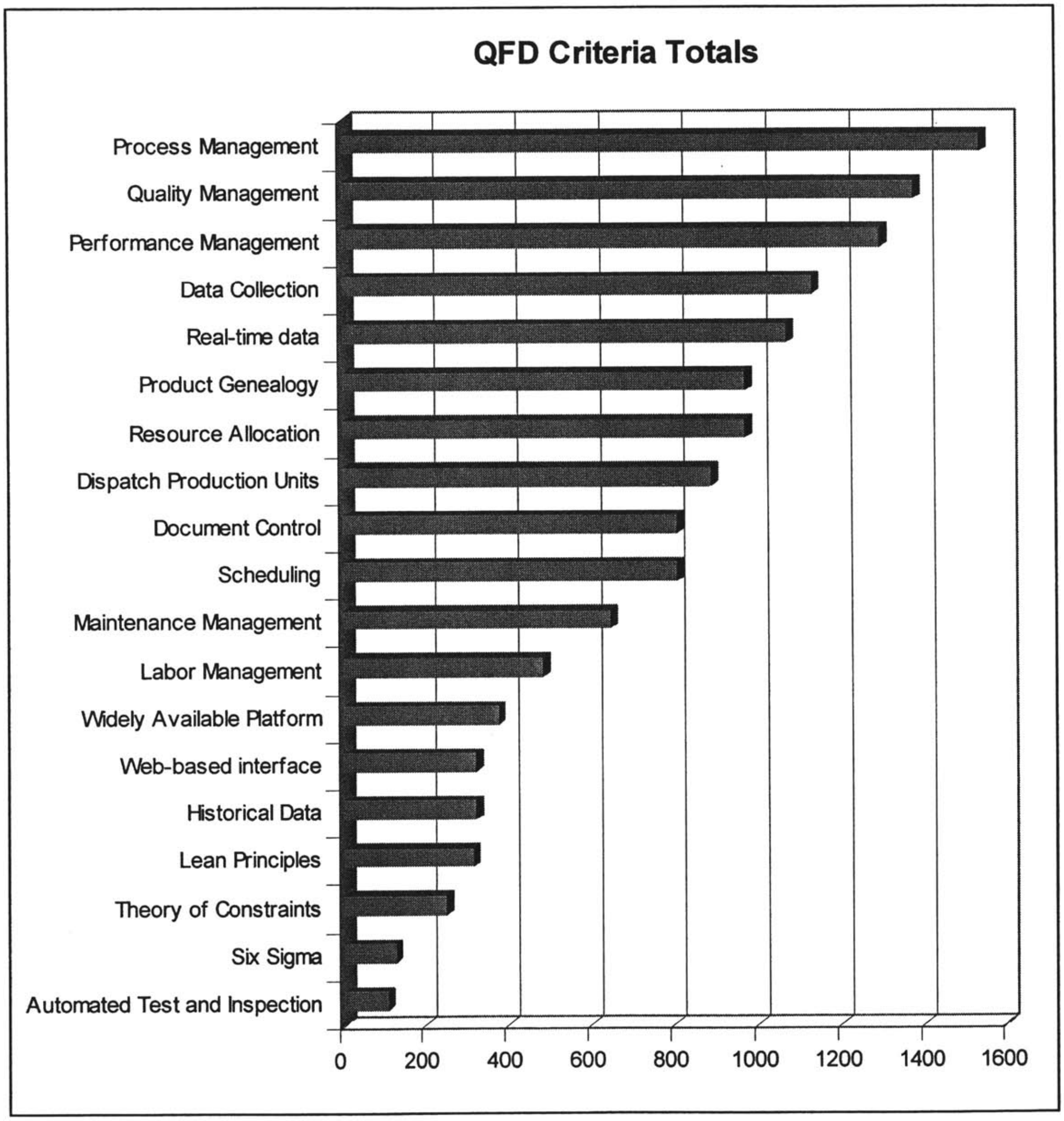
Combining this with the results for the remaining eight vendors (and QFD scores), the following ranked list can be formed. It should be noted that all of the vendors on this list feature prominently in industry tradeshows and magazines.

1. PRI Automation (945)
2. Apriso (927)
3. InterCIM (864)
4. DataSweep (837)
5. CIMNET (801)
6. nMetric (783)
7. iBASEt (639)
8. Applied Materials (387)

In Figure 2.6, we show the sorted totals of each criterion. This chart shows the extent to which the criteria are met by the capabilities of the vendors in the analysis. It clearly shows that while Process

Management, Quality Management and the other MES modules rank fairly high (are provided by the current vendors), integration with Lean and Six Sigma principles and Automated Inspection rank fairly low. Therefore, by considering these capabilities in the functionality of an MES application, the sponsor company can possibly leapfrog the competition by providing a superior product.

**Figure 2.6: QFD Criteria Totals**




A more thorough QFD analysis could be an exercise for a future project. Regardless, the above is sufficient to illustrate the point.

## 2.6 Industry Trends

However, this competition may be tempered by two significant trends in the industry today. The first is that MES firms have started to realize the significant benefits that can be achieved by closer integration with enterprise level systems.

Secondly, as a result, consolidation is increasingly the strategy in the market. Consider Table 2.5 below. During the period 1998 to Q1 2002 there were over sixteen acquisitions in the industry. This trend is projected to continue with larger ERP and equipment firms acquiring MES firms to complement their product offerings.

**Table 2.6: Recent Acquisitions in the MES Industry**

| Company | Acquired By: | Year |
|---|---|---|
| EnaTec | Wonderware | 1995 |
| Wonderware | Invensys | 1998 |
| Consilium | Applied Materials | 1998 |
| Consilium (FlowStream assets) | Base Ten Systems | 1998 |
| FASTech | Brooks Automation | 1998 |
| Industrial Computer Corporation | GenRad | 1998 |
| POMS | Honeywell | 1999 |
| Promis Systems | PRI Automation | 1999 |
| Hilco Technologies, Inc. | ORSI Automatzione | 1999 |
| Realtime Information Systems | CIMNET | Q1 2000 |
| M 2r S.A. | Aspen Technology | Q2 2000 |
| Base Ten Systems | ABB | Q4 2000 |
| ORSI Automazione, S.P.A. | Siemens Automation & Drive | Q1 2001 |
| Compex | Siemens IT PS | Q3 2001 |
| PRI Automation | Brooks Automation | Q1 2002 |
| Propack Data | Rockwell Automation | Q1 2002 |
| GenRad | Teradyne | Q1 2002 |
| Real World Technology | Divine | Q1 2002 |

## 2.7 Patent Analysis

The patent analysis undertaken utilized two resources: eBusiness Patent Search by Robert Hirt (Sponsor Company) and the U.S. Patent and Trademark Office website (www.uspto.gov). The focus of the task was on those eBusiness processes that are linked to manufacturing and support the fast flow of material within a factory (i.e. WIP tracking and control, event driven material request, automation of processes, direct link from orders to Manufacturing Execution Systems and machines). Broad areas of patent research include Human Machine Interface, Manufacturing Execution Systems and Shop Floor Control. An analysis of the relevant patent classes was completed to determine the areas that a potential patent would be filed. Additionally, a patent search of previously defined competitors was completed to provide a deeper understanding of the potential for further patents in the industry and what functions, if any, could be potentially patentable.

**Hirt Study Findings**

A research of the patents in eight areas related to eManufacturing was conducted by Robert Hirt of the Intellectual Property Department of ABB Power T&D in Raleigh, NC (see Table 2.7 below). A total of 78 relevant patents were identified and documented in the research study.

**Table 2.7: Areas of Patent Filings**

| Area of Patent Filings | Patents |
|---|---|
| Factory Automation Control | 20 |
| Factory Management Systems | 17 |
| Industry Specific Factory Automation | 14 |
| Remote User Manufacturing | 3 |
| Manufacturing Design Tools | 2 |
| Manufacturing Analysis and Simulation | 5 |
| Business Related Systems | 13 |
| Software Technology Articles | 4 |
| **Total** | **78** |

The most relevant patents were identified by the amount of times they have been cited in subsequent patent filings (see Table 2.8 below).

**Table 2.8: Most Relevant Patents by Number of Citations**

| Patent # | Assignee | Citations |
|---|---|---|
| 4665492 | N/A | 103 |
| 4698766 | British Aerospace Public Limited Co. | 54 |
| 4831582 | Allen-Bradley Company, Inc. | 54 |

| | | |
|---|---|---|
| 4604718 | Simulated Designs, Ltd. | 45 |
| 4835450 | Kabushiki Kaisha Toshiba | 31 |
| 5311438 | Andersen Consulting | 26 |
| 4901218 | Renishaw Controls Limited | 21 |
| 5283943 | N/A | 19 |
| 4621410 | Molins PLC | 16 |
| 4716124 | General Electric Company | 13 |
| 5050292 | Trovan Limited | 11 |
| 5594858 | Fisher-Rosemount Systems, Inc. | 10 |
| 5285392 | McKinsey & Company, Inc. | 9 |
| 5787283 | IBM Corporation | 9 |
| 5530857 | Bull S.A. | 8 |

A closer look at the patents gave an idea of what is involved. For example, the most frequently cited patent, US 4665492, is titled "Computer automated manufacturing process and system". In essence, the patent describes how various systems (CAD, CAM, controllers, servos, etc) communicate in order to build a product. The second most popular patent filing, US 4698766, is titled "Industrial processing and manufacturing systems". It recalls the existence of agents (i.e. machine tools, conveyors, workpiece, etc.) that act in manufacturing of a product. It then goes on to define structured way of defining them in order to standardized the application and make it re-useable. These top two patents are quite representative of the rest of patents.

**Relevant Patent Classes**

An analysis of existing US patent classes revealed that there is one (1) general and 4 sub-classes that would be relevant to a discrete MES. These are:

- **General Class 700** - Data processing: generic control systems or specific applications
- **Sub-Class 705** – Data processing: financial, business practice, management, or cost/price determination
- **Sub-Class 707** – Data processing: database and file management, data structures, or document processing
- **Sub-Class 709** – Electrical computers and digital processing systems: multiple computer or process coordinating
- **Sub-Class 717** – Data processing: software development, installation, and management

Any patents emerging from implementation by the system proposed by the sponsor plant will fall under Class 700. This is obvious as the system can be considered a data processing or computer apparatus designed for and utilized in a particular system, process, and environment, and is utilized for the solution of a particular problem in a field other than mathematics. The production facility would be considered as the environment and a specific production line the process. The solution built on Aspect Integrator Platform would be considered as the computer apparatus.

**Competitor Patent Search**

A search of relevant competitor patents was also completed. By researching patents filed and obtained by competing MES providers, potential areas for further MES related patents could be identified.

To obtain a list of patents filed or obtained by each of the competitor companies previously identified, the U.S. Patent and Trademarks Office website was utilized. Each company was evaluated by searching the Patent Assignee Name by the title of the company. While the majority of companies held few or no patents, several large companies, such as Siemens and Honeywell, held thousands of patents. For these companies, the search criteria were refined to include a combined search on company name and "manufacturing" or "software." These additional criteria assisted in pruning down the number of relevant responses. The search results are presented in Appendix C per the competitive landscape presented previously.

**Summary of Patent Search and Analysis**

A search of both eManufacturing and MES competitors' patents has proven that it is feasible to patent processes related to the application of IT in a manufacturing environment. For the most part, patents related to E-Manufacturing are high-level processes descriptions for communication of the various levels of available technology (i.e. ERP, CAM, CAD, etc). Patents related to MES competitors typically describe very specific processes that have been customized to fit a single application.

The Hirt Study revealed that the basic processes have already been patented with several patents surrounding eManufacturing and potential existing in Factory Management Systems and Remote User Manufacturing. The most likely potential for patents exist in Patent Sub-classes 707, 709 and 717 involving database management, multiple computer coordination with lesser potential in software development, installation and management. In addition, few direct competitors have filed for patents with most having none or non-related patents.

Based on this, we conclude that current advertised technologies in the area of eManufacturing cover the vast majority of ideas disclosed in eManufacturing patent filings. Therefore, only new technologies need to be considered any further. Finally, a combination of generic processes that provide an encompassing technological solution to a production problem might yield a specific patentable idea for the sponsor company.

## 2.8 Discussion

In this chapter we provided an overview of the MES industry, defined the intended market for the sponsor company, discussed the benefits provided by an MES and identified the key players. We also provided an indication of the capabilities lacking in current product offerings. In performing this industry analysis, there are a few important observations that should be noted.

First, given today's challenges of managing a global supply chain, collaborating with multiple partners through various information systems, shorter product life cycles, and demanding customers, the ability provided by an MES to connect the shop floor to the enterprise is becoming increasingly important to manufacturing firms who want to succeed.

The impetus behind connecting the enterprise to the shop floor is the need for real-time data. Howeever, there are some serious disconnects between what real-time means on the shop floor and the enterprise. At the enterprise level, an acountant may understand real-time to be within a day while at the shop floor, real-time usually mean 'as soon as possible' and is in the order of minutes. More important however, is the quality of the data that is fed to the enterprise from the shop floor. As described in Section 2.4, an MES has the capability to reduce errors in data captured on the shop floor (in addition to reducing the time needed to capture the data). Regardless, with more accurate data, decision makers are equipped to make better decisions.

Second, an MES allows a manufacturing firm to transform its shop floor from a paper intensive manufacturing process to an electronically driven process which increases operational visibility. The resulting benefits include improving the information flow on the shop floor, removing non-value added activities of handling and managing information details, reducing inventory stocks (or at a minimum allowing easier identification of problem and bottleneck areas), improving tracking of quality and reducing unpredictable levels of Work In Process (WIP). Overall, an MES increases profitability of the company, but as we will discuss in a subsequent chapter, even more significant benefits can be derived by integrating the MES with good manufacturing principles.

Third, this analysis revealed that several large competitors are moving into the Manufacturing Execution System arena. Large equipment or ERP firms are acquiring or partnering with smaller MES firms in order to provide a complete solution to their customers. Others are in the process of creating their own MES products through internal development. Though a slower route to a product, it somewhat guarantess better integration with existing products. The sponsor company has chosen this latter route to an MES product and will have to increase its speed to market with an internal solution if it is to be a successful player in this market.

This market dynamic and strategy is somewhat supported by Gans, Hsu and Stern in [7]. When the strength of intellectual property is weak, as shown in this chapter, and the relative cost of acquiring complementary assets is high, internal development dominates. The sponsor company has invested a significant amount of capital into the underlying development platform for this technology and plans to develop an MES internally. The suggested implication for management by Gans et al. is that they should expect that head-to-head market competition will be risky because of the imitability of the technology. This has been verified in the market where advances in MES applications are quickly duplicated by vendors. One notable competitive dynamic is that most innovation will come as a result of internal development. What does this mean for the sponsor company? It could be that they are following the correct strategy by continuing to develop an MES internally. If not, however, Gans et al. still predict market and technological stability.

Fourth, few of these companies hold patents in the area of MES software. The basic premise of such patents has already been captured in existing patents. Thus little opportunity exists in the foreseeable future for patents in this area. This becomes important when developing new MES functions because existing patents in this area have been written broad enough to cover any predicted new functionality. Potential for patents would exist in development of new and novel technology that supports new functions of an MES but not necessarily the functions themselves.

Fifth, what sets the sponsor company apart from its competitors and as a current and future leader is its long history of manufacturing technologies developed in the Automation segment. While this market is not new to the sponsor company, it is still critical to continue to develop it and to increase its expertise in order to maintain its leadership status. Further support for internal development of this application is given by [8]. When the technology is new and familiar and the market is not new to the firm, the suggested governance structure is internal development, acquisitions or licensing. It has been suggested that the sponsor company pursue an acquisition of a smaller MES firm or license from one. However, the current financial climate has not permitted this action. Investigation of these strategies continues by other groups within the sponsor company.

In the next chapter we discuss the basic functions of Manufacturing Execution Systems in detail. As part of the initial industry analysis, the MES framework seemed to be the most widely used. It is within this framework that the functions of an MES are described.

# CHAPTER 3: MES FUNCTIONALITY

## 3.1 Chapter Overview

This chapter provides a concise framework of component functionality that should be included in every MES. We begin with a short overview of an MES application and recap of the benefits associated with its implementation. As an MES is not a standalone application operating in a vacuum, the next section will discuss the integration of MES to other key Manufacturing Information Systems and the requirements of the necessary interfaces.

Research has shown that MES can be characterized in the following eleven (11) functions [9]:

1. Resource Allocation and Status
2. Operations/Detailed Scheduling
3. Dispatching Production Units
4. Document Control
5. Data Collection
6. Labor Management
7. Quality Management
8. Process Management
9. Maintenance Management
10. Product Tracking and Genealogy
11. Performance Management

A detailed description of these eleven functions forms the core section of this chapter. In this section, we attempt to give functional overviews and a description of key functions for each. Next, we propose a hierarchical structure for defining the functions in an MES. This structure is useful for development and understanding of how an MES functions.

Finally we present the prototypical architecture used in MES's and conclude with a discussion of the chapter key findings.

## 3.2 MES Overview

A MES is a factory floor information and communication system. Its primary goal is to integrate real-time data from the shop floor to enable efficient production, manage manufacturing processes, and feed shop floor information back to enterprise applications.

With increasing demands from customers, shortened product lifecycles and toughening competition, discrete manufacturers must develop more efficient production processes and closer integrate the shop floor to the enterprise. The need for capable and proficient MES applications has never been stronger. Customers demand to know where their order is at all times, shareholders demand that companies maintain control of their inventories, and production workers demand better tools with which to work. To succeed, manufacturers must make their production processes more flexible and visible enough to provide information across the enterprise upon request. A MES meets these needs by integrating the data on the shop floor and providing it to other manufacturing information systems. This is clearly evidenced in Figure 3.1 in the next section. MES serves as a critical link in pulling information from the equipment and control layers and delivering it to enterprise systems. "The MES is at the center of the enterprise's entire fulfillment cycle....As such, the MES can provide the greatest benefit for the organization through its potential to link with the critical pieces in the enterprise." [10]

## 3.3 Integration to Other Systems

Before describing the functions in detail, it is important to remind the reader that an MES needs to communicate with several other systems for full benefit to be derived. Figure 3.1 below shows the scope of Manufacturing Information Systems and some of the various systems that an MES application is required to communicate with.

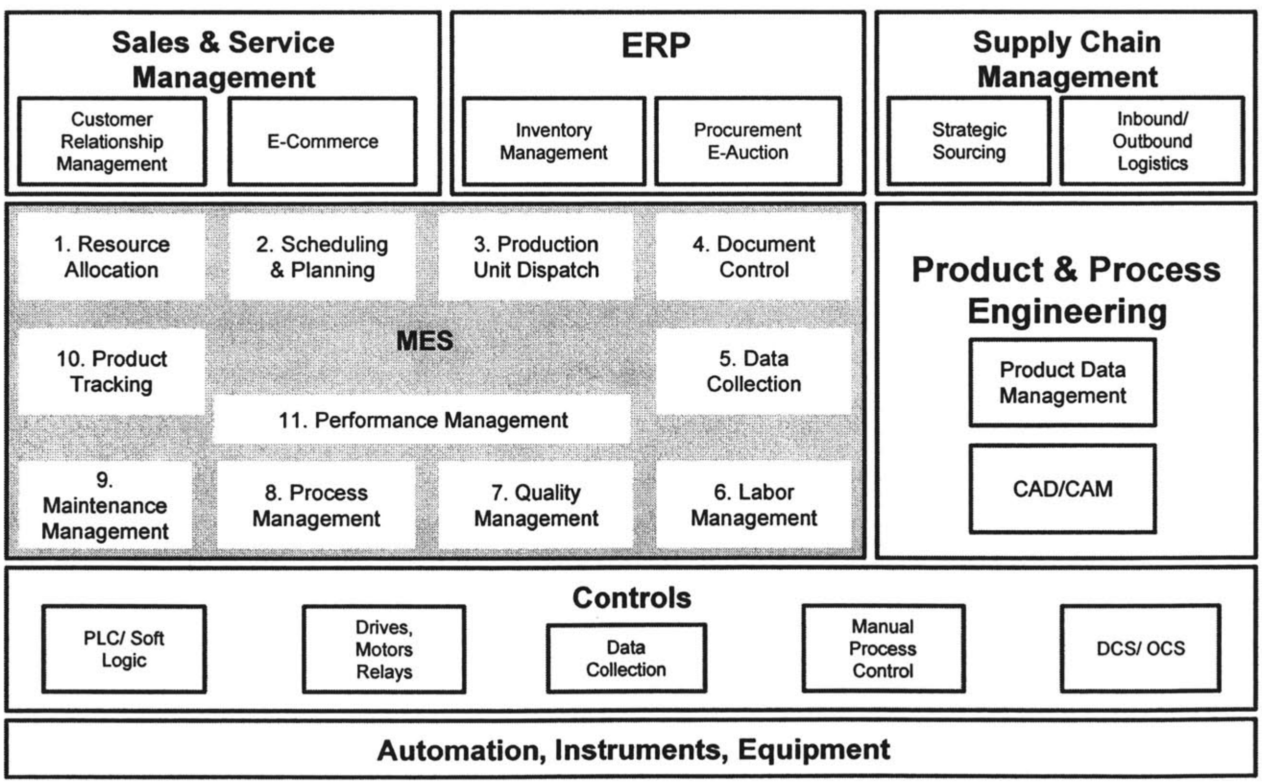



**Figure 3.1: Scope of Manufacturing Information Systems**

This section describes the data transferred between the MES and other manufacturing information systems. Specifically, these other systems include:

- Enterprise Resource Planning (ERP) Systems
- Supply Chain Management (SCM) Systems
- Product Data Management (PDM) Systems
- Customer Relationship Management (CRM) and other Sales/Service Systems
- Control and Automation Systems

MES generally links these systems to actual production status and capabilities. It passes costs, cycle times, throughput and other performance data to the ERP system; order status, production capacities and capabilities to the SCM system; availability data to sales and service systems; product yield and quality data to engineering systems; and instructions and recipes to controls.

Conversely, it gets ERP plans and routings for its work dispatch; master plans and schedules from SCM, configurations and order information from sales and service; work instructions and operational parameters from engineering; and data on actual performance and operating conditions from controls.

Appendix D shows the requirements of integration of an MES to various systems. The MES system must communicate efficiently with all these systems to efficiently manage the data in a production environment.

## 3.4 MES Functions

### 3.4.1 Overview

This section aims to describe the key functions of the eleven (11) modules of an MES system. The specification for each module includes a functional overview, a list of suggested functions and a list of a hypothetical database tables and fields. The detailed functionality found in Appendices E through O draw heavily from an assessment of the system specification for a customer site. [11], [12], [13]

### 3.4.2 Resource Allocation

This function manages resources including people, documents, machines, tools, materials, and other equipment that must be available in order for work to start at operation. It provides a detailed history of resources and insures that equipment is properly set up for processing and provides status real time.

The critical functions in resource allocation include the ability to modify resources and to see the current status of all resources. Resource types include people, documents, tools and pieces of equipment. For resources such as people and documents, the Labor Management and Document Collector modules should be used respectively. Several of the MES modules will use the information in the Resource Management module, thus it should have the capability to be accessed from any page where a resource is used. This allows the details and status of the resource to be viewed immediately.

### 3.4.3 Operations Scheduling

This function provides sequencing based priorities, product quantities, resource status and due dates associated with production orders. It is finite and it recognizes alternative and overlapping/parallel operations in order to calculate in detail exact time or equipment loading and adjust to shift patterns.

Why is Advanced Planning and Scheduling important? The key drivers that commercial solutions have repeatedly mentioned are:

- Increased Customer Service Levels
- Increased on-time delivery
- Reduce Planning cycle times (less time on preparing schedules, more to improve system)
- Rapid due date quoting (capable-to-promise)
- Shorter, more predictable lead-time's
- Reduced WIP, Inventory
- Increased Throughput
- Improved key asset (Critical Constrained Resources) utilization

The boundary between the functions of APS solutions within Manufacturing Execution Systems (MES) is not always clearly defined. Commercial solutions tend to offer a suite of products within the categories of MES/ supply chain management/planning and functions that may lie in the 'Scheduling Component' of one suite, may be found in a different component of another. Similarly, use of a stand-alone 'Scheduling Component' in some cases is not even possible or would limit its capabilities without integration with other components.

Scheduling tools comprise of three integrated aspects:

- **Factory Modeling** – The capability to design the tool such that it models the actual factory processes accurately and in to sufficient detail to apply Theory of Constraints principles.
- **Process Control** – Automating (or structuring) decision/calculation processes to create an optimal factory schedule from customer demand.
- **Process Optimization/Improvement** – (Automated) Capability to increase factory performance (through historic data collection/analysis) by:

### 3.4.4 Production Unit Dispatch

This function manages flow of production units in the form of jobs and work orders. Dispatch information is presented in sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It takes the output from the scheduling tool and displays the work orders at the required workstation. This can be a manual dispatch by personnel such as the production supervisor or can be done automatically.

This function allows the supervisor or other production manager to release orders to the floor. This can be done automatically based on preset order parameters or can require an approval. The supervisor can release orders to a particular workstation based on a product routing.

### 3.4.5 Document Control

This function controls documents that must be maintained with the production unit, including work instructions, operational method sheets, drawings, standard operating procedures, batch records, and engineering change notices. It sends instructions down to the operations, including providing data to operators or recipes to device controls. It also includes the control and integrity of environmental, health and safety regulations, and ISO information such as Corrective Action procedures.

The Document Control System should be accessible via the MES system to allow users to get the latest documents. Types of documents to provide the user range from operator instructions to engineering documents. They could exist in any one of various formats (.doc, .xls, .pdf) or size (A, B, C, D or E).

### 3.4.6 Data Collection/Acquisition

This function provides an interface link to obtain production and parametric data that populate the forms and records attached to the production unit. The data may be collected from the factory floor either manually or automatically from equipment in an up-to-the-minute time frame.

Appendix I provides a listing of the data storage/collection functional requirements required for connecting to the real manufacturing processing line. Some of the key functionality include real-time data collection of continuous and discrete data, a data export tool and the ability to collect data from various sources on the shop floor.

### 3.4.7 Labor Management

This function provides status of personnel in an up-to-the-minute time frame. It includes time and attendance reporting, certification tracking, as well as the ability to modify personnel status. It may interact with resource allocation to determine optimal assignments.

This function addresses the management of personnel related requirements. This includes the ability to view and modify personnel status. Personnel include production associates, production managers, supervisors and other production related roles. This is an integral part of the entire MES function and is referenced in all MES functions.

### 3.4.8 Quality Management

This function provides analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. It may recommend action to correct the problem, including correlating the symptom, actions and results to determine the cause. It may also include SPC/SQC tracking and management of off-line inspection operations and analysis.

This function essentially manages the quality aspect of the MES system. It uses data from the data collection module to analyze and report production data. Some key functions are continuous process control, statistical process control, annotation of charts to show events and trends, process data analysis, historical data analysis and graphical analysis.

### 3.4.9 Process Management

This function monitors production and either automatically corrects or provides decision support to operators for correcting and improving in-process activities. These activities may be intra-operational and focus specifically on machines or equipment being monitored and controlled as well as inter-operational, which is tracking the process from one operation to the next.

This function should include control of product flow, alarm management, 'ready-access' to process info, elapsed process cycle times and poke yoked workflows. This function basically controls the electronic movement of product and work orders between operations. As a work order is completed, it is added to the queue of the next workstation in the product routing.

### 3.4.10 Maintenance Management

This function tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance as well as the response (alarms) to immediate problems. It maintains a history of past events or problems to aide in diagnosing problems. Maintenance management systems provide historical, current and planned maintenance events to the facility based equipment. They also keep track of spare part inventory, reorder points and can go as far as automatically interface with purchasing and invoicing systems.

### 3.4.11 Product Tracking and Genealogy

This function provides the visibility to where work is at all times and its disposition. Status information may include who is working on it; components materials by supplier, lot, serial number, current production conditions, and any alarms, rework, or other exceptions related to the product. The on-line tracking function also creates a historical record. This record allows traceability of components and usage of each end product.

This function provides a critical function of the MES system. As production associates complete work or a product and signal completion, the system automatically assigns the work order to the queue of the next workstation in the product's routing. This allows critical visibility into the location of product in real-time. Not only is the location available, but also other critical data around the material.

### 3.4.12 Performance Management

This function provides up-to-the-minute reporting of actual manufacturing operations results along with the comparison of past history and expected business result. Performance results include such measurements as resource utilization, resource availability, product cycle time, conformance to schedule and performance standards. It draws on information gathered from different functions that measure operating parameters. These results may be prepared as a report or presented on-line as current evaluation of performance.

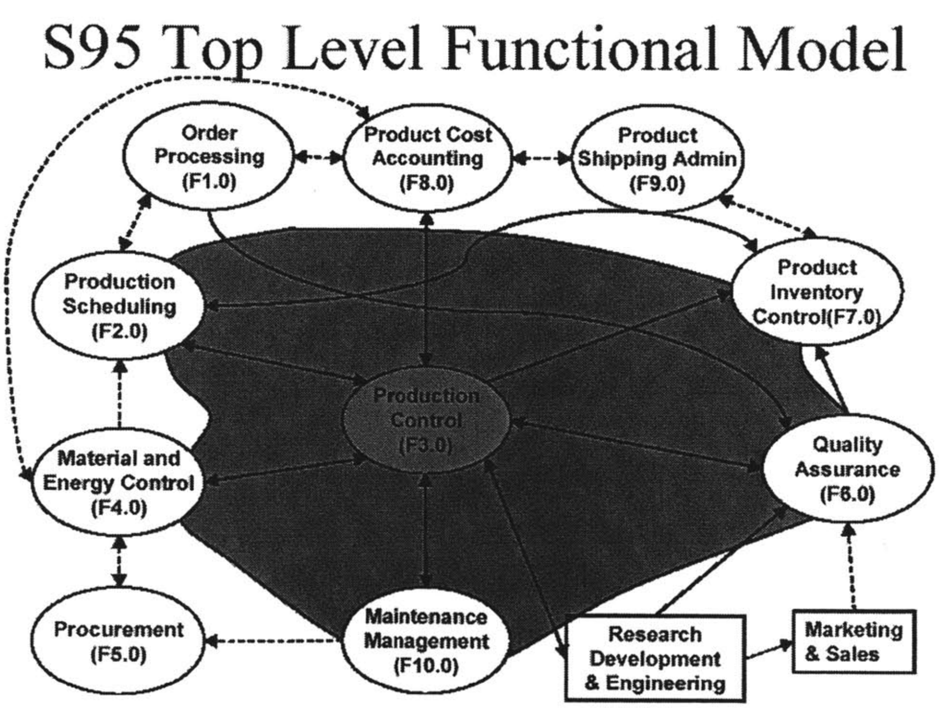
The key outputs of this function are user-configurable reports that show plant performance compared to a pre-defined benchmark or historical performance. The ability to save regularly used reports and distribute to other users in various formats should be allowable.

### 3.4.13 Comments on MESA Framework

The MESA standard may be described as too narrow and focused on the shop floor only but the author believes that this is necessary for understanding what systems can be implemented on the shop floor and what actually happens on the shop floor. Other standards, like the ISA-95, take into account the enterprise level of systems and blur the lines even further between shop floor and enterprise.

ISA, the other dominant standard for MES systems, is the Instrumentation, Systems and Automation Society consensus committee defined Standards Project 95. This set of standards is known as SP-95 "Enterprise Control System Integration." The applicable standard is ISA SP95.03 "Enterprise- Control System Integration – Part 3: Models of Manufacturing Operations. The figure below depicts the top level functional model in ISA 95 and it can be seen that it in fact covers broader areas than production at the shop floor level.

**Figure 3.2: ISA 95 Top Level Functional Model**



Agreeably, the MESA standard may be narrow in one sense however. The attempt to define these eleven functions as part of one standard has become difficult. For example, Scheduling has developed into an entire field of scheduling algorithms and intense research. Maintenance has gone on to become an entire service industry and using it in the MESA framework can be limiting. So in a sense, the framework is limiting but rightly so. Going beyond this adds confusion and deemphasizes the shop floor.

## 3.5 Functional Categories and Hierarchy

In this section, we propose that the eleven functions of an MES system can be segmented into four categories – ***Foundation, Enablers, Workhorses and Reporters***.

**Foundation**

The Data Collection module forms the foundation of an MES system. This involves the naming convention, data architecture of the entire system and the platform/mode used to collect data. The data should be collected in a way that it is easily retrievable and the structure should be intuitive enough to see clearly what data is stored where. Every other module requires data, manual or automatic, to function. By ensuring that the data model is robust and intuitive, it becomes very easy to integrate the other modules.

**Enablers**

This group consists of modules that can function independently, but primarily provide key information to the other modules. Little or no analysis is done on this level and the main function is to provide supporting data to the Workhorses and Reporters. The modules in this group are Labor Manager, Document Collector and Resource Manager.

**Workhorses**

The modules in this group complete the bulk of the calculation and analysis. These include Scheduler, Process Manager, Product Dispatcher, Product Tracker and Maintenance Manager. These applications pull information from the enablers that allow them to conduct analyses, drive decision-making, and manage production.

**Reporters**

Performance Analyzer and Quality Manager store and output historical production data to support decision-making. As opposed to the Workhorses, these two applications do not automate production processes but are critical to support continued operational improvements by recording historical data on a variety of plant processes.

**Figure 3.3: Proposed Functional Hierarchy**


The numerous interactions between the modules of an MES make the development of an MES an extremely complex task. This segmentation gives a developer a potential roadmap of how to create a new MES and also a framework within which to understand the larger MES picture. For example, we recommend that the Data Collection function be implemented first. It should be designed to accommodate various types of data in various formats. Having the data available now allows a rough categorization of the data into more manageable forms and their relative attributes. The Workhorse layer then manipulates and uses the data at lower levels to make decisions and manage production workflows. The Reporter layer basically analyzes the data from the shop floor and gives performance analyses that further enable decision making.

This hierarchy has the potential to increase the modularity of the MES functions. For example, the Resource Manager, Labor Manager and Document Controller, once made to accommodate various types of data, can be integrated with any database containing formats recognizable to the MES. This hierarchy provides an improvement over the basic MES eleven modules because it primarily aids in understanding the MES modules.

## 3.6 Architecture

Figure 3.4 shows a typical structure of an MES system. At a conceptual level, the elements of the architecture can be divided into five primary categories: 1) Database Server, 2) Application Server, 3) Clients, 4) Production Equipment and 5) Production Support Equipment.

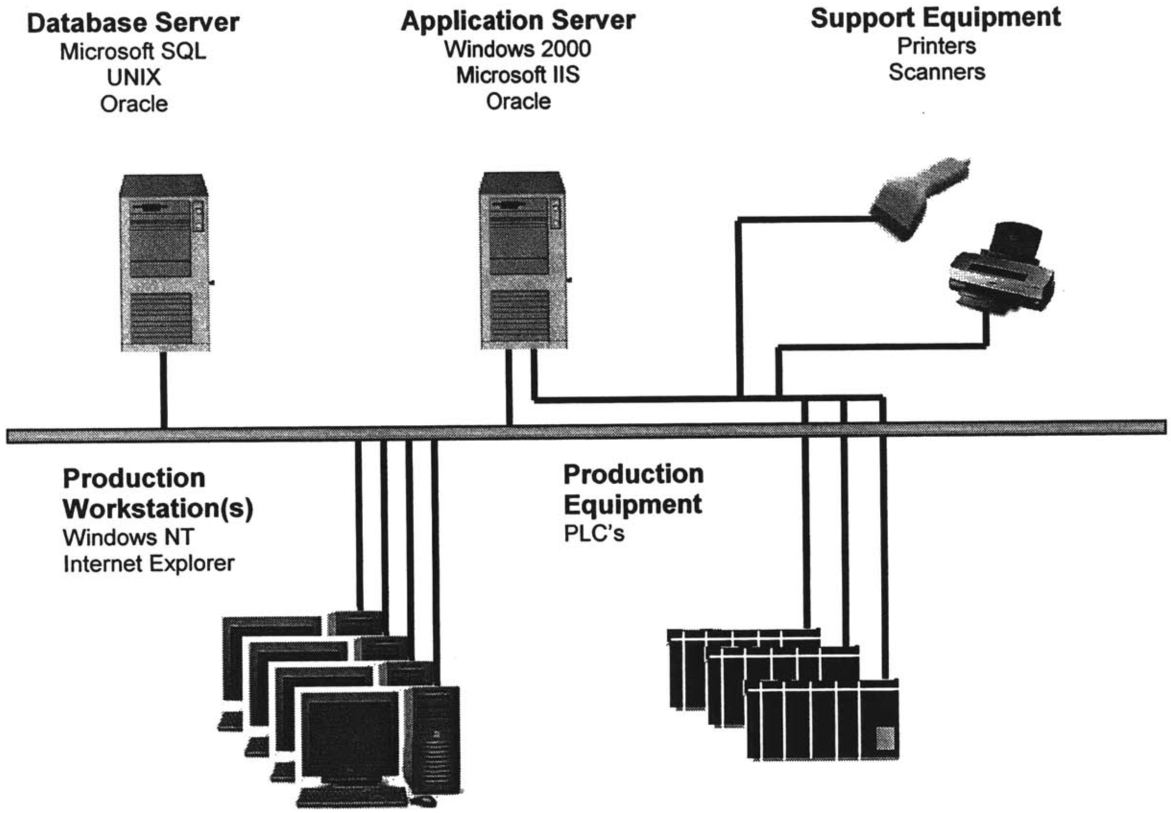



**Figure 3.4: Typical MES Architecture**

**Database Server**

The Database Server is the back-end system in the architecture and typically supports database systems like Microsoft SQL Server, UNIX or Oracle. The Database Server interfaces with the Application Server via database drivers like JDBC/ODBC or ADO and houses both an Active and Historical databases. Production data is normally stored in the Active database and is periodically transferred to the Historical database.

**Application Server**

The Application Server provides the communication link between the Clients and the Database Server and the home of the MES. The Application Server typically runs technologies similar to Windows 2000, Microsoft Transaction Server (MTS) or Microsoft Internet Information Server (IIS). MTS and the database drivers (JDBC/OBDC or ADO) work together with the MTS Objects and the Database Interface Layer to communicate with the Database Server. IIS communicates with MTS via HTTP. IIS also includes Active Server Pages that interface with the JDBC/ODBC and ADO drivers via Component Object Model (COM).

**Client**

The client usually provides a web-centric interface to each functional component of the MES. A thin client is a low-cost, centrally-managed computer devoid of CD-ROM players, diskette drives, and expansion slots. The term derives from the fact that small computers in networks tend to be clients and not servers. This is especially advantageous because the bulk of the data processing occurs on the Application Server and little has to be loaded on the operator workstation. Typical technologies like Microsoft Internet Explorer are used to represent the client in MES systems.

**Production Equipment**

The next integral segment of an MES is the production equipment where vital information is derived. Production equipment can take several forms (Injection molder to assembly robot) and they all usually require some Programmable Logic Controller (PLC), SCSI bus or Serial I/O port to communicate to the MES. OPC (Object Linking and Embedding (OLE) for Process Control) Data Access is the OPC specification that deals with getting real time data from production equipment.

**Production Support Equipment**

Support equipment includes devices such as barcode readers, scanners, printers, RFID tags, and pallet jacks. MES connection to these devices can reduce non-value added activities like transcribing data from one form to another and the likelihood of human error.

## 3.7 Discussion

In this chapter we used the MESA framework to analyze the individual functions of an MES. This framework allowed a clear and sensible organization of the various MES sub-functions and was valuable in understanding the information flows and dependencies. For each function discussed, a hypothetical database structure was described. This database helped to solidify understanding of the way an MES operates and demonstrate some key facts about an MES.

Firstly, significant capability remains to be exploited by integrating the various functions. Each becomes more powerful when information is transferred between it and the others. The various modes of data, when combined and presented to the enterprise level can become extremely useful.

On the contrary, decoupling of functionality into individual, standalone, reusable subsystems (not quite information hiding, but separation of concerns) increases the modularity of the system and drives reusability of components within other programs or by themselves. There is some economic benefit to this as shown in Chapter 2 where several MES vendors are seen to sell individual parts of MES functionality without providing all functionality.

Thirdly, it was shown that the typical architecture used in an MES system is fairly simple. The five categories identified are fairly well known and implementation is fairly straightforward in most environments. However, what is typically difficult is the customization of the MES to fit an existing manufacturing environment and the challenges associated with acceptance and change in any organization.

Throughout the research, some good practices in managing an MES were identified. Firstly, frequent and regular data transfers to the historical database to keep the active database small are advisable. Secondly, it is prudent to regularly collect performance statistics. As demands on the MES application and database change over time, these statistics can serve as a baseline from which decisions can be made regarding performance and scaling. Thirdly, small, simple interfaces between components and the integration and use of COTS products make for easier modifications and updates.

Finally, our recommendation to the sponsor company was to use the suggested functional hierarchy as a guide to understanding MES and developing their own product from the ground up. However, this does not mean that alternatives like acquiring or partnering with an existing MES provider is not viable. Simply, it is intended to be a strategic guide in development.

# CHAPTER 4: THE PRINCIPLED MES

## 4.1 Chapter Overview

This chapter demonstrates the integration of widely accepted good manufacturing principles with a Manufacturing Execution System. We show how MES can be used a complement to process improvement based on these principles. The learnings and findings in this chapter are a result of interviews, surveys of several MES applications, and research of industry whitepapers and conference presentations.

We start with a description of some of the most recent technology advances that allow this integration then describe how an MES can be used to enable lean implementation and Six Sigma improvement methods. In the end, these principles are meant to drive process improvement at the shop floor level, so there is obvious synergy to be exploited by this integration.

## 4.2 Trends impacting Manufacturing Execution Systems

Several technology advances are allowing manufacturers to better realize the integration of the enterprise to the shop floor. The technologies involved all enhance the flow of customized information to the appropriate users and improve the reaction of systems to changes on the shop floor.

Advances in Radio Frequency Identification (RFID) permit product inventory to be tracked real-time on the shop floor. With this technology, manufacturers can better manage their inventory, respond faster to changes on the shop floor and improve their customer service tremendously. Industry standards are still needed and entities like the Auto-ID center at MIT, corporations and some industry groups continue to make this a focus.

The communication standards between entities in the supply chain are improving steadily. Extensible Markup Language (XML) tags increase the capability of databases and information transfer. In particular, XML provides re-usable workflows, data translation and mapping, business logic for optimization and alerts and a scalable hub architecture that is easy to support. Other communication standards like RosettaNet and BizTalk are becoming more and more popular. Microsoft's .Net and Sun's J2EE development languages are also emerging as standards for development platforms.

There is a recent thrust in manufacturing information systems to adaptive planning as opposed to optimization. To meet this end, there has been an increasing use of intelligent agent software to manage exceptions and the shop floor. Adaptive agents are being used to alert ERP systems of changes on the shop floor and to suggest reactions or autonomously make changes in scheduling plans. Beyond the Lean Enterprise and the Flexible enterprise lays the adaptive enterprise where adaptive execution, autonomous agent architecture, intelligent agents, holonic systems and self-aligning systems will be the main technologies. Indeed, the future looks more and more like artificial intelligence meets the shop floor.

And finally, advances in web services connect the enterprise relatively effortlessly to the shop floor (than EDI and older information protocols). The customer can now determine where orders are in the supply chain and obtain accurate delivery dates.... manufacturers can better manage capacity and track production efficiency.... and suppliers can react quicker to quality requirements.

These trends provide improved information management that supports operational excellence, coordination and integration of the extended supply chain and enhanced manufacturing visibility. As manufacturers aim to become more flexible, these new technologies will enable them to meet these goals and MES designs of the future need to incorporate these trends. MES will need to become more robust, intelligent, and self-aligning applications that deliver the right information to the right place when needed. However, is technology enough? As the popular saying goes, "IT added to a bad process equals a bad process with IT." Several companies have put initiatives (Lean, Six Sigma) in place to simplify the production process and reduce the number of steps before implementing expensive IT systems. But why not use IT to help simplify the process and aid future improvements? The following sections propose how an MES can be infused with Lean and Six Sigma principles to aid process improvement.

## 4.3 Integration of Lean with MES

### 4.3.1 Lean Overview

People have continually sought to make things faster, better, and cheaper. Many technologies have been developed to support these goals. Computers in particular have freed workers from labor-intensive tasks and extended their abilities; however, they also enable people to "make mistakes at the speed of light," as more than one pundit has observed.

The principles of lean manufacturing have become the bible for companies large and small. On the surface, these principles – teamwork, communication, continuous improvement, and waste elimination – seem obvious, but taken as a whole they provide a true foundation for efficiency.

Toyota started the lean revolution in Japan in the 1950s, and their results were a serious wake-up call:

- Production inventories reduced 90%
- Productivity of people doubled
- Scrap and errors to customers cut 50%
- Time-to-market reduced 50%.

The precepts of lean are now widely practiced, and manufacturers are working aggressively to squeeze every drop of "fat" out of their operations. Many leading-edge companies, however, recognize that achieving the next level of *kaikaku* – dramatic improvement – requires more than just waste elimination. [14] Appendix P provides an overview of the key concepts of lean principles. [15]

In the book Lean Thinking (Womack), technology's role in lean thinking is described as important but being slow to impact the majority of the value chain. It is also described as a rapid game changer in only a small portion of industries. However, we believe that these principles can be integrated with an MES thus bringing similar benefit to any manufacturing environment where an MES is employed. In the following sections, we illustrate possible manifestations of lean principles integrated with an MES.

### 4.3.2 Value

"Value can only be defined by the ultimate customer." [15] Value is defined from the customer's perspective, and an MES can implement functions that add benefit to the customer, whether internal or external. A MES can allow a customer to know where product is in the production process real-time and provide an accurate estimate of product availability. In the event of quality issues on the shop floor, production can alert the sales organization if there is a possibility that the field will be affected.

For internal customers like production associates on the shop floor, value can be gained by providing only the information that is needed for the product currently being assembled. Further value can be derived when the MES detects the product on the work order entering the work area (through bar code scan or RFID tags) and automatically displays the related information. This reduces the typical non-value added time spent searching for assembly information.

The productivity of the operator can be further increased by standardizing work instructions so that operators new to workstation re familiar with the layout of the MES screen and have access to animated work instructions. Labels and documentation can be printed at the workstation upon demand by the operator or automatically as parts are scanned or enter the work area.

Inspection activities can be shortened or eliminated by linking testing equipment to the quality system in the MES and checking measured values against desired values. In the project at the sponsor company, this is achieved with digital gauges through a small input/output data-gathering module in the program. This can be duplicated with any measuring device that passes data to a personal computer.

### 4.3.3 Flow

Lean thinking goes beyond the firm, across all activities the product touches, from order entry, to human resource to sale and product availability. As such, the MES that supports a lean organization should be integrated with the information systems in these other functions. For example, the labor management module can be connected to HR systems, maintenance linked to equipment/asset management systems, genealogy and tracking linked to PDM systems. In Appendix D, we gave examples of data transferred between MES and other systems.

A MES supports flow by displaying the production in a process map giving a real-time view of flow disruptions - allowing production supervisors to respond quickly to problems. The MES also accurately reports lead time components. It not only tracks how long a part sits in inventory but how long it takes an operator to assemble a product.

### 4.3.4 Pull

The MES can provide value by electronically requesting work from the next workstation and passing this on upstream in the process. The MES is essentially being used to automatically request material if WIP is insufficient.

Additionally, as demonstrated by Mike Hoag and his team at MIT, an electronic kanban is possible. Here, the kanban is maintained electronically – as parts are used up, a signal is sent to the upstream supplier (internal - upstream workstation/stocks or external - parts supplier) for replenishment. This removes the proximity and visual requirement for standard kanban implementation.

### 4.3.5 Perfection

Transparency is critical – MES provides window into production from all levels of the organization but the transparency has to be reciprocal; the customer orders that are driving production need to be visibly displayed to all the factory workers so that they can see the changes when the product is built. Everyone involved must be able to see and must understand every aspect of the operation and its status at all times. [15] Employees should be able to see the current level of customer satisfaction and (through an Andon board) view an electronic display-on-request of how production is doing against customer demand.

MES's reduce the potential for error from operators using incorrect information by providing the latest revision (instant update) of drawings, assembly instructions and test records. There is easier tracking and updating of controlled documents and special manufacturing instructions can be communicated immediately to the factory floor.

### 4.3.6 Product Costing

Aligning firms along a product-line basis and showing cost along each product line can be accomplished through product genealogy and product tracking. Costs can be attached to each part in the BOM and tracked throughout the part's life in the production process, and as a result, costs (and revenues) can be attached to each product line. As a result, focus can be placed on the most profitable products and customers.

### 4.3.7 5S

A MES can lead to a clean and manageable work area. By adding standard modules to the desktop of the MES, operators can go to a different workstation and understand the format and come up to speed faster, again shortening the learning curve. By digitizing the paper assembly instructions, less space in the work area is used up and it immediately becomes neater.

Discipline is added to the assembly process when the MES controls the workflow in the workstation. By following the directions and process of the MES, there is less chance for operator error and less variation between operators.

### 4.3.8 Visual Control

A visual plant layout can be created by adding location coordinates and orientation of equipment, walkways and flows. With this virtual plant, managers can see the performance of the process and drill down within each process step to understand the root causes of exceptions in performance.

Digital displays showing output compared to demand or yield versus quality objectives can be linked to the actual performance of the workstations. White boards that need to be manually updated will be replaced by digital displays that are updated real-time and are available to everyone throughout the plant.

In summary, Table 4.1 shows some of the ways that an MES can support the implementation of lean on the shop floor.

**Table 4.1: MES Support of Lean Implementation**

| |
|---|
| **Value to Customer** |
| Real time online customer order tracking - improve customer value |
| |
| **Flow** |
| Easy detection of flow disruptions |
| Accurate measure of lead time components |
| |
| **Pull** |
| Automatic material request |
| |
| **Perfection** |
| Real-time digital Andon boards |
| Transparency to the shop floor level |
| Ease of tracking / updating controlled documents |
| |
| **Value to Operator** |
| Automated retrieval of operator instructions |
| Standardized work - animated work instructions |
| |
| **Product Costing** |
| Accurate costing of product lines |

**5S**

Reduction of paper in the work area

Standardization of digital workflow

**Visual Control**

Visibility of plant performance

## 4.4 Integration of Six Sigma with MES

### 4.4.1 What is Six Sigma?

First, what it is not. It is not a secret society, a slogan or a cliché. Six Sigma is a highly disciplined process that focuses on developing and delivering near-perfect products and services. Why "Sigma"? The word is a statistical term that measures how far a given process deviates from perfection. The central idea behind Six Sigma is that if you can measure how many "defects" you have in a process, you can systematically figure out how to eliminate them and get as close to "zero defects" as possible.

Often, an inside-out view of the business is based on average or mean-based measures of the past. Customers don't judge on averages, they feel the variance in each transaction, each product shipped. Six Sigma focuses first on reducing process variation and then on improving the process capability. Customers value consistent, predictable business processes that deliver world-class levels of quality. This is what Six Sigma strives to produce. [16]

The DMAIC (Define-Measure-Analyze-Improve-Control) methodology is the process regularly used to drive Six Sigma rigor into the improvement process. However, at its core, Six Sigma revolves around a few key concepts. **Critical to Quality (CTQ)** describes attributes that are most important to the customer. These CTQ's are measurable characteristics of a process or product to which targets and specifications can be assigned. They are normally derived from the needs of the customer. A **Defect** is defined as any occurrence of failure to deliver what the customer wants. **Process Capability** describes the level of quality that the process can deliver. **Variation** measures the extent of different performance levels that the customer sees and feels. **Stable Operations** ensures consistent, predictable processes to improve what the customer sees and feels and **Design for Six Sigma (DFSS)** entails the design of processes to meet customer needs and process capability requirements. Appendix Q provides an overview of the key concepts of the Six Sigma methodology. In the following sections, we suggest possible ways that an MES could support Six Sigma principles as represented by DMAIC.

### 4.4.2 Define

In the Define phase of the project, one determines the project CTQ's, have the project charter approved and create a high level process map. In the process management module of the MES, a clear visual of the process should be included that shows a high level view of the process.

By annotating this visual with key performance indicators, an improvement team can see the worst performing steps and focus their efforts here. Further detail can be added such that one can view historical process performance and sort the processes by level of performance. Or for example, sort delay causes by product, shift, operator or any other factor desired.

### 4.4.3 Measure

In the Measure phase, we develop a focused problem statement, identify the response variable(s) and how to measure them, collecting data for these variables, analyze the measurement system (through a Gage Reproducibility and Repeatability analysis), assess any existing specifications and determine the performance capability of the variables. These measures can be around the product or the process. The Table below lists some sample measures of product and process.

**Table 4.2: Sample Product and Process Measures**

| Product | Process |
|---|---|
| • Performance within tolerances | • Throughput Time |
| • Performance within specifications | • Inventory |
| • Defects | • Uptime |
| • Failures | • Yield |
| | • Labor Costs |

By linking the MES directly to digital gauges measuring product dimensions, the data can be stored directly in the MES historical database and mined for defects and out-of-tolerance performance. Metrics can be reported directly from the MES and quick defect feedback given to the operator to facilitate root cause problem solving. Linking the MES to the equipment on the shop floor also allows reporting of process uptime, yield, quality information and process-specific parameters. In general, the availability of historic data and causal information makes defect history available to improve root cause analysis.

### 4.4.4 Analyze

In the Analyze phase one looks at the data and characterizes the response (is the problem with the mean or the variation?) prioritizes the key X's (possible root causes) and determines the vital few that impact the primary measure. The main takeaway from this phase is a statistical definition of the problem. We also use graphical analysis, multi-variate analysis, ANOVA, and basic statistical tools to identify the likely families of variability.

Based on the data collected by the MES, we can identify variability in the system, perform predictive statistical monitoring and determine quality problem correlations. One of the most useful tools in this phase is regression analysis of some output metric to key input variables. This allows one to form hypotheses, experiment with changing the input variables and detect any effect on the output.

### 4.4.5 Improve

In the Improve phase, we identify the likely X's (possible root causes), use Design of Experiments to confirm the vital few factors and confirm the optimized solution to the problem stated in the Define phase. Another key requirement of this phase is the risk assessment of the implemented changes.

As a result of the statistical models determined in the Analyze phase, one can now experiment and receive results real time from the MES. This provides a faster turnaround time to gather improvement results and improvement teams can determine what changes to implement sooner.

### 4.4.6 Control

In the Control phase, we mistake proof the process, measure the final capability and put controls in place that allow the process to be sustained over the long term. The project is documented and all key learnings translated where applicable to other processes in the plant.

One of the key benefits of an MES to this phase is the real-time process performance monitoring feature of an MES. Once key metrics are identified, they can be tracked for exceptions and alerts sent to the responsible persons when exceptions are detected. In addition, a link to documentation of prior related projects can be placed on the workstation 'desktop' to direct operators to key learnings.

To support control of the process, the MES can be used as a manufacturing engineering knowledge database. We can store information, pictures and videos that can be used to mistake proof the process, train new operators and reduce the learning curve or prevent loss of knowledge due to retirement, layoffs or resigning engineers.

In summary, there are many ways that an MES can enable the use of Six Sigma methodologies. Some of these are listed in Table 4.3.

**Table 4.3: Summary of MES benefits to Six Sigma**

| **MEASURE** | **ANALYZE** |
|---|---|
| • Direct capture of product data<br>• Availability of historical data<br>• Data pre-formatted in suitable forms (Pareto, histograms, etc.)<br>• Quicker identification of exceptions | • Statistical monitoring<br>• Data is transferred directly into statistical programs |
| **IMPROVE** | **CONTROL** |
| • Easier implementation and rollout to other workstations<br>• Faster availability of process or product data | • Continuous process performance monitoring<br>• Mistake proofing the process<br>• Project documentation<br>• Translated learnings to other workstations |

This analysis provided valuable insight from three perspectives. First the value of Lean and Six Sigma is seen in the description of the two principles. Second, the technology advances in MES application and emerging technologies that will impact MES are described. Third, a linking of principles and these technology advances clearly show the possible benefits that will be derived from MES applications in the future. This is shown below in a table summarizing these findings.

**Table 4.4: MES, Principles, Supporting Technologies and Benefits**

| Principle/Concept | Benefit | Possible Technology | MES Module |
|---|---|---|---|
| Lean – Value | • Real time online customer order tracking<br>• Automated retrieval of operator instructions<br>• Ease of tracking / updating controlled documents<br>• Standardized work - animated work instructions | • RFID<br>• Wireless LAN | • Production Unit Dispatch<br>• Process Management<br>• Document Control |
| Lean - Flow | • Easy detection of flow disruptions<br>• Accurate measure of lead time components | • XML<br>• Microsoft .NET | • Process Management<br>• Maintenance Management |
| Lean - Pull | • Automatic material request | • XML | • Production Unit Dispatch<br>• Product Genealogy<br>• Scheduling |
| Lean - Perfection | • Real-time digital Andon boards<br>• Shop floor transparency | • RFID<br>• Wireless LAN | • Process Management |
| Lean – Product Costing | • Accurate costing of product lines | • Robust databases languages – SQL | • Labor Management<br>• Maintenance Management<br>• Product Genealogy<br>• Resource Allocation |
| Lean – 5S | • Reduction of paper in the work area – digital BOM's<br>• Standardization of digital workflow | • Robust development platforms – J2EE, MS .NET | • Data Collection<br>• Production Unit Dispatch<br>• Process Management |

| | | | |
|---|---|---|---|
| | | | • Product Genealogy |
| Lean – Visual Control | • Visibility of plant performance | • XML<br>• Intelligent agent architecture | • Performance Management |
| Six Sigma – Measure | • Direct capture of product data<br>• Availability of historical data<br>• Data pre-formatted in suitable forms<br>• Quicker identification of exceptions | • COM standard<br>• Intelligent agent architecture | • Data Collection<br>• Process Management |
| Six Sigma - Analyze | • Statistical monitoring<br>• Data is transferred directly into statistical programs | • Robust development platforms – J2EE, MS .NET | • Data Collection<br>• Quality Management<br>• Performance Management |
| Six Sigma - Improve | • Easier implementation and rollout to other workstations<br>• Faster availability of process or product data | • Robust development platforms – J2EE, MS .NET | • Process Management<br>• Data Collection |
| Six Sigma - Control | • Continuous process performance monitoring<br>• Mistake proofing the process<br>• Project documentation<br>• Translated learnings to other workstations | • Robust development platforms – J2EE, MS .NET | • Process Management<br>• Performance Management<br>• Document Control |

## 4.5 Discussion

In this chapter, we proposed several ways in which Lean and Six Sigma principles can be integrated with an MES. We described the technologies available that make this possible and clearly linked the principles, technologies, MES module and benefits of this integration. We also outlined several of the emerging trends to be found in MES applications.

All technology trends in the MES industry support more flexible manufacturing and improved production efficiency. The industry has seen increased outsourcing, globalization, mass customization of customer orders, improved warranty cost management and shrinking product lifecycles. As a result, manufacturers, in an effort to stay competitive and respond faster to production changes, are trying to closely tie the wider enterprise to the shop floor. This allows redirection of orders to meet service levels, allocation of capacity to maximize revenues, and production to match actual demand - thus improving the overall customer experience.

First, a key learning of this chapter is the direction of MES. This direction includes more decision support from the aspect of intelligent agent architecture integrated with the MES. It includes automated rescheduling and rules based dispatch of work orders. MES applications will also include extensive process & production visualization and highly interactive graphical work instructions representing complex execution workflows.

Second, we suggested ways in which an MES can be used to support Lean and Six Sigma principles. There are benefits to be gained from this integration – not only is the process simplified but inventory turns can be reduced, costs may be taken out of the process, employee productivity increased, asset utilization improved and real-time shop floor information can be made visible to the larger enterprise.

A search for companies or entities that have investigated the use of IT to enable Lean or Six Sigma improvement on the shop floor yielded no results. The author interviewed several professors and industry professionals specifically for examples about this topic and none had previous knowledge of such an exercise. The reader must be cautioned that implementation of such an MES as described in no way means, guarantees or can be substituted for implementation of Lean or Six Sigma principles in a firm. Lean is much more than just an information technology application. The author seeks only to suggest ways that an MES can complement a lean effort and be differentiated from existing MES applications. Typically in lean circles, technology is considered as only a tool in the production environment, this chapter attempts to show that it can be more than just a tool alone.

In the next chapter, we provide some recommendations to the development of an MES with the schemes described above and to the implementation of an MES in the plant environment. Finally, we restate the key learnings of the overall project and give some suggestions for future work.

# CHAPTER 5: CONCLUSION

## 5.1 Key Learnings

As a result of this research, a number of key learnings were extracted. These learnings were as follows:

- ***A Manufacturing Execution System transforms the shop floor from a paper intensive process to an electronically driven process and its real value is it's ability to connect the shop floor to the enterprise.*** The benefits of an MES include increased operational visibility, improved information flow on the shop floor, removal of non-value added activities of handling and managing information details, identification of inventory problems and bottleneck areas and improved tracking of quality.

- ***Close integration of the individual MES functionalities allows significant benefits to be derived but decoupling allows for modular design thus increasing reusability of the individual components.*** Significant capability remains to be exploited by integrating the various functions. Each becomes more powerful when information is transferred between it and the others. However, decoupling of functionality into individual, standalone, reusable subsystems increases the modularity of the system and drives reusability of components within other programs or by themselves. There is some economic benefit to this as shown in Chapter 2 where several MES vendors sell individual parts of MES functionality.

- ***MES architecture is relatively simple but customization becomes difficult due to large variation in manufacturing environments***. The five segments identified – Database Server, Application Server, Support Equipment, Production Workstation, Production Equipment - are well known and implementation is straightforward in most environments. However, what is difficult is the customization of the MES to fit an existing manufacturing environment and the challenges associated with acceptance of change by production personnel.

- ***Several equipment manufacturers are acquiring or partnering with MES firms in order to complement their product offerings***. Large equipment and ERP firms are acquiring or partnering with smaller MES firms in order to provide a complete solution to their customers. Others are in the process of creating their own MES products through internal development. Though a slower route to a product, it somewhat guarantees better integration with existing products. The sponsor company has chosen this latter route to an MES product and will have to increase its speed to market with an internal solution to be a successful player in this market.

- ***Few companies hold patents in the area of MES software.*** The basic premise of such patents has already been captured in existing patents. Market research has shown that several companies have products on the market with exactly this concept so at a general level, this concept might not be patentable. Patent opportunities more likely exist around the technology that make the capabilities described in the paper feasible.

- ***The MES of the future will integrate decision support capability***. Intelligent agents that make decisions based on certain production operating characteristics will be integrated with the MES. This 'decision automation' will enable production workers to focus on the quality of the product and making further improvements to the process. MES applications will also include extensive process & production visualization and highly interactive graphical work instructions representing complex execution workflows.

- ***MES applications need to be more robust and "off-the-shelf."*** Solutions need to be lightweight, have the capability for customized designs and require less time for implementation.

- ***It is possible to integrate Lean and Six Sigma principles with IT and in particular use an MES to aid implementation of these improvement processes.*** In addition to process simplification, inventory reduction, increase of employee productivity and improved asset utilization, real-time shop floor information can be made visible to the larger enterprise. Typically, there is disdain for the IT system in favor of process improvement methodologies. Here, we suggest ways in which IT can be used to enable these improvement principles.

## 5.2 Recommendations

At the completion of this research, a number of strategic recommendations were presented to the sponsor company. These recommendations were as follows:

- ***Leverage the manufacturing technologies, large installed base, experience and knowledge developed in the automation industry.*** While this market is not new to the sponsor company, it is still critical to continue to develop it and to increase its expertise in order to maintain its leadership status. The sponsor company should identify an existing customer (internal or external) who is willing to be the lead user of a prototype MES system.

- ***Use the suggested functional hierarchy as a guide to developing an MES application.*** However, this does not mean that alternatives like acquiring or partnering with an existing MES provider is not viable. Simply, it is intended to be a strategic guide in development. An integrated approach is required for developing an MES. Currently, several pieces of a possible MES are being simultaneously developed. An organization needs to be created that will lead and coordinate the efforts to develop an MES.

- ***Using the industry research provided in this paper, investigate the acquisition or merger with an existing MES provider.*** Even though the sponsor company has a wealth of experience in the automation industry, there is a learning curve associated with fully understanding the discrete MES industry and creating an organization to develop and sell and maintain the product.

- ***When implementing an MES, certain practices are useful to follow.*** Frequent and regular data transfers to the historical database to keep the active database small are advisable. It is prudent to regularly collect performance statistics. As demands on the MES application and database change over time, these statistics can serve as a baseline from which decisions can be made regarding performance and scaling. Simple interfaces between components and the integration and use of COTS products make for easier modifications and updates.

- ***Incorporate Lean and Six Sigma principles as a way to differentiate from existing MES providers.*** As shown in Chapter 2, very few MES providers have chosen to integrate or support improvement principles in their applications. By showing that this MES will aid in process simplification and process improvement, the sponsor company can leapfrog the existing competition.

## 5.3 Future Work

As a continuation of this research, there are a number of opportunities to extend the work that has been presented. These opportunities are as follows:

### 5.3.1 Product Development

With the completion of this paper, the necessary due diligence on the MES industry and MES functionality has been completed. The sponsor company now has the capability to develop an MES in-house, partner with an MES provider or acquire a provider outright. Currently, the strategy is to develop in-house and use existing internal facilities as the testing ground for the product. This strategy is outlined below.

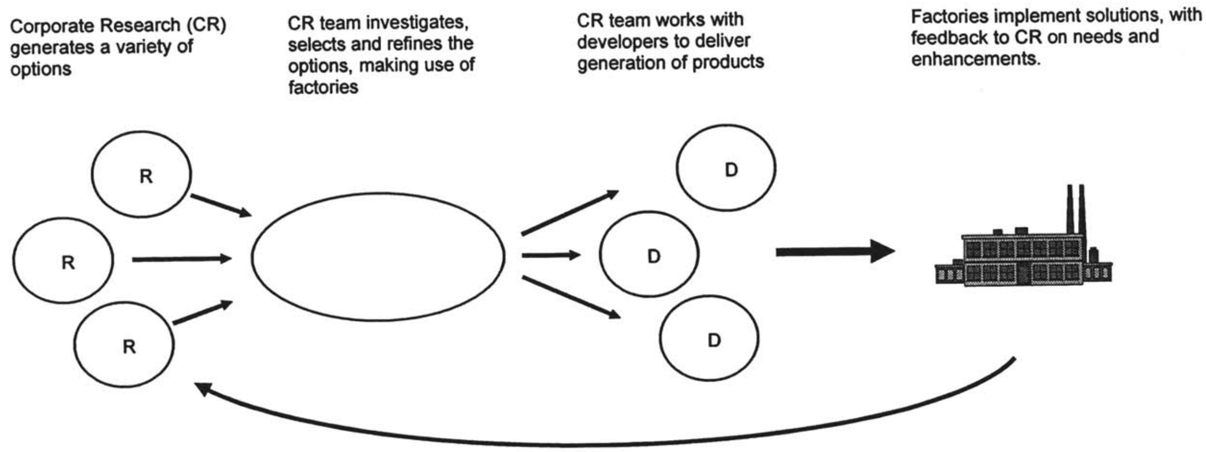



**Figure 5.1: Current product development strategy**

Some benefits to this strategy is that the sponsor company can leverage its knowledge of the proprietary software platform Aspect Integrator Platform (AIP) and automation equipment knowledge to develop an MES that works well with its existing products. This almost guarantees an immediate market for the product among its existing customers.

Research showed that some key requirements of the product are:

- Communication and integration to other manufacturing information systems
- Client-server technology and use of Application Programming Interfaces (API's) for connectivity
- Meet all the functional requirements described in this paper
- Flexible enough to meet a plant's dynamic environment

As part of his research, Jason Seay identified several software development strategies and other technology advances that benefit MES functionality. Some further work needs to be completed in developing the software.

### 5.3.2 Product Commercialization

The next phase of the development process will be commercialization of the product. This refers to go-to-market strategy of the product. For the purpose of this paper, some aspects of the commercialization strategy have been completed. Namely, intellectual property analysis, competitive analysis and product value add. Others were completed by Mike Hoag during his internship (business plan, identification of market size, proof of concept, resource analysis and training plan).

Further work in this area requires:

- Identification of the assets needed to complete this product
- Definition of the target customers
- Identification of lead customers to give input to the product team
- Formation of an internal group to champion and develop the product
- Definition of the support and maintenance organization for the product
- Creation of a pricing strategy

Sections of the above list were completed to varying degrees during this project but in-depth work is still required.

### 5.3.2 Implementation

Finally, a study needs to be undertaken as to the challenges of implementing an MES in a new or existing production facility. A survey of case studies at a recent MESA conference [17] showed that some of the key challenges to MES implementation were:

- The process was found to be more complex than expected
- The costs were more than originally estimated
- A risk of insufficient resources to manage the implementation or maintain and support it afterwards
- There was no system or plan in place to manage future configuration changes
- It was difficult at times to establish connection to external suppliers
- Solutions were too hard-wired and not flexible to changes
- Multiple data formats need to be considered
- Several systems needed to be integrated
- Uncertainty in competition times led to 'padding' of the turnaround-time

The recommendations of these MES customers were to:

- Establish strong project leadership
- Give complete access to information
- Create as detailed requirements as possible
- Leverage the experience of current staff
- Obtain executive involvement early

These brief lists provide some indication of the challenges faced by customers and MES providers. They give an indication of the direction of further research. In the meantime, we suggest the following roadmap for implementing an MES incorporating the previously stated challenges and recommendations by MES customers.

**Establish a Project Charter**. One of the most important early steps to be completed should be the clear definition of the project scope and approval of the main stakeholders. The project plan should be created at this step and be as detailed as possible with resources identified for each step. If no resource has been identified, the project should be halted until this is done. Very important here is the dedication of strong leadership for the life of the project and a team composed of members from all groups who will interact with the system. Other critical deliverables for this phase are a committee of stakeholder who can advise the project, communication plan, document index and a draft training plan. Typical tools here are Gantt charts and other project management tools.

**Develop the Business Case**. Identify the Manufacturing Execution System vendor that the firm plans to work with. Ensure that they understand the scope of the implementation and that they have a clear multi-generation plan for updating the application. Despite the difficulty, make a concerted attempt to define exactly what the benefits of the MES will be as not all MES implementations result in the same amount of benefit. Key to this phase is a baselining of the existing processes and systems and measurement of the existing quality. Outputs of this step should be high level As-Is and To-Be models and a gap analysis. Some tools that are useful here are process maps, and simple cost-benefit and return-on-investment analyses.

**Complete a Feasibility and Risk Analysis**. Determine and document the perceived risks involved in the implementation. In the project at the sponsor company, these risks were financial, technical, temporal and organizational. The most severe risk experienced by the author is the constant scope creep of the project.

**Perform a Requirements Analysis**. The project team should identify as many customer requirements and system requirements as possible. A scorecard with the target specifications, lower and upper limits should be developed and used throughout the project. Some example system requirements are software, hardware, interfaces, layouts, database definitions, data conversion approach and system architecture.

**Implement the system and Evaluate Performance.** At this point, the verification criteria should be developed before implementing the system. The scorecard should be used throughout to track progress to the goals. All risks should be continuously assessed and retired as soon as possible. Users should be involved as soon as possible with testing through conference room pilots. The feedback given by actual users as part of acceptance testing is invaluable to the correct functioning of the system.

**Establish a Transition Plan.** At this point it is important for plant personnel to take over ownership of the system and start training other users. The implementers, especially those external to the plant, should take an increasingly lesser role in the project. This allows self-sufficiency of plant personnel.

**Go Live.** The team at this point should verify customer satisfaction with the installed system and evaluate quality, final cost, system performance and further enhancements thoroughly. An important task is to document all lessons learned throughout the implementation as these will be useful in the next implementation.

These suggestions for implementation are not meant to be a hard and fast methodology. Instead they should serve as an outline of steps that have proved helpful in the past. The length of time and difficulty in implementing such a system will more than likely depend on the complexities of the manufacturing environment and the resources dedicated to the project.

## 5.4 Final Remarks

"Future manufacturing enterprises will use technology as a key parameter in the lean equation to achieve new levels of efficiency. Intelligent controls, expert systems, improved supply chain management, and exploitation of emerging technologies will be among the tools of lean enterprises." [18]

In this thesis, we defined the functional requirements for an MES product and presented ways that some manufacturing principles could be aided by an MES. Analysis performed at the sponsor company - Feasibility Study, Customer Value Add, Competitive Analysis and Risk Analysis and others - provide a foundation for defining the product, better understanding the industry and the entering the market.

As a result of this project, the sponsor company has a clear strategy of what to productize, a definition of the products and a robust process to do it. By combining the details of the functional specification with market information of key competitors and market capabilities/deficiencies and a defined development process, the sponsor company will have a concrete product roadmap. This roadmap will not only consider development of products from current projects but also pinpoint how future projects will fit within the framework.

# APPENDIX A: MARKET RESEARCH SOURCES

**List of market research sources used in competitive analysis**

- Arcweb - http://www.arcweb.com/ - Enterprise and Automation Advisory Services for Industry Executives
- Biz web - http://www.bizweb.com/ - Database of over 43,000 companies
- Company Sleuth - http://www.companysleuth.com/ - Free service that will track information on publicly traded companies
- Corporate Information - http://www.corporateinformation.com/ - directory of directories for finding company and industry information
- Dun and Bradstreet - http://www.dnb.com/ - Provides industrial business reports
- eMarketer - http://www.emarketer.com/ - Focuses on gathering statistics from various research reports and present their own take
- FindArticles.com - http://www.findarticles.com/ - Free service from LookSmart for searches of thousands of published articles
- The Industrial Resource Network - http://www.powersourcing.com/ - Searchable database for locating industrial suppliers
- Kompass - http://www.kompass.com/ - International company/product database that claims listing for more than 60 countries
- Manufacturers News - http://www.mninfo.com/ - Extensive database and detailed profiles for thousands of U.S. manufacturing firms
- McKinsey Quarterly - http://www.mckinseyquarterly.com/ - Excellent free online version of McKinsey Consulting's quarterly report
- Statistical Resources on the Web - http://www.lib.umich.edu/govdocs/stecind.html - site for finding links to government, business and industry statistical data
- Thomas Register - http://www.thomasregister.com/ - Leading directory of American manufacturers.
- Vertical Net - http://www.verticalnet.com/ - Offers more than 40 communities devoted to industrial and b2b services

# APPENDIX B: CAPABILTIES OF MES VENDORS

## Capabilities of Existing MES

| Criteria | Applied Materials | Apriso | AspenTech | Camstar | CIMNET | CIMx | DataSweep | GenRad (Visiprise) | Honeywell | iBASEt | IFS | InterCIM | Invensys | Lilly Software | nMetric | PRI Automation | ProfitKey | Rockwell | Technomatix |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical Data | | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| Widely Available Platform | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Data Collection | | ✓ | ✓ | | ✓ | | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dispatch Production Units | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | |
| Document Control | | | | | | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ |
| Labor Management | | ✓ | | | ✓ | | | ✓ | | | ✓ | ✓ | | ✓ | | | | | |
| Maintenance Management | | ✓ | | | | | | | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| Performance Management | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Process Management | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Product Genealogy | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | ✓ |
| Quality Management | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Resource Allocation | | ✓ | | ✓ | ✓ | | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ |
| Scheduling | | ✓ | ✓ | | ✓ | | ✓ | | | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Real-time data | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Automated | | | | | | | ✓ | | | | ✓ | | | | | | ✓ | | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test and Inspection | | | | | | | | | | | | | | | | | | | |
| Web-based interface | | | | ✓ | ✓ | | ✓ | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | | | ✓ |
| Lean Principles | | | | | | ✓ | | | | | ✓ | ✓ | | | ✓ | | | ✓ | |
| Theory of Constraints | | | | | | | | | | | ✓ | | | ✓ | | ✓ | | | ✓ |
| Six Sigma | | | | | | | | | | ✓ | | ✓ | | | | | | | |

# APPENDIX C: COMPETITOR PATENT ANALYSIS

**Direct Competitors**

- Invensys: 11 patents obtained mainly in the area of conditioning and refrigeration units. No current patents on any software capabilities.
- PRI Automation: 16 patents obtained mainly associated with a material handling system for microprocessor wafer production. No current patents for software related products.
- Lilly Software: 2 patents obtained for a method and apparatus for scheduling work orders in a manufacturing process. System described does include a software component for handling the scheduling of orders and tracking material flow.
- GenRad: 68 total patents obtained mainly in the area automated circuit test apparatus. 18 patents obtained relating to software. Most software related patents describe a method and test apparatus for quality checking of electronic components.
- Applied Materials: 2010 total patents obtained mainly in the area of microprocessor production. 304 total patents obtained relating to software processes to assist in microprocessor production.
- Schneider: 774 total patents obtained relating to electrical components. 31 patents obtained relating specifically to software. Software patents include web interfaces to programmable controllers and inter-network communications.
- Emerson: 1346 total patents obtained mainly in the area of household electrical systems such as washing machines and waste disposals. 47 patents related to software. However, no software patents are related to manufacturing processes. Most are associated with control systems for a variety of devices.
- Camstar: 1 patent obtained for a system and method for implementing revision management of linked data entities.
- Honeywell: 5,287 patents obtained in a variety of areas. 664 software-related patents in a variety of areas.
- Rockwell: 4,043 patents obtained in a variety of areas. 334 patents related to software. Some specific patents relating to manufacturing environments such as "Virtual Toolbox for use with industrial control system" and "Walk-through human/machine interface for industrial control."
- AspenTech, DataSweep, ProfitKey, Technomatix, Industrial and Financial Systems (IFS), iBASEt, CIMNET, CIMx, CIMlinc, Citect (previously Ci Technologies), InterCIM: Zero patents obtained or filed.

**Same Industry Non-competitive**

- Siemens: 16,766 total patents obtained in innumerable areas. 983 patents related to software with some applications to manufacturing environments.
- Alstom: 195 total patents obtained mainly in the area of gas turbine parts and energy production. 18 patents related to software. However, no current patents relating to software systems for discrete manufacturing of parts.

**Latent Competitors**

- GE Fanuc: 27 total patents obtained mainly in the area of programmable controllers. Some software related patents for collecting data and monitoring power.
- Business Objects: 2 patents obtained both relating to a relational database access system.
- IBM: 495 total patents in mainly computer related areas. Many patents related to the application of IT to manufacturing systems.

# APPENDIX D: MES INTEGRATION TO OTHER SYSTEMS

## Interface with ERP Systems

The following are example requirements for the MES System to interface with an ERP system

- It should allow real-time communication with the ERP System through industry standards such as business API, XML or other tools dealing directly with the database models
- The ERP System should furnish the Bill Of Material (BOM) for each product to the MES system
- Each item on the Bill Of Material that is to be manufactured should have the manufacturing process outlined in routing steps which usually have time standards attached to them
- THE MES System should provide production posting triggers to the ERP System as the part moves through the production process
- The MES System should summarize the consumptions by part number and deliver it to the ERP System
- When product has gone through Finished Part Packaging, the MES System should perform production posting to the ERP System
- The ERP System should furnish the schedule of builds for the week. Quantities of each requested version number and the expected completion date will be managed and reported by the MES
- The ERP System should issue work order number for the MES System. This permits the MES System to track the required build by this tracking number

The ERP System is normally required to do the following functions and as such, the MES System is only to feed data to the ERP to support these elements

- Provide resource, labor and material status and usage to the corporate planning/costing system
- Provide order status for customer inquiries
- Provide accurate visibility of WIP and finished goods inventory to provide better control on production planning and execution

## Interface with Supply Chain Management Systems

The supply chain management system expects information related to supplier quality. Example requirements are

- Time spent on rework of defective supplier material
- Scrap produced as a result of defective material
- Receiving Inspection
  - Online instructions for inspection
  - Data on incoming products can be collected at receiving
  - Storage of supplier data
- Tracking of Non-Conformances
  - Online processing and assignment
- Supplier Rating
- Corrective Action

### Interface with Product Data Management Systems

The engineering systems have several requirements of the interface to the MES system:

- Work instructions
- Work instruction updates and revisions
- Automatic distribution of changes in work instructions
- Distribution of stop orders
- Product yield and quality data
- Operational parameters
- Tracking of special prototype orders

### Interface with Sales and Service Systems

Requirements of the interface to Sales and Service systems include:

- Availability data based on availability of resources and material
- Order configurations and special instructions
- Order tracking
- Configurations
- Product manufacturing history for defect returns

### Interface with Control Systems

Some requirements of the interface with the control system are:

- Interface to analog devices and sensors through analog I/O dedicated PC cards
- Interface with logical states/digital I/O to relay machines and relay devices

- Interface to serial or other intelligent serial devices through serial lines with RS-232 compatibility
- Interface to various PLC types (such as Philips, Siemens, Schneider or Allen-Bradley) through dedicate machine interfaces
- Serial connections to QC measurement devices
- Serial links for user input from operators and maintenance
- Process and product data collection for tracking and control purposes at every operation (bar scan)
- Instructions and recipes to controls
- Data on actual performance and operating conditions from controls

# APPENDIX E : RESOURCE ALLOCATION

Specific functions include:

**Add, Modify or Delete a resource** - This requires special authorization for all actions with options corresponding to the type of resource. The user should be unable to delete a resource that is currently in use. However, the capability should exist to make resources available/unavailable for use.

**View Resource Status/Details** – The 'People' details should include Picture, Employee Hire Date, Time and Attendance record, Current Status (at work/absent) and Current Location/Workstation. The Labor Management function should have even more details.

- The 'Equipment' details should include features such as Current Operation Status, Last Maintenance, Next Maintenance, Maintenance History, Cumulative Downtime, a Photo of the equipment, Links to related documents, Location in the plant and History of all Changes over a specified period.
- The 'Document' details should include Document Title, Author, Location, Status, Type, and a Front Page Preview. More details are captured in the Document Management function.
- The 'Tools' details should include Checked out/in status and by whom, Current Location, Storage Location, Supplier and Maintenance Owner.

**View list of all resources** - This function gives a report of all resources in a plant in list format and allows sorts of the list by location, equipment supplier, equipment maintainer, resource type and current status.

**Possible Databases, Tables and Fields for Resource Allocation Module**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Document Control** | **Document** | Number, ID, Log |
| **Labor Management** | **Employee** | ID, Number, First Name, Last Name, Cost Center, Department, Site, Email, Phone, Current Logged in Station, Certification, Training, Assets Allowed, Time Log, Work Log |
| **Maintenance Management** | **Machine** | Last Maintenance, Next Maintenance, Supplier, Supplier Contact, Work Order Number, Work Order History, Task Ids, Task Descriptions |
| **Supply Chain Management** | **Supplier** | ID, Name, Contact Details, Parts Supplied |

# APPENDIX F : OPERATIONS SCHEDULING

The production process is driven by a customer schedule, which formulates a plan that will be subsequently executed. The follow up to this plan ensures efficiency to the organization. Example requirements are:

- Allows the planning of all manufacturing resources including machines, tools and personnel
  - Workforce availability (shifts/hours/day, breaks, days off, training)
  - Raw Material Availability (stock levels, re-order points, training)
  - Resource Availability (Maintenance, scrap rate, setup/teardown time, repair)
- Allows planning prior to commitment or execution of plan
- Due Date Quoting (Capable –to-Promise, or negotiated)
- Hour by hour based planning, using a graphical 'plan board'
  - Simple Factory model composed of basic representations
- Account for the build up of Work In Process (WIP), to ensure production overruns do not occur
- Planned Raw Material Release Date (but maintaining ConWIP)
- Ability to track the quantity of assembled and finished products
- Ability to schedule in changeover and maintenance and non-working hours
- Ability to adjust the resource's capacity and efficiency and labor standards
- Ability to set the detail behind each work order, including
  - Product Name
  - Due Dates
  - Standard cycle times, product efficiency
  - Resource requirements including personnel, materials, and tool(s)
  - Quantity of pieces
  - Visual Management techniques for status of each order
  - Order Management should be real time (allows prioritization of late orders)
- Issue the plan in the form of a report, email or Visual Management display
- Performance Measurement
  - % On time delivery
  - % CCR Utilization
  - Throughput, WIP (daily, weekly, monthly – trends)
- Real time feedback required to update the plan

    - Uses real efficiencies (scrap, downtime) to determine when order will be completed
- Ability to identify Critical Constrained Resources – Capacity/Material constraints
- Size of buffers in front of Critical Constrained Resources
- Allow for exception handling – 'rush' material lead times, 'rush' capacity, overtime
- Exception Alert – materials, workforce
- What-if Scenario Planning
    - Optimize against suitable criteria
    - Assess impact of chosen criteria on KPI's
    - Use Rules (Maximize Profit, Minimize number of Late Orders, Minimize Average lateness, Minimize Cycle Time

**Possible List of Databases, Tables and Fields for Operations Scheduling**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Scheduling** | **Shift** | Shift(i) Start, Shift(i) End |
| | **Break** | Break(i) Start, Break(i) End |
| | **Year** | Year(i) Start, Year(i) End |
| | **Hour** | Hour(i) Start, Hour(i) End |
| | **Resource** | Critical Constraining Resource (i) |
| **Labor Management** | **Employee** | ID, Number, First Name, Last Name, Cost Center, Department, Site, Email, Phone, Current Logged in Station, Certification, Training, Assets Allowed, Time Log, Work Log |
| **Maintenance Management** | **Machine** | Last Maintenance, Next Maintenance, Supplier, Supplier Contact, Work Order Number, Work Order History, Task Ids, Task Descriptions |
| **ERP System** | **Inventory** | Part Onhand Quantity, Part Current Demand, Part Kanban Required Quantity, Part Kanban Actual Quantity |
| **Customer Order System** | **Order Detail** | Product Due Date |

# APPENDIX G : PRODUCTION UNIT DISPATCH

Specific functions include:

- View of order list as outputted from ERP or Scheduling function
- Ability to set automatic release of order to floor
- Ability to approve and release orders to shop floor
- Ability to sort orders by due date or product type of quantity
- Ability to assign an order to a particular workstation

**Possible Databases, Tables and Fields for Production Unit Dispatch**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Dispatching Production Units** | **Job** | Job(i), Order (i), Order Assigned Date, Production Start Date |
| **Process Management** | **Process** | Product Process(i) |
| **ERP System** | **Inventory** | Product Routing, Product Bill Of Material |
| **Customer Order System** | **Order Detail** | Product Due Date, Finished Product Order Requirement |

# APPENDIX H : DOCUMENT CONTROL

**Storage**

This requires the ability to create a secure electronic area for electronic files regardless of their format and associate these files to people, processes and equipment (among others) to provide immediate access to related documents. Some example requirements are:

- A secure storage repository for the intellectual property of an organization. Electronic documents, regardless of format, are stored within the MES database or related client/server database
- Ability to search documents by title, document number, file name, project, author, related equipment, site, etc.
- Through a built-in checkout, check-in process, a complete revision history of each document is maintained. This feature also prevents two users from modifying the document at the same time. If check-out is not required for edit or revision purposes, documents may be viewed on screen or sent to a printer, eliminating the need to physically locate and copy the document
- For viewing purposes third party viewing programs should be used to view files created in different applications without the user needing the application on his computer
- Use a method to organize important information about each document. Specifically, information relating to the document, including its location, release, current status and audit trail: who created a document, when it was put into the database and why it was created are all part of the information about every document. A complete revision history of every document provides an archival dimension for document tracking, circumventing laborious historical research during an audit on the genesis of a particular document
- Availability of a master list of all documents
- The buttons on the screen represent the different functionality available to users (according to user status and clearance) including adding a new document, deleting or editing a document, finding, checking-in or -out a document, or viewing a document

**System Management**

- This function allows document and system managers to create custom security protocols for different individual users and workgroups. Through this module, document types are defined and managed. Combined, these two features enable a limited document set to be created for a specific employee or workgroup using the documentation. This means that the MES can be used not only for document control, but also as an information access system for workers on the production floor.

- Once a procedure or specification is released, MES should be used as a paperless production manual through terminals on the production floor

**Approval**

The Approval module enables the automation of routing and approval processes in an organization.

- Approval routings should be user definable and may include both serial and parallel sequences. The system should allow for the routing of either individual documents or packets containing multiple documents
- Distribution list for all documents
- Capability to send change notifications by email
- Utilization of the Approval module should allow for the distribution of documentation with positive notice that the recipient received and signed for the documents
- Possible use of the module for training notification
- The FDA has now allowed electronic signatures to be used in the distribution of documents within an FDA/GMP regulated facility. MES should support electronic signatures, allowing paperless documents
- Document check-in/check-out

This also includes the distribution of documents for required viewing by specific employees at login.

**Organization**

This module allows users to graphically file any document, including CAD, word-processing or spreadsheets into projects, processes, or any logical grouping required by the user. Example requirements are:

- A graphical tree structure to manage documents in outline form
- Hyperlink to all documents
- Custom icons assignable to each document type allowing rapid visual identification of the document type by the user
- Configuration of products with released documents, allowing multiple variations of product to be documented without physically reproducing the drawings, specifications, bills of materials or other related documents. This feature is very helpful where products vary only in minor degrees.

- Individuals working on a project have instant access to the current released version of any document
- Individuals know if there is another revision in process
- Ability to sort documents by size, name, creation date, major product etc.

**Possible Databases, Tables and Fields for Document Control**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Document Control** | **Document** | Master ID, Number, Title, Author, Description, Format, Size, Location, Status (Release, Draft), Release Date, Last Revision, Audit Trail, Check Out Required, Checked Out/In, Checked Out/In By, Checked Out/In Date, Related Assets, Security Level |
| **Labor Management** | **Employee** | ID, First Name, Last Name |
| **ERP System** | **Inventory** | Product Routing, Product Bill Of Material |
| **Customer Order System** | **Order Detail** | Product Due Date, Finished Product Order Requirement |

# APPENDIX I : DATA COLLECTION/ACQUISITION

**MES Database**

The baseline information strategy is to create a shared area (MES database) where all the potential users of data will extract or provide data. The MES database is a read/write area that ultimately publishes its' data using standardized names or 'tags' so that the user of the data can more intuitively work with the data. The MES database does not log or trend or analyze data. The MES database requires unified hardware and software systems to be used. These unified systems are to use the same naming convention with common engineering units. Example functional elements are

- Connectivity to new equipment that embraces the MES database methods should not require any programming (by the end user) either on the MES system or the equipment to enable browsing of the standardized names. It is expected to deploy demonstrated industry standard connection methods for this data connectivity, including such protocols as COM or OPC.
- Browsing of these standardized names should be a tool available at all levels of access in the enterprise. List boxes of available tags, with filtering and sorting ability should allow the user to access the data points of interest. This concept may include
    - Hierarchical or a grouped structure shall permit the variables to be classified into areas to simplify the search of a variable
    - The hierarchical structure can also be described as a grouping technique. This hierarchical structure should use elements described below
        - Line name – ill typically contain several machines or several cells
        - Cell name – the equipment that may perform several operations to a production part, it can contain several modules, e.g. a complete other machine
        - Module name – a group of several operational stations contained in a definable machine frame. The module can work on a part with or without any of the other modules
        - Station name – a grouping of one or several working units
        - Unit name – lowest grouping of equipment function, as this level performs a singular operation to the production piece
- Drag and drop methods from the should permit population of data queries

The following is example of data content required

- The supervisory start cycle and stop cycle for the equipment

- The schedule of the operations required for the next processing operation. This determines the version to be manufactured, and is based upon the production part that is entering the machine
- Process values including discrete and continuous data
- Events including parameter changes and machine alarms
- Results of processing (pass/fail)
- Bar code scan data
- Product serialized 'Birth Certificate'
- Hold, Scrap and Disposition codes
- Operator 'badged in' name
- Product routing sequences
- Product names and identifiers

The following machine control level work is required to support introducing data into the MES database

- In some cases interaction with the original equipment manufacturer (OEM) to understand the control system programs
- The protocol and PLC programming for the MES database should support continuous parameter acquisition as well as per part acquisition

**Data Export**

Data Export is a function by which data can be extracted and issued to many third party analysis applications. The MES database must be open enough to extract any data, in any format for any future application. Example requirements are:

- Continuous process data, discrete process data, event data, SPC data, signature data, and graphic images should be included
- Time stamp of the measurement time
- Export to Excel, Microsoft Access and other COTS software applications
- User triggered – when it is to be transferred
- User controlled – what range is required
- The process and production data should be sent up to the MES database transactionally for instant accessibility. This central data repository is imperative for proper, timely management analysis of process, production, maintenance impact type data
- Automation of this data transfer is desired including 'batch' file techniques

- Technologies to share information between the applications are strongly desired including tools such as Active X, OLE, COM, and XML

**Signature Analysis**

Signature Analysis is a tool that will acquire a process value that exhibits a characteristic waveform or 'signature'. This signature is compared against the mastered value limits to determine if the signature is OK or not OK, hence validating the process control. Example requirements are:

- Acquisition of a parameter is to be from a PLC, DCS, or directly from an analog signal form a sensor
- Acquisition should be sample based. The signature can be simplified before storing to the MES database but must ensure that information is not lost
- Positive and negative tolerances to be unique per sample
- The evaluation of the sample to occur within the start and endpoint of the sample's acquisition
- It should be part of the validation and alarming scheme
- A unitary pass/fail bit can be used for subsequent operations that will validate the part
- The signature should be stored
- The limit set should be stored under the event logging system, which should record changes to the limit set when they are changed
- Overlays of the same signature on a trending system should be available across a user defined time window
- Automatic calculation and optimization of each limit is required during the trend overlay session
- Limit set configuration is to be contained at the facility level

**Recipe**

Recipe control is a method to store and retrieve the entire machine based set points and limits of the unit, station, module or cell. It permits an electronic record to be stored for the product with all the product specific variables assigned in this record. Example requirements are:

- Recipes should reside locally and in a central location
- The MES system should record the changeover as an event in the event logging system
- Recipe delivery should occur in the following possible ways
    - Local retrieval of a recipe from a central server containing all recipes

- Central delivery of recipe to the workstations which require changeover to the new product
- Management and format of recipes
  - Parameters should be stored by product, and mode of production
  - Storage and retrieval to be capable to the unitary level
  - Content control, to ensure recipes do not get put into the wrong equipment causing personal injury
  - Storage and retrieval of process set-points
  - Storage and retrieval of calibration set-points
  - Storage and retrieval of configuration values including station names, product ID, routing, database name, and other product characteristics
  - A local recipe file should also be maintained on the MES database

**Possible Databases, Tables and Fields for Data Collection**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Data Collection** | **Data** | ID, Format, Source, Frequency, Last Collected, Collection Protocol (<COM>, <OPC>, <User>), Primary Display Method, Export Format (i), Range Start, Range End |
| **Labor Management** | **Employee** | ID, First Name, Last Name |
| **Quality Management** | **Event** | Event Name, Event Occurrence |
| **Process Management** | **Process** | Process ID, Process Name, Line Name, Line Description, Station Name, Station Description |

# APPENDIX J : LABOR MANAGEMENT

Specific functions include:

**Add, Modify or Delete a person** - This requires special authorization for all actions. Users are unable to delete an active person but should have the ability to make a person active for use in production.

**View Person Status/Details** – This function should include a Picture, the ability to view an employee's work history, time and attendance record and their Current status (at work / absent) and current location.

### Time and Attendance Reporting

The labor tracking information from the MES System should be available on the time and attendance system's database for generating reports, queries, etc. The following are example requirements for Time and Attendance on the MES System

- At MES System operator interface screens, the operator should be allowed to scan his/her login. The user login should be recorded along with the date/time at the machine and whether the person is logging in /out of the system
- The MES System should provide the necessary access to the user, based on his/her configuration and default privileges at the work place
- The communication mechanism should support the following integration to Time and Attendance Systems
    - MES System should receive the employee's ID as well as training level from the Time and Attendance System
    - MES System should receive the work center to account # relations
    - MES System should issue the employee ID and work center account # to the Time and Attendance System.

**Possible Databases, Tables and Fields for Labor Management**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, all other |
| | **Asset** | Name, Description, Location, all other |
| **Labor Management** | **Employee** | ID, Number, First Name, Last Name, Cost Center, Department, Site, Email, Phone, Current Logged in Station, Certification, Training, Assets Allowed, Time Log, Work Log |
| **Process Management** | **Station** | Name, Description |

# APPENDIX K : QUALITY MANAGEMENT

**Continuous Process Control**

**Process Data Collection**

During the manufacture of product, many pieces of information could be collected as the product evolves from a basic state to a complex finished state. This section allows for methods to extract data from the MES database

- The MES database should continue to collect data at the end of every machine cycle at all required equipment locations
- Additional process data collection methods may include
    - Automated collection by time interval
    - Automated collection by event

**Continuous Process Control**

The system should perform analysis on each enabled alarm. It should also provide the ability for the users at all levels in the organization to perform analysis on historical data. Examples of functional requirements are

- Trend display of a parameter showing its CPC limits
- Trend display shall show any time frame, with all recorded parameters from that time
- Trend display shall provide ability to overlay different parameters simultaneously
- All process and product data collected should have the ability to have CPC limits applied to them
- Look up a specific part's CPC history and have the ability to find all parts made under a specific CPC limit set
- Each alarm for each parameter can be enabled and displayed by the user
- When a limit parameter is changed a record of this event should be recorded
- Changes to the CPC limits are to be applied to the current CPC limit
- CPC limits are product specific
- Where the CPC limit does not exist on the machine a separate alarm will be provided by the MES system to the machine control, to provide immediate feedback to prevent continuation of manufacturing out-of-control product
- New CPC limits may be calculated based on user defined sets
    - Statistical methods are to be a method to set these limits. This should be consistent with the SPC methods described in the *Statistical Process Control* section
    - Min/Max methods are to be a method to set these limits

- o Plus/minus tolerance from mean are to be a method to set these limits
  - o Percentile from mean of the sample set are to be a method to set these limits
- New CPC limits may also be set by manual input
- Alarm limits configurable could include
  - o Plus (+) minus (-) tolerance alarms including hi-hi, hi, low, low-low
  - o Deviation alarms (+/- offset or % from target)
  - o Rate of change alarm
- The trending system should give the ability to annotate the alarm condition, on or after the event has occurred

**Annotation and Reporting of Data Curves/Points**

- This includes the ability to document anomalies, events, or conditions onto a trend chart. This would allow others to benefit from the experiences of others, and to provide traceability of the processes in the event of a processing problem or a recall situation
- Annotation could be placed at any time on the chart, current or in the past
- Reporting could include by shift, day, week or month. Each annotation should have a time stamp.

**Statistical Process Control**

The intent of SPC is to achieve control of the process and eliminate defective products.

**Common elements of Statistical Process Control**

Some examples of common tools and methods in the MES database are

- It is assumed that all values that can enter the SPC system are in the MES database
- Event based or user inputted samples
  - o Data sources to include a variable time base, event or manual driven data entry methods (control limits and samples)
  - o Ability to flag (annotate) and assign cause to any sample
  - o Each sample will be typically a series of measurements. The quantity is to be user definable but ideally at least 30 for statistical significance
- Graphical analysis by using Pareto, pie, and stacked bar charts
- Frequency histograms with display of skew, kurtosis, all limits, normality, mean and standard deviation
- Control charts – $C_p$, $C_{pk}$ and standard deviation to be displayed

- Range charts (X-bar, R, etc.)
- Selection and display of any measured parameters
- The ability to flag samples, ignore samples, and mark samples showing a corrective action has occurred
    - Each flagged sample should allow comments for the sample and allow corrective action comments
- The control limits and specification limits should automatically changeover based upon the product type being measured
- When a limit parameter is changed a record of the event should be recorded
- SPC alarms visually conveyed to the local operator
- Alarming of sample or alarming of SPC system using standard run rules
    - Alarm indication of the 'out of spec' sample should show as another color on the control chart
- Interface screen should provide graphical data displays in real-time

**Machine SPC –values found in the machine control**

The data collection of a sample should be based upon a definable event or definable time base. Configuration controls are necessary to allow recalculation of the upper and lower control limits but specification limits should not be recalculated. Manual adjustment is permitted only to some engineering security level with the capability to allow feedback to the process.

**Product SPC – measurements after processing from manufactured product**

- Storage of the samples should be logged with the serialized part ID. This is to allow subsequent analysis of the part's SPC data to be married with process or lot data.
- Product Measurement – product can be measured from many locations within a plant, including the QC bench, QC lab and from manufacturing checkpoints. Product data is the data resulting from measuring product.
    - The MES database and connections should allow product data collection from these various locations
    - Product data sources include weigh scales, calipers, high gauges, etc.
- All part history should be displayable at a QC bench by scanning a QC lookup code. This should find the scanned production part in the SPC section of the database and alter the current display to show this part. It is expected that all product specific control limits, specification limits and other characteristics shall be displayed when the subject part is being displayed. This product history is to display the characteristics and limits that were used at the original time of measurement

- Based on the product type, the MES system should allow an operator to enter product specific attribute data. The data should be recorded as part of the birth certificate of the product. The product type is available by retrieving this information (per part scanned) from the database. Software interface screens at each location should provide specific online procedures for performing QC measurements. These procedures are based on machine and product type
- Interface screens should be configured to allow operators to select pass/fail results without having to write down or type this data for each part visually inspected
- The interface screen could prompt the operator to perform QC testing at preset intervals
- The interface screen should provide graphical data displays in real-time
- The local collection device should take advantage of serial device communication protocols with QC testing devices to allow automatic input of test data. This should eliminate the need for manual input and the possibility of input errors

**Full Process and Enterprise SPC recording, analysis and reporting system**

This system should be used conjunction with the SPC Data collection from the factory. Most analysis of data should occur on the shop floor as events and out of control situations occur. It is more likely that analysis of old data and the control limit set will be used to determine the root cause of issues

- Perform statistical analysis on online data to
  - Allow analysis of process parameters to engineers/product leaders
- Perform statistical analysis on historical data to
  - Allow historical data to pass judgment on current production
  - Look up a specific part's SPC history and have the ability to zoom in and out the time scale to observe more or less SPC samples
- Integrated Corrective Action and Improvement system

**Possible Databases, Tables and Fields for Quality Management**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |

| | | |
|---|---|---|
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Document Control** | **Document** | Document ID (Test Report Form) |
| **Data Collection** | **Data** | Format, Source, Frequency, Last Collected, Primary Display Method, Export Format(i), Range Start, Range End |
| **Labor Management** | **Employee** | ID, Number, First Name, Last Name |
| **Quality Management** | **Parameter** | Data Source, Alarm(i), Upper Specification Limit, Lower Specification Limit, Annotation(i), Annotation Timelog(i), Available Range Start, Available Range End, USL Last Changed, LSL Last Changed, Event Log, Test Report Form |
| **Process Management** | **Process** | Station Name, Station Description, Process Name, Process(i) |
| **Product Tracking** | **Part** | Part Serial Number, Part Birth Date |

# APPENDIX L : PROCESS MANAGEMENT

**Control of Product Flow between Part Creation and Finished Part Packaging**

The production part travels through several independent machines which each performs several operations. Most operations may involve sub-components and require specialized processes to transform the product. Many types of processing, routing and operator induced failures may occur. As a result the following example tracking and control elements are required:

- Use the serialized part label for all tracking requirements
- When an operator scans the serialized part label of a product, the MES database should verify the status of the product before it is allowed to continue in the equipment
- Where active control techniques cannot be used, passive routing should be used. The passive methods to be used are described in the *Passive Routing* section
- Example finite scheduling operations required
  - This function gives the ability to control what is to be done to the part. Once a schedule is defined upon a part the completion of what was started is required.
  - The ability to disable the active control nature of the scheduling system, enabling passive control
  - Specifying to the machine control (in a manner consistent with its abilities) the ability to state the required operations
  - Storage of what operations were done and if there were successful
  - Storage of the operation date and time
  - Storage of the lots used (lot traceability) for the operations performed
- Approval of operations – ability to allow a single operation that the control system has marked incomplete (or failed) to be re-classified as acceptable and complete. This assumes that the system is actively looking at the success or failure of the operation based on the machine control. Example functionality includes
  - Traceability of who approved the part and when
  - Approve of any unique operation by a bar code scan
- Rework on operations – ability at each location to accept product again. Example constraints on this functionality include
  - Rework ability is a function of the route definition
  - Routing redefinition should only be permitted on equipment that supports active control and scheduling, as to avoid equipment damage
- Part number printing at final assembly – A part number label may be required to be printed, applied and checked at the assembly area of the processing line. Example functionality includes

- Printing to a thermal transfer bar code printer. Label content may include any one or a combination of the following elements. It is considered that all or some of these elements will be human readable while others are bar-coded
    - Product name
    - Product number with revision level
- Allow the use of pre-printed part number labels, which requires that the MES database check the applied label. This could be through a prompt to the operator or through a bar code scan

- Measure time duration between process step X and process step Y – This function would be used as a part of active control to ensure the part belongs at this process already. Functional needs could be
  - Part elapsed time must be user definable from seconds to days
  - 'Part early alarm' should allow marking the part as defective if it is true. Also user defined

**Control of Product Flow for Finished Part Packaging**

This section involves packaging of finished product at the end of the processing line. The following are example functions

- When an operator scans the production part's serialized label, the system should validate the product
- Ensure that the proper product is packed in the proper container through bar code scan and validation of the container product number. This can be accomplished by
  - Visual techniques including lighted indication of product to pack and container to use
  - Audio techniques including verbal commands of product to pack and container to use
  - Alarm indication of incorrect pack sequence
  - Ability to turn off audio and visual techniques

- The MES system should record the packing container serial number and the product number
- In the case of multiple products merged and packed in the same container, the MES system should ensure all products packed are recorded

**Control of Product Flow for Shipping and Receiving**

The shipping area may be the same area as the receiving, and consequently are described together in this section. The shipping function specifically addresses the activity of picking a part from the Finished Goods area or warehouse or stocking location and placing it onto the vehicle or conveyance system that will transport the product to the customer. The following are example functions:

- When the shipping clerk scans the serial number of the container prior to putting it in the truck, the MES system should verify the status of the product before it is shipped.

- For the above, validation errors of an alarming system should be used to alert the operator that a problem has occurred
- Manual entry or bar code scan data for data input

**Passive Routing**

When bar code scanning is operational on parts traveling through the shop floor equipment, but PLC or machinery connection is not utilized, their travel is tracked by passive routing. This is an observance function that is used in place of active control. It can be assumed that the operator may not scan the part, and this will be seen and acted upon only at the next location where active control is present. Example functional requirements are

- Processing continues with or without bar code scanning
- Part is assumed to have done process step X or process steps X, Y, Z when it is scanned at this workplace
- Operator Start
  - The operator should not start their process or activity until the validation rules have been satisfied
  - Parts that fail the validation checks should alert the operator or control system
- When this element changes state (it becomes enabled or disabled) a record of this event should be recorded

**Active Routing**

'Routing Control' or 'Active Routing' are phrases describing this function. This scheme assumes barcode scanning is operational on parts traveling through the shop floor equipment and the control system (PLC) should receive and deliver information to the MES system with regards to the part

- Cycle Start
  - The equipment should not start until the validation rules have been satisfied
  - Parts which fail the validation checks should alert the operator or control system
- Cycle End, Cycle Abort - At the end of the machine cycle or when the part processing is terminated the PLC is to issue the following items back to the MES system. The MES system in turn is to use this information for inventory reporting functions, and to have ready for the next requesting machine or user
  - Process step X or process step X, Y, Z is updated from the PLC as a validation that each component was actually consumed
  - Process step X or process step X, Y, Z is updated from the PLC as a validation that each component was successfully processed

- When this element changes state (it becomes enabled or disabled) a record of this event shall be recorded

**Validation Rules**

These rules are tested before a part is to be transformed into the next process step. It is executed based upon a part being scanned at a workplace (station, bench, location, etc.) This is independent of active or passive control. The following are example validation rules

- If this is a non-automated workplace then the operator is required to be logged into the workplace.
  - Operator ID using a 'badge in' system.
  - Operator cannot start the machine until they are 'badged in'. This implies active control is required.
  - The 'badged in' name is the name is the name that all tracking will be related to
  - Operator ID to be matched against a qualification matrix to ensure they are trained to run this machine
  - Alarms, parameter changes and other events to be logged with the Operator ID
  - Operator ID to be auto logged out in the case of parameter changes to prevent tampering of setup
- If this is a label creation (birthing) workplace using pre-printed labels, the proper product label is to be applied
- During part creation, the part cannot exist in the database
- All the necessary manufacturing operations on the product are complete
- The proper product (based on final part number) belongs at this station. This may also be referred to as a routing check
  - Multiple products not from the same family are to be acceptable without performing changeover. This is applicable on a flexible (robotic) line that can alternate between the products and also observed on machines that can produce two or more separate products and have on exit point
- The part should be checked to see if the part has not already been packed in the Finished Goods area
- The station/location has run out of a sub-component and a new lot needs to be entered
- The part has not violated any SPC or CPC limits
  - Multiple products not from the same family are to be acceptable without performing changeover. The limit set is evaluated by the product that is, or just has, currently been produced
- The MES system has a complete system failure
- The following additional validation rules are required for Finished Part Packaging
  - The containers fill/weight limit set-point is not exceeded
  - The part number on the label matches the part number on the product about to be packed

- These validation rules should be independently enabled and disabled. If the rule has changed state then this event will be logged
- Feedback and annunciation of validation acceptance: A good beep or 'chirp' is required
- Feedback and annunciation of validation failure: alert the operator or control system using the following techniques
    - Control techniques including stopping the automated system, or prevent data delivery to processing equipment
    - Audio techniques should be verbalized by the PC audio hardware
    - Visual techniques including red light, etc.

**Visual Management on the Shop Floor**

Visual Management is a technique to deliver operational information to production associates on the shop floor. With this information, the people should see daily, weekly and monthly expectation or goals from management. The information must be timely to allow production associates to quickly see and correct for poor performing areas of operation. Performance indicators of red, yellow and green are always used throughout the displays. These should always be referenced to a goal and example areas include scrap, quality, labor, downtime, inventory turns, as well as yield and performance of a plant.

Operators should interact with this system through client Human Machine Interfaces computers are Information Portals. These interfaces should handle entry and display data at key locations in the production process. It is critical to display all interface points in a similar manner therefore displays should be similar. Example requirements and content are:

- Scheduled product
- Quantity of product required per shift – 'goal'
- Actual quantity of good and scrap product produced per shift
- Scrap reason pareto per shift
- Downtime pareto
- Current status based upon a machine being down
- From the Event Logging System, the following could be prepared
    - Pareto of machine events
    - Pareto of frequency of all events
    - Pareto of operator change events – typically quantity of changes per parameter
    - Performance Indicators
- Green, Yellow, Red indication on good and scrap pieces, to support visual management

- Display size should permit easy viewing of information from at least 100 ft (30 meters)

**Area Management**

The MES system should provide a central "cockpit" or "control center" approach for viewing production/process within all areas of the plant. Example requirements are:

- Individual machine statistics, including number of starts, number of faults, amount of time running, total time in fault, etc. This data should be aggregated in a form to easily recognize deficient areas. Use of pareto charts should be strongly considered
- 'Mining' or 'Drill down' of the area of concern to zoom in on area of concern. The types of information under the top level should be linked to many of the areas described in the shop floor and enterprise reporting sections
- Total number of defective and/or scrapped parts in each area
- Names of operators and other staff logged in at each machine
- High-level view of the production process parameters, such as raw material and vendor supplied part quantities currently in use at each machine. Lot numbers in use at each station and approximate material remaining in each location.
- The schedule of product to be run on each line and the current status of each
- Notification and review of alarms and events occurring on the shop floor. The system should also provide a method for the supervisor to enter new exceptions and comments concerning the events and alarms observed. Real-time notification is stressed
- Recipe control and part changeover should be accessible through this portion of the system

**Part Changeover**

Changeovers allow the machine control and its associated set points and CPC limits to be altered to run the next product part or next style. The MES database configuration at this location for validation and material use is also considered part of this changeover. The following are example requirements for the Part Changeover at the work center:

- The physical process changes required at the work center are to be prompted to the operator for confirmation
- The changeover process should be protected by proper security, and should not allow alteration from outside the facility
- The following methods could be used:

- o Alternate product selection based upon a multi-position selector switch available through the machine control
- o Alternate product is based upon the local machine control's recipe system. Any local change-over parameters should be adjusted to match the selected product loaded from the recipe

- If the changeover requires removing some components of the old part type, then the current material lot disposition (put in warehouse, leave by work center, etc.) should be requested from the user
- If the changeover requires bringing in different components for the new part type, then the material lot information for these components should be requested from the user
- Verifies product part number based on Bill of Material by revision level and alerts the machine operator if not in synchronization

**Possible Databases, Tables and Fields for Process Management**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Log, all other |
| | **Machine** | Name, Description, Location, Status, Current Task, Setup Time, Log |
| | **Tool** | Name, Description, Location, Status, Current Location, Log |
| | **Asset** | Master ID |
| **Document Control** | **Document** | Document ID (Test Report Form) |
| **Labor Management** | **Employee** | ID, Number, First Name, Last Name |
| **Quality Management** | **Parameter** | Data Source, Alarm (i), Upper Specification Limit, Lower Specification Limit, Annotation (i), Annotation Time Log (i), Available Range Start, Available Range End, USL Last Changed, LSL Last Changed, Event Log, Test Report Form |
| **Process Management** | **Process** | ID, Description, Name, Line Name, Line Description, Station Name, Station Description, Owner, Related Assets, Related Documents, Location, Product Line(i), Key Parameter(i), Serialized Part Time(i), Current Employee, Current Part, Current Inventory, Cycle Time Log, Average Cycle Time, Event Log |

# APPENDIX M : MAINTENANCE MANAGEMENT

**Maintenance Tracking and Scheduling**

It manages the preventive maintenance of equipment and tools in the plant. It allows maintenance supervisors to schedule and modify maintenance tasks, sends notices to maintenance workers for scheduled maintenance and allows users to view scheduled maintenance and history. The following modules could be part of a Maintenance Management System used to track and schedule maintenance tasks

- In a work order module, all preventive and unscheduled tasks are assigned and tracked
- Assign tasks to a particular resource
- Assign a maintenance work orders to a specific worker
- Upload work order to a PDA and allow the maintenance technicians to stay mobile (wireless data terminals) that can let them carry this device to point of support
- In an analysis module, reports and analysis of maintenance data are generated
- Deliver process and downtime data to a maintenance user
- Give alerts when equipment requires preventive maintenance
- Notify maintenance management personnel of resources that require preventive maintenance and their schedule availability

**Possible Required Databases, Tables and Fields for Maintenance Management**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Main Contact, Main Telephone Number, Web Page, Picture, Site Diagram, Blueprint, ISO or other certifications, Products Produced |
| | **Asset** | Name, Description, Location, Supplier, Supplier Contact, Required Training, Last Maintenance, Next Maintenance, Site, Asset Log, Asset Documentation |
| **Labor Management** | **Employee** | Name, Certification, Training, Assets Allowed, Email, Phone, Cost Center, Department, User ID, Employee Number, Current Location |
| **Maintenance Management** | **Work Order** | Work Order Number, Estimated Time, Task Descriptions, Task ID's, Actual Downtime |

# APPENDIX N : PRODUCT TRACKING AND GENEALOGY

NOTE: In the following requirements, serialized bar coding is the technique referenced to track product. In the future radio frequency identification tags may be used instead.

### Serialized Bar Coding of a Product

This function should ideally occur as the product is first entered into the production process. This could be at receiving, move to the production line, after the first process step in production or at any point in the process. As the production part is produced, the operators is required to apply a bar coded serialized label to the part. The operator then scans the bar code label. Example requirements for product serialized bar coding are:

- Creation of a serialized label causes a record to be created in the database
- Bar code format and size shall conform to customer specifications and affixed to parts requiring traceability
- This bar code label is used for all subsequent tracking requirements as part of the genealogy requirements
- This bar code label is used for reports
- Part Creation Functionality
  - Creation by scanning of a preprinted label
  - Creation of a label by printing to a thermal transfer bar code label printer
  - Creation of a label by manually entering the serialized label
  - When the operator scans the serialized label, the system shall validate the part. The part will be checked according to specific validation rules
  - Label reprinting functionality to allow a temporary label to be utilized during manufacturing and a final customer label applied prior to shipping. The label content should be the same as the temporary label to eliminate additional label cross references

### Genealogy of Each Product

This section describes the requirements for tracking the genealogy of the product. During the manufacture of a product, many pieces of information are to be collected as the product evolves from a basic state to a complex finished state. Product data resulting from measuring the product, whereas the process data are parameters from the equipment and process that transform the product. Example **Genealogy requirements include:**

- The equipment used to produce the part

- The equipment 're-used' for re-working a part, and the details of re-work made to the part
- The events on the equipment which occurred during part manufacture/assembly
- The parameters used on the equipment that helped assemble/create the part. Data may be collected at the end of every machine cycle at defined equipment locations. The final list of required data should be configured from the available data in the MES database.
- The operators who participated in assembling/creating the part and the respective workstation
- The date and time that each operation was started and finished
- Genealogy of a product that is a customer return
- This requirement would be used when defective product is returned to the source facility and rework of the product is to occur. The new information regarding the product is to be amended to the original genealogy information. (The original information is retained)

**On Hold (Quarantined) or Scrapped Product Status**

Scrapping and Holding parts or sub-components is done to prevent subsequent processing of parts, as a method of error proofing. Parts or sub-components placed on hold are synonymous with quarantined parts. The quantity and type of scrap or holding status may be used for production reporting. Example requirements scrapping and holding product are:

- Scrap and hold can come from a bar code scan (manual). The sequence of performing this could be as follows: The operator scans the scrap, then the hold code, then the part number then the serialized 'lot number'.
- Scrap and hold codes should come from the MES database (automated). This should be extracted from the database at the end of the machine cycle or when the part processing is terminated.
- Scrap and hold codes should have a common code for the description amongst facilities.
- Scrap parts and parts on hold should not be allowed to continue in the manufacturing process
- Hold code 0 may be used to state that the product is not on hold. Reclassification of a product that is currently on hold to a product that is not on hold should be through a special bar code label controlled by the QC department. It is expected that the person's name that alters the hold state is tracked in the MES database
- Scrap code 0 may be used to state that the product is not scrap. A part that is scrapped cannot be unscrapped
- Any user can scrap or put product on hold

**Dispositioned Product Status**

The disposition code is a method to indicate the location of a product. The product may be dispositioned to a rack or location. If a product is not dispositioned it may be assumed to be in the manufacturing route.

Dispositioning allows unfinished product (WIP), or finished product that is sent to the warehouse to be located. Example requirements of dispositioning are:

- Disposition code can come from a bar code scan (manual). The sequence of performing this could be as follows: The operator scans the disposition code, then the serialized bar code label.
- Disposition code can come from the MES database (automated). This should be extracted from the database at the end of the machine cycle or when the part processing is terminated.
- Dispositioned product should not interfere with the part continuing in the manufacturing process. A single part entering the manufacturing process should be classified as 'Disposition Code 0'
- Products that are dispositioned to a location may be 'batch-processed'. This is to allow multiple parts to be processed simultaneously.
- Any user should be able to use and perform this function

**Traceability of Sub-components**

This section describes the requirements for tracking material flow through a facility. This includes the receiving area, quarantine area, QC area, assembly/manufacturing area on the production line and the shipping area. Example requirements are:

**Receive new lots at receiving department. This may include the following requirements:**

- Record lot #, Quantity, Date of Receipt, Part Number. It is considered that Supplier Name, Purchase Order and Invoice # may also be required
- All materials should be marked in the MES database as 'on hold' (quarantined) until QC verifies material quality. After verification, QC should update the material as 'Ready for Use'. Appropriate alarms should be issued to the manufacturing equipment if this material is still 'on hold'.
- Manual entry or bar code scan data for data input

**Receive new lot at processing line. This may include the following requirements:**

- Scan the part number, the 'on hold' code, then the serialized lot number
- Manual entry or bar code scan data for data input
- Validation that the part number is a valid version and is valid for the currently running product type
- Validate the existence of this lot based on what was received at the receiving department
- Validate that the lot is not 'on hold' or is not scrap
- Record the lot start date/time
- Functionality of lot entry of any product's lot should be available at any scanner on the line
- Feedback of lot entry acceptance: Audio or visual
- Feedback of lot entry failure: Audio or visual

**Consumption of material at the processing line**

- Each component part number and version shall be configured to a route or family where it is consumed as part of normal operation. The component received at the line needs to be validated to ensure it is the correct part number and version
- Validate that the current lot is not 'on hold' or is not scrap. If an 'on hold' lot has been started on the line then the next production part should not be allowed to continue.
- Lot Countdown Function: Utilizes the quantity of components left at the workstation. When the lot is empty the operator is to enter a new lot when the old runs out. Lot countdown to alarm the operator and issue request to stocking personnel.
- Lot consumption's of components to be recorded by the MES database

**Track serialized sub-components**

- This allows tracking of each bar coded serial number of a sub-component, which is added to the product. These serial numbers will typically have a product identifier

**Possible Databases, Tables and Fields for Product Tracking and Genealogy**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Main Contact, Main Telephone Number, Web Page, Picture, Site Diagram, Blueprint, ISO or other certifications, Products Produced |
| | **Asset** | Name, Description, Location, Supplier, Supplier Contact, Required Training, Last Maintenance, Next Maintenance, Site, Asset Log, Asset Documentation |
| **Document Control** | **Document** | Document ID, <Document Details> |
| **Labor Management** | **Employee** | Name, Certification, Training, Assets Allowed, Email, Phone, Cost Center, Department, User ID, Employee Number, Current Location |
| **Process Management** | **Process** | Process ID, <Process Details> |
| **Product Tracking** | **Part** | Serial Number, ID, Name, Description, On Hold Status, On Hold Reason, Current Location, Supplier Name, Receipt Date, Number, Related Document(i), On-hand Quantity, Event Log |

| | | |
|---|---|---|
| | **Product** | Serial Number, ID, Name, Description, On Hold Status, On Hold Reason, Current Location, Related Document(i), On-Hand Quantity, Start Process(i), End Process(i), Employee Start Process(i), Employee End Process(i), Event Log |
| **ERP System** | **Module** | Product Bill Of Materials, Product Routing, On-hand Quantities |
| **SCM System** | **Module** | Supplier ID, Supplier Name, Part Receipt Date, Supplier Contact Details |

# APPENDIX O : PERFORMANCE MANAGEMENT

**Production and Operations Reports**

**Enterprise Level**

The following are example requirements for Production Reports available via the MES System.

- A primary set of reports to match the customers current reporting methods
- A secondary set of reports to permit detailed analysis of facility operations
- Where data is not automatically available to complete a report, a data entry form should be available to allow manual data entry to occur.
- These reports should have time resolutions including hourly, shift based, daily, weekly, monthly and yearly
- Example indicators and reports are:
    - Scheduling and planning performance, including planned downtime for preventive maintenance, changeovers and breaks
    - Quality performance including loss from scrap parts, part parameter to set tolerances
    - Pareto of downtime frequency and duration
    - Pareto of scrap

**Facility – Managerial/Engineering Level**

The following are example requirements for production reports available via the MES System at the managerial/engineering level. It is expected that security roles be defined, and procedures and policies be implemented for the users on this part of the system. This is required to ensure that competition, customers and suppliers cannot extract data. Example requirements are:

- Hourly, shift, daily, weekly, etc. reports (available in color) should be provided for the following
    - Part tracking report for a specific part to show its history through each operation. This should include, but is not limited to, lot numbers, time stamps, operator names, process set points and actual values, product measurements and events (alarms, messages, parameter changes)
    - Quantity and Location of Work In Process
    - Process and Quality reports including SPC and CPC alarms with product measurements and ability to correlate to other process parameters
    - Reporting of quantity of each product on hold, sorted by product or hold reason
    - Customer return quantity and age of product

- Open query of information. The following elements should be built upon open query tools using techniques that are familiar to the generic computer user
  - Entry of time range of a processing step to show all parts in that range, this should show where parts are, including if they are scrapped, on hold, in WIP or shipped to the customer
  - Manual entry or bar code scan to allow a report showing all parts which used a particular subcomponent lot number
  - Reports the start date and finish date of a lot/part/work order
  - Trend a process or product parameter using the start and finish time of the lot as the time scale
  - The reports should take a reasonably short time (< 2 minutes) to run
  - Reports should be printable and available in color
- Look up part specific process, product and traceability data. The expected users of this data are research and development, quality, process engineering and those persons involved with manufacturing excellence
- Ability to look up values including discrete values that are a singular summation value recorded per part (average, minimum, maximum), signature value (a series of samples) per part, a continuous value which is logged against time
- Displayed values should be available in table format or graph
- Displayed values should be extractable to external analysis programs (Excel or SPC analysis software)
- Several values should be viewable on a single chart
- Overlay of product values from Part A with Part B, where Part A could be a master part
- Overlay of process A with process B where process A is the master process
- Ability to look at events which occurred during the selected time span
- Search methods of process data for display may include search by unique part number, search by unique serial number, search by start time and duration

**Miscellaneous Reporting Requirements**

- Ability to produce ad-hoc reports via a graphical interface using software packages such as MS Access, Crystal Reports or simple SQL queries
- Provide data mining user security
- Ability to produce reports on a fixed schedule versus on demand
- Allow each user to have a list of default reports available

**Event System**

The Event logging system shall track such events as downtime, alarms, and parameter changes. It is expected that all potential cause of machine events are logged. Typical reports coming from the vent system are paretos, run charts, bar charts and histograms of machine faults, downtime, normal operation and loading/unloading of machines.

Alarms provide a means to identify fault conditions and notify appropriate system users of those fault conditions. Alarms are typically set up and generated from the production data collected from various sources of the shop floor. Alarming should be handled so that alert information will be sent to notify the appropriate people, but users are not pestered by low priority nuisance alerts. All information monitored on the system will be assigned a resource ID. This ID will relate to a specific subsystem in site. Alarms will be sent to personnel based upon their level of responsibility, their area of responsibility, and the severity of the alarm. The two methods by which the alarms are sent are e-mail and pager. E-mail alerts could be low priority alerts. The conditions indicated are not critical, but do require attention and can become more serious later. The alerts send out via email, will repeat at a defined interval until the problem triggering the alert is resolved.

Pager alerts will be high priority alerts that need resolution immediately. These alerts should be sent directly to the responsible personnel for the area in which the alarm is occurring. If the alarm is not acknowledged in a certain period of time the pager alert will then be escalated and another set of pages will be sent. This should continue until the alarm is acknowledged or the highest level of escalation is reached.

Alarms should be configured so that most alarms will go to the immediately responsible personnel first. Supervisors and managers will be paged either for certain types of critical alarms or as part of an escalation scheme. This reduces nuisance alerts to higher-level personnel, while keeping them informed if something does need their attention.

**Some typical events to be logged are:**

- Operator change event which includes all change parameters
- Machine fault event which includes all faults causing downtime or stalling
- Speed event which includes waiting for operator times
- Downtime and processing faults (including MES system faults), normal operation and waiting for loading/unloading of each component, changeover and calibration of equipment

**Events should be logged with the following parameters**

- Start and finish date and time
- Operator name from a scan of the operators badge (or some other login function) into the workstation
- Before and after value of the event
- Any event is to have a log entry, to allow the operator to document the issue which caused the event to occur

**Typical reporting requirements are**

- Manual entries of event and alarm comments should be required to allow for exceptions and explanations of the events or alarms
- Should prepare event summary data for the shop floor displays
    - Pareto of machine events
    - Pareto of frequency of all events
- Time based queries to furnish all events between two times at a specific machine or by a specific operator
- Event based queries between two times to look for the occurrence of an event
- Summary of parameter changes per operator between two times
- Charting of parametric events (parameter changes) with SPC data, and process data
- Charting of non-parametric events (machine downtime, faults) with SPC data and process data

**Possible Databases, Tables and Fields for Performance Management**

| Database | Table | Fields |
|---|---|---|
| **Resource Allocation** | **Site** | Name, Description, Address, Main Contact, Main Telephone Number, Web Page, Picture, Site Diagram, Blueprint, ISO or other certifications, Products Produced |
| | **Asset** | Name, Description, Location, Supplier, Supplier Contact, Required Training, Last Maintenance, Next Maintenance, Site, Asset Log, Asset Documentation |
| **Document Control** | **Document** | Document ID, <Document Details> |
| **Data Collection** | **Data** | Data ID, <Data Details> |
| **Labor Management** | **Employee** | Name, Certification, Training, Assets Allowed, Email, Phone, Cost Center, Department, User ID, Employee Number, Current Location |

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|---|---|---|
| **Process Management** | **Process** | Process ID, <Process Details> |
| **Maintenance Management** | **None** | Work Order ID, <Work Order Details> |
| **Product Tracking** | **Part** | Serial Number, ID, Name, Description, On Hold Status, On Hold Reason, Current Location, Supplier Name, Receipt Date, Number, Related Document(i), On-hand Quantity, Event Log |
| | **Product** | Serial Number, ID, Name, Description, On Hold Status, On Hold Reason, Current Location, Related Document (i), On-Hand Quantity, Start Process(i), End Process(i), Employee Start Process(i), Employee End Process(i), Event Log |
| **Performance** | **Report** | ID, Name, Description, Format, Display Format, Owner, Start Range, End Range, Related Product, Related Employee, Related Data (i), Related Asset (i) |

# APPENDIX P : OVERVIEW OF LEAN PRINCIPLES

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| **Lean Thinking** | ➢ *Lean thinking* is doing more with less while providing customers exactly what they want when they want it<br>➢ *Lean thinking* is the antidote for wasteful activities (known as ***muda*** in Japanese)<br>➢ The five principles of *lean thinking*<br>• *Specify **Value*** – define value from the customers perspective<br>• *ID the **Value Stream*** – identify the set of value adding activities<br>• *Ensure **Flow*** – ensure that all value-creating steps in the value chain flow<br>• *Establish **Pull*** – let customer pull product as needed vs. pushing product<br>• *Work to **Perfection*** – use continuous improvement to seek perfection |
| **Value** | • Specifying *value* is the critical first step in lean thinking<br>• *Value* is defined by customer and expressed in terms of a specific product<br><br>**How to Specify Value**<br>• Challenge the traditional definitions of *value*<br>• Define *value* by looking at the whole process and not just pieces of the process<br>o Maximizing each sub-process **does not** necessarily maximize the whole<br>• Establish a target cost for each process if no waste existed, and work towards target |
| **Value Stream** | ➢ The *value stream* is the set of actions required to satisfy a customer need<br>• The value stream includes activities both internal and external to the firm<br>➢ A typical *value stream* consists of three different categories of steps or tasks:<br>• *Problem Solving Tasks* – from product conception, design, launch<br>• *Information Management Tasks* – from order taking to scheduling<br>• *Physical Transformation Tasks* – from raw material to delivery<br>➢ A *value stream* analysis identifies three types of actions that satisfy a customer need:<br>• Steps that create value<br>• Steps that do not create value, but are unavoidable (*Type One **Muda***) |

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| | • Steps that do not create value, and are immediately avoidable (*Type Two* ***Muda***)<br>➢ Work to eliminate the last two types of actions, since they are wasteful activities |
| **Flow** | ➢ After eliminating muda from the value chain, ensure that remaining steps create *flow*<br>• Requires the elimination of 'departmental' and 'batch-and-queue' thinking<br>➢ ***Continuous Flow*** – product continuously worked from raw material to finished good<br>• Uses low-volume production as opposed to high volume assembly lines<br>• Aligns organizational design and employee incentives with creating value<br>• *Continuous flow* facilitates improvement in two ways:<br>▪ ***Kaizen*** – evolutionary change - continuous, incremental improvement<br>▪ ***Kaikaku*** – revolutionary change - radical improvement<br>**How to Establish Flow**<br>➢ Focus on the actual object (the design, part order, product, etc.)<br>➢ Ignore traditional boundaries (job, careers, functions, departments)<br>➢ Rethink specific work practices to eliminate backflows, scrap, stoppages<br>➢ Implement the above three steps together<br>**Where to Establish Flow**<br>➢ *Design Phase* – cross-functional teams should use a Quality Function Deployment (QFD) as the standard methodology to facilitate flow in the design process<br>➢ *Order Taking* – use takt time and visual controls to ensure production = sales<br>➢ *Production* – use heijunka, poke-yoke, jidoka, takt time, visual controls, 5 S's<br>**Kaizen**<br>➢ *Kaizen* is evolutionary change – continuous, incremental improvement<br>➢ *Kaizen* is a process involving a series of activities whereby ***muda*** is quickly eliminated by workers pooling ideas and increasing efficiency<br>**Kaikaku**<br>➢ *Kaikaku* is revolutionary change, or radical improvement with out-of-the-box |

solutions that fundamentally change the way an activity is performed

**Heijunka**

- *Heijunka* is smoothing variations in order flow unrelated to actual customer demand
- *Heijunka* is the process of level loading and sequencing the timing of production.

**Jidoka**

- *Jidoka* is using automation with "human intelligence", giving machines the ability to shut down automatically in the case of defects

**Poke-Yoke**

- *Poke-Yoke* is mistake proofing, or the use of fail-safe devices to prevent defects

**Takt Time**

- *Takt time* is the rate of production needed to synch output with customer demand
    - *Takt Time* = Production Time / Required Production (i.e. if the demand is 10 widgets per hour, then the takt time is 6 minutes per widget)

**Continuous Flow Time (a.k.a. Touch Time)**

- *Continuous flow time* is the actual time needed to perform a process if it is worked continuously from start to finish (without interruption) – also referred to as *touch time*

**Cycle Time**

- *Cycle time* is the total time required for a task to be complete.
    - Elements include processing time (***takt time***) as well as travel & queue time

**Lead Time**

- *Lead time* is the total time to go from raw inventory to the finished product.
- *'Order to Remittance Lead Time'* refers to the total time from when an order is placed until the finished product is shipped.

**Visual Control**

- *Visual Control* is a method where all can tell at a glance if a process is in control
    - ***Andon Board*** – a status board that serves as a common, disciplined &

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| | pacing tool.<br>**5 S's**<br>➢ The *5S's* are building blocks for shop floor discipline and control<br>➢ The *5S's* are five practices leading to a clean and manageable work area<br>• *Seiri* (organization) – ***Sort***<br>• *Seiton* (orderliness) – ***Standardize***<br>• *Seiso* (purity) – ***Sweep***<br>• *Seiketsu* (cleanliness) – ***Simplify***<br>• *Shitsuke* (discipline) – ***Self Discipline*** |
| **Pull** | ➢ *Pull* is a method of manufacturing in which each process withdraws the parts it needs from the preceding process when it needs them, in the exact amount needed.<br>➢ In its purest form, *pull* uses customer need as a signal to begin all upstream activities<br>• Combats building an pushing unwanted goods/services (often thru discounts)<br>• Customer demand becomes more stable in a *pull* system<br>**Created Demand**<br>➢ *Created demand* is when part orders are made based on inaccurate forecasts, thus creating supply strains that are unrelated to actual customer demand |
| **Perfection** | ➢ *Perfection* is a realistic goal once the first four principles of lean thinking are in place<br>• Transparency within the value chain ensures firms work towards adding value<br>• Employee incentives are aligned with improvement<br>• Perfection is pursued in relentless, repetitive kaizen events<br>• Radical changes (***kaikaku***) make further improvements by reinventing processes<br>**Policy Deployment**<br>➢ *Policy Deployment* is critical for successfully implementing lean thinking<br>• Agree on a few simple goals for transitioning from mass to lean thinking<br>• Select a few projects to achieve these goals<br>• Designate the resources for getting projects done |

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| | • Establish numerical improvement targets and a timetable |
| **Lean Enterprise** | ➢ A *lean enterprise* is a continuing conference of all concerned firms to create value<br>• Customer value is only maximized when firms implement lean thinking together<br>• Requires transparency in the activities of the company, suppliers, and customers |
| **Muda**<br>("Waste" in Japanese) | ➢ *Muda* is any human activity which absorbs resources but creates no value<br>• *Excess Inventory*– Maintaining more parts than immediately needed - stockpiling<br>• *Over Production* – Running machines efficiently, but producing items not needed<br>• *Excess Motion* – Unnecessary product movements<br>• *Human Touches* – Unnecessary human movements<br>• *Transportation* – Unnecessary transportation of goods<br>• *Waiting* – Employees waiting for an upstream operation to deliver product<br>• *Customer Defects* - Goods and services which don't meet customer needs |

# APPENDIX Q : KEY CONCEPTS OF SIX SIGMA

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| **Quality Approaches and Models** | ➢ ***DFSS*** – (Design for Six Sigma) is a systematic methodology utilizing tools, training and measurements to enable us to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels.<br>➢ ***DMAIC*** – (Define, Measure, Analyze, Improve and Control) is a process for continued improvement. It is systematic, scientific and fact based. This closed-loop process eliminates unproductive steps, often focuses on new measurements, and applies technology for improvement.<br>➢ ***Six Sigma*** – A vision of quality which equates to 3.4 defects per million opportunities for each product or service transaction. |
| **Quality Terms** | ➢ ***Black Belt*** – Leaders of team responsible for measuring, analyzing, improving and controlling key processes that influence customer satisfaction and/or productivity growth. Black Belts are full-time positions.<br>➢ ***Control*** – The state of stability, normal variation and predictability. Process of regulating and guiding operations and processes using quantitative data.<br>➢ ***CTQ: Critical to Quality (Critical "Y")*** – Element of a process or practice which has a direct impact on its perceived quality.<br>➢ ***Customer Needs, Expectations*** – Needs, as defined by customers, which meet their basic requirements and standards.<br>➢ ***Defects*** – Sources of customer irritation. Defects are costly to both customers and to manufacturers or service providers. Eliminating defects provides cost benefits.<br>➢ ***Green Belt*** – Similar to Black Belt but not a full-time position.<br>➢ ***Master Black Belt*** – First and foremost teachers. They also review and mentor Black Belts. Selection criteria for Master Black Belts are quantitative skills and the ability to teach and mentor. Master Black Belts are full-time positions.<br>➢ ***Variance*** – A change in a process or business practice that may alter its expected outcome. |
| **Quality Tools** | ➢ ***Control Chart*** – Monitors variance in a process over time and alerts the |

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| | business to unexpected variance which may cause defects.<br>➢ ***Defect Measurement*** – Accounting for the number or frequency of defects that cause lapses in product or service quality.<br>➢ ***Pareto Diagram*** – Focuses on efforts or the problems that have the greatest potential for improvement by showing relative frequency and/or size in a descending bar graph. Based on the proven Pareto principle: 20% of the sources cause 80% of any problems.<br>➢ ***Process Mapping*** – Illustrated description of how things get done, which enables participants to visualize an entire process and identify areas of strength and weaknesses. It helps reduce cycle time and defects while recognizing the value of individual contributions.<br>➢ ***Root Cause Analysis*** – Study of original reason for nonconformance with a process. When the root cause is removed or corrected, the nonconformance will be eliminated.<br>➢ ***Statistical Process Control*** – The application of statistical methods to analyze data, study and monitor process capability and performance.<br>➢ ***Tree Diagram*** – Graphically shows any broad goal broken into different levels of detailed actions. It encourages team members to expand their thinking when creating solutions. |

# GLOSSARY OF ACRONYMS

| Acronym | Definition |
|---|---|
| ABB | Asea Brown Boveri |
| ADO | ActiveX Data Objects |
| AIP | Aspect Integrator Platform |
| ANOVA | Analysis of Variance |
| API | Application Programming Interface |
| BOM | Bill of Material |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| CCR | Critical Constrained Resource |
| COM | Component Object Model |
| COTS | Commercial Off The Shelf |
| CPC | Control Process Charting |
| CPG | Consumer Packaged Goods |
| CRM | Customer Relationship Management |
| CTQ | Critical-To-Quality |
| DAO | Data Access Objects |
| DFSS | Design For Six Sigma |
| DOE | Design of Experiment |
| ERP | Enterprise Resource Planning |
| FDA | Food and Drug Administration (US) |
| GRR | Gage Repeatability and Reproducibility |
| HMI | Human Machine Interface |
| HTTP | HyperText Transfer Protocol |
| IIS | Internet Information Server |
| IIT | Industrial$^{IT}$ |
| IT | Information Technology |

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|---|---|
| J2EE | Java 2 Platform, Enterprise Edition |
| JDBC | Java Database Connectivity |
| KPI | Key Performance Indicator |
| LAN | Local Area Network |
| MES | Manufacturing Execution System |
| MESA | Manufacturing Enterprise Solutions Association (formerly Manufacturing Execution System Association) |
| MIS | Manufacturing Information System |
| MTS | Microsoft Transaction Server |
| ODBC | Open Database Connectivity |
| OEM | Original Equipment Manufacturer |
| OLE | Object Linking and Embedding |
| OMS | Operational Method Sheet (Assembly Instruction) |
| OPC | Object Linking and Embedding (OLE) for Process Control |
| PDM | Product Data Management |
| PLC | Programmable Logic Controller |
| QA | Quality Assurance |
| QC | Quality Control |
| QFD | Quality Function Deployment |
| RFID | Radio Frequency Identification |
| SCM | Supply Chain Management |
| SCSI | Small Computer System Interface |
| SFC | Shop Floor Control |
| SPC | Statistical Process Control |
| SQL | Structured Query Language |
| TCP/IP | Transmission Control Protocol / Internet Protocol |
| WIP | Work-In-Process |
| XML | eXtensible Markup Language |

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