Manufacturing Execution System (MES)

An Examination of Implementation Strategy

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ABSTRACT

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The priorities of executing the manufacturing orders generated by an MRP system are often in operational conflicts with the dynamics of the manufacturing floor. It is not uncommon for a given manufacturing order to reach the shop floor several weeks or longer after being “opened” by an MRP system where it may face a chaotic case of large queues, machine down-time, parts shortage, scrap problems and other resource management constraints. Many companies have resorted to the Manufacturing Execution System (MES) software solution to resolve these problems. This method first gained popularity in mid-90’s within the semiconductor industry. An MES approach is an on-line, real-time data gathering, analysis and storage to assist in short-interval scheduling (shift or day) manufacturing operations with an emphasis on revising scheduling priorities. It is essentially an information system tool for the shop floor and if designed properly, it may be used as an advisory system for effective decision-making. However, in implementation MES faces several challenges including the proper software platform/architecture, integration within ERP or a stand-alone best-of-breed, amount and type of data/information to be exchanged with the MRP engine, and a user-centered interface for various layers of decision making. This paper will provide a detailed background on various technical, software, and organizational factors that the use of an MES implementation may impose upon the practitioner. Furthermore, and as a case study, it will discuss a systematic implementation strategy for MES at a high-tech company in California. The discussion of the critical success factors in implementation planning will hopefully be of value to both practitioners and researchers in similar projects.

Table of Contents

List of Figures	vii
Chapter 1 - Introduction	1
Chapter 2 - Review of Literature	2
2.1 The Beginnings of MES.....	2
2.2 Functionality	3
2.3 Deficiencies and Future of MES	6
2.4 Integration with ERP, APS, MRP	9
2.5 System Architecture of MES	13
2.6 Current Out of Box (OOB) MES	15
2.7 Cost/Reward of MES	16
Chapter 3 - Thesis Work and Validation	18
Chapter 4 - MES as a System	20
4.1 General Concepts	20
4.2 Premises	21
4.3 Inputs	22
4.4 Adapting the Manufacturing Environment	26
Chapter 5 – Systematic Planning Approach to MES Implementation	27
5.1 Stage 1 - MES Explored	31
5.2 Stage 2 - MES Project Feasibility	31
5.3 Stage 3 - Project Analysis	32
5.4 Stage 4 - Decision Strategies	33
5.5 Stage 5 - Choosing a Vendor	34
5.6 Stage 6 - Statement of Work (SOW)	35
5.7 Stage 7 - Gap Analysis	36
5.8 Stage 8 - System Architecture	37
5.9 Stage 9 - Pilot Program	38
5.10 Stage 10 - Implementation	39
5.11 Stage 11 - Test Prototype MES	44
5.12 Stage 12 - Verification and Validation	45

5.13 Stage 13 - Full Scale Implementation	46
5.14 Stage 14 - Monitor and Maintain	47
Chapter 6 – Case Study	48
6.1 MES Metrics	50
Chapter 7 – Conclusion	52
Bibliography	53

List of Figures

Figure 1: Two-tier MES architecture	8
Figure 2: MES and other modules.....	10
Figure 3: MES Planning and Control Inputs	22
Figure 4: V-Model of Systems Engineering.....	30

Chapter 1: Introduction

Manufacturing Execution Systems solve many issues plaguing the manufacturing environment. Benefits are numerous and only accomplished through the provision and collection of data in real-time. Recent advances in computing technology and data management have paved the landscape for the growth of MES. In a highly competitive market, advantages provided by MES systems have spurred the adoption of the software over the past two decades.

MES provides improved visibility, integration, resource management, as well as document and product control, which ultimately deliver higher throughput and quality. Such benefits position the adopting company in a strong and competitive position, and as such continue to provoke the rapid adoption of MES. “The MES market was estimated to be worth \$4.7 billion in 2011 and to reach \$8.9 billion by 2016 at a compound annual growth rate (CAGR) of 13.6% from 2011 to 2016.” (“Manufacturing Execution System (MES) Market,” 2012) As seen, the demand for MES systems continues to grow. To provide for this adoption rate, a systematic method of planning and control for successful implementation must be accurately described and available to all companies large or small.

How does a company move its existing manufacturing environment to interface with MES and control the various stages of the implementation process? The lack of information surrounding this issue has prolonged the integration of MES into the average small to medium sized company’s manufacturing environment. To address this issue, not just MES must be understood, but also all other factors that influence the implementation. These factors range from type and architecture of software/hardware, to people and machines involved, to the specifics of reporting and functionality desired. All will be carefully organized and discussed with an ultimate goal of categorizing and synthesizing the requirements of MES implementation to provide a systematic implementation strategy. This planning tool will provide concise entry and exit criteria for 14 stages of implementation.

Chapter 2 - Review of Literature

Numerous articles and books were examined in the formation of a strong knowledge basis for this thesis. Searches throughout the academic field using strings such as “Application of Manufacturing Execution System,” “Future of Manufacturing Execution System,” “MES Case Study,” “Integration of MES” among others brought more than forty articles and three books with current and applicable information to be synthesized. The amalgamation of this information offers a thorough understanding of the field, and validity to this thesis.

2.1 The Beginnings of MES

The term Manufacturing Execution System (MES) was first coined in the early 1990's. At its focal point, this system attempts to offer the best shop floor control and visibility through real time data collection and analysis. The core strength of MES lies in the interface between the factory floor and management. “MES emphasizes the information transfer between the production layer and the business layer and optimizes the production process of the whole enterprise through the information integration.” (Bo, Zhenghang, & Ying, 2004, p. 157) This real time conveyance of information provides management with up to date information with which to make fully informed decisions. To examine the full utility of MES an associated enterprise resource planning (ERP) system must be assumed. In short, this ERP system enables interaction of MES with other functions within the company, and completes the allocation of information to a company wide audience. The quality of implementation and thorough integration of MES dictates the level of functionality to be achieved.

2.2 Functionality

The functionalities of a fully implemented MES offer a strong competitive advantage. The concept of MES as an information management system proves the easiest to comprehend. A clear understanding of the functionalities offered by a complete MES provide for easy identification of its numerous benefits.

Manufacturing Enterprise Solutions Association (MESA) International an association representing professionals working surrounding manufacturing execution systems, defines eleven specific MES functionalities.

First of these functions is the management of resources. MES provides the ability to control machines, labor skills, materials, and documents among other resources necessary for an operation to be performed. History of resources, current setup, availability, and other critical information is simultaneously available to the technician on the shop floor and the manager. The control of this information provides for real time status updates and process control.

Scheduling of work orders is the second function of MES. Sequencing of work based on priority, attributes, and resource requirements seeks to minimize setup time and maximize flow through the production system. An accurate calculation of time spent is compiled from each independent operation even with the added complexity of overlapping or parallel operations. The scheduling feature of MES also provides for level loading of labor and equipment.

Production unit dispatch is next on the list of functions. MES operates a real time dispatch for all production operations, carefully managing quantity and buffer of product throughout the floor reducing work in progress (WIP). "A MES handles factory operations. It supervises the process control systems, it decides the routes that the products follow through the system, and it decides when and where operations on products start." (Valckenaers & Van Brussel, 2005, p. 428) Due to the real time feedback loop, decisions that alter the established schedule can be easily accounted, and production routed accordingly. MES works with all factory production scenarios including rework or salvage.

One of the truest strengths of MES lies in document control. The implementation of MES eliminates the usage of paper driven methods of document control. This functionality provides benefits that spider throughout the company. Every user of MES has access to the required documents. The technician has access to all information related to the production unit including work instructions, standard operating procedures (SOP), engineering change orders (ECO), bill of materials (BOM), history, and other mandatory information that before MES would have been difficult to obtain, and keep with the order in paper form. Also, paper travelers with both production information and possible sign off by technicians are controlled by MES electronically. This adds security and reliability on the feedback loop from production on the manufacturing floor.

Data collection sets the bar for significance in MES. Listed as a function, this facet provides all data related to production to the hands of management in formats that provide valuable metrics and insight into the characteristics of the production. "The essence of MES is to receive and collect manufacturing data and provide real time information to the entire organization enabling timely management decision support." (Baljet, 1999, p. 1078) This data can be collected either automatically from intelligent equipment or manually from human interface forms. Metrics and red flags update automatically in this real time feedback loop. Sent with the order through the entire manufacturing process, this data is eventually archived for easy retrieval and historical calculations.

Sixth on the MESA list of functionalities lays labor management. Basic function surrounds controlling employee status and attendance throughout the workday. Upon interface with an ERP system financial costs may be assigned to specific projects based on the employee's logged actions. By determining the status of the employee, value and non-value added activities could be identified and addressed due to full understanding of the associated cost. On a higher level, employee certification and clearance tracking as well as possible optimization of labor are operations provided by the labor management functions of MES.

MES offers real time analysis of quality. Data collected from manufacturing operations may be synthesized and displayed in means easily read to identify issues requiring follow up action. Smart manufacturing execution systems offer the ability to examine historical records for similar defects identifying root cause from previous symptoms. Fully implemented systems include statistical process control and supplier quality control feedback loops. Under the data collection function of MES, quality control has the ability to perform any inspection and sign off electronically in manual input forms. The ability to identify possible quality defects and alert in real time presents a reduction in rework and an increase in customer satisfaction due to a more reliable product.

Process management is a byproduct of data collection from resources, labor and equipment. MES supervises production while adjusting for maximized production activities either automatically or by supplying information to make an informed decision. Production units are tracked both intra-operational, within one operation, and inter-operational, between operations. MES will flag any discrepancies from the as planned operations to alert management.

The ninth functionality is maintenance management. Albeit a relatively simple task, the MES system provides means of tracking operation based maintenance. Identified by operating hours, the scheduling of total preventative maintenance can be integrated into the system. Immediate issues are flagged to management's attention. All maintenance concerns are logged in history for reference, and to aid in diagnostics of current issues.

Product tracking and genealogy manifests itself as another collaboration of the aforementioned data collection throughout the shop floor. As product moves through production, status information on human and mechanical resources as well as other identification information or feedback from actions on the shop floor are recorded. This recorded data provides traceability and historical information on the creation of the end product and all of its components.

Ultimately, the eleventh function of MES is performance analysis. Performance analysis completes the feedback loop to management. Information on current production patterns is compared to historical results. Similar user friendly and straightforward reports and visualizations present valuable metrics including resource utilization, cycle and takt times, schedule adherence, and quality information among other useful comparative information. “MES, the core of the production management, has the ‘middleware’ role linking the production layer to the enterprise management layer.” (Bo et al., 2004, p. 159) MES imparts upper level management the clearest visualization of the actions transpiring on the shop floor. The analyses supplied by MES clearly identify strengths and weaknesses and aid in the never ceasing quest for continual improvement.

The strengths of MES and the discrepancy between a paper driven system and one controlled by MES are easily apparent. Numerous companies have implemented this system and have realized the benefits that will be covered later in this chapter. In most manufacturing environments this standard MES is quite sufficient, but some deficiencies are spurring the development of a new generation of MES.

2.3 Deficiencies and Future of MES

Some major issues surround the standard manufacturing execution system. First, integration between other crucial software throughout the company should be streamlined. Companies such as Oracle or SAP have attempted to solve this issue by developing operating platforms for every aspect of the company, but the specific software modules only interface well with other Oracle or SAP software. Issues arise when best of breed software must be integrated to work concurrently. Methods of data structure, storage and retrieval differ between systems and so cause discrepancies between programs. Collaboration between vendors and open source software seeking to provide communication between differing systems has begun to combat this problem.

Issues also arise in application of MES to flexible manufacturing. MES exists with a relatively rigid structure. This works well for most manufacturing environments. When there is a high level of flexibility required on the manufacturing floor, MES is not capable of easily adapting to this change in process and associated data collection. MES can be configured for any reasonable manufacturing environment, but lacks the speed of adaptation and change in a highly flexible environment.

These deficiencies drive the future of MES. Currently emerging is a new breed of heavily programmed MES called Reconfigurable Manufacturing Execution System (RMES). The new systems offer simplified applications of MES to new processes through reconstructive dimensions and implementation designs. Complex algorithms provide a flexible framework for process objects to be constructed and tracked. These object-oriented techniques are best summarized by Cheng, Shen, Deng, and Nguyen (1999).

An integratable MES which is open, distributed, interoperable and collaborative is achievable. Each component of the MES Framework was developed by inheriting a proper design pattern, which is considered as the basic designs for architecture, framework messages, and interfaces of this component to interoperate and collaborate with the other components. The specific properties and implementation of the component can then be added into the component in a systematic approach. The component is integratable into the MES Framework in a plug-and-play fashion. (Cheng, Chang, Wu, 2004, p. 254)

Holonic manufacturing systems take the integration concept a bit farther. This system's strengths lie in the integration of the design with nature. Employing concepts of bio-mimicry this evolved system looks to continually forecast production in an effort to expand the myopic decision making inherent to common MES. Holonic MES systems employ concepts modeled after food foraging behavior in ant colonies. As part and a whole simultaneously, these novel systems offer a foresight unattainable from standard MES.

The main coordination and control mechanisms ensure that the process plans are properly executed and emergently forecast the workload of the manufacturing resources as well as lead times and routings of the products. The design empowers the product instances to drive their own production; the coordination is completely decentralized. In contrast to many decentralized designs, the manufacturing execution system predicts future behavior and proactively takes measures to prevent impending

problems from happening. (Valckenaers & Van Brussel, 2005, p427)

A third solution attempts to add flexibility to MES. This specific application endeavors to facilitate the use of flexible manufacturing systems (FMS) in conjunction with MES. Such a design seeks to provide for traditional manufacturing but adds machine and routing flexibility characteristic of highly automated manufacturing environments. Such a design requires “A two-tier MES architecture suitable for bridging the gap between an FMS controller and an ERP system.” (Choi & Kim, 2002) This configuration exists as two MES running concurrently. Operating interchangeably, reprogramming one with a new FMS configuration will not inhibit the other. This can be seen below in Figure 1.

Figure 1: Two-tier MES architecture.

This proves to be a complex interaction not just in programming and implementation, but primarily in scheduling. “The schedule generated by the main-MES is sent to the FMS-MES in the form of ‘FMS order’ to be used as constraints when the FMS-MES is generating its ‘FMS schedule’, which is then sent back to the main-MES. When there is a conflict in the FMS schedule, the main-MES will generate a revised schedule, and so on (until the conflict is resolved).” (Choi & Kim, 2002, p. 274) The biggest issue facing FMS enabled MES is the interface with the data intensive machines and the FMS controller. As the demand for flexible manufacturing operations continues inventive solutions will be developed that continue to push the bounds of MES.

These novel systems all seek the clearest understanding of the current and future operations of the factory floor. To obtain such a precise understanding, data from all other control systems under the enterprise resource planning system (ERP) umbrella must flawlessly interface with MES. Due to this inherent need, the interface with other systems in the company is of utmost importance.

2.4 Integration with ERP, APS, MRP

MES cannot function as a separate unit. It depends on numerous modules under the ERP umbrella. MES will provide for brilliant shop floor control, but relies on data inputs from numerous areas within the company. All of these modules fall under the master enterprise resource planning system.

The eleven functionalities described earlier define the different functions for which data must be exchanged. These functionalities interface directly with four other modules. As seen in Figure 2 on page 10, the four main modules that share data with MES are Supply Chain Management, Customer Relations Management, Production Control & Management, and Production & Process Engineering. These analogous modules under ERP align with functions of MES, and benefit by working in parallel with the MES system.

Figure 2: MES and other modules

Scheduling and production control seem to overlap the ERP modules Advanced Planning and Scheduling (APS) as well as the more common Manufacturing Resource Planning (MRP or MRP II). As this presents an often complex issue of defining barriers between systems, it is mandatory to map out the interaction among the playing partners. In the development of the computer software systems used in manufacturing management, MRP or MRP II systems are mandatory for an MES system, but an MES system does not necessarily require an APS system to provide all functionality. The better mapping of the data flow and the desired processes of each module, the better the outcome of the implementation and associated return on investment for the company.

MES and APS share almost identical inputs, but synthesize information for differing purposes. "The main objective of the APS system is to improve the production planning and scheduling to allow a certain business objective to be achieved." (Broner, 2004) APS seeks to fulfill difficult planning calculations based

off all available resources of the company. This complex task mirrors some of the more high level planning available in most MES systems. The flow of information between the systems provides APS with a real time understanding of the inputs required to make the best decision such as inventory levels, current cycle times, labor and machine availability, etc. Ideally, this information is retrieved from the MES system in real time. Major issues arise when data must be formatted or changed when interfacing between systems built by differing companies. Such large amounts of information with complex structure alterations make the process time intensive. Because of this issue most APS run only once a day. Once the APS runs, the synthesized schedule must then be exported back to MES. Orders must be frozen on the floor when the APS schedules. Therefore the schedule is based off a snapshot of the shop floor instead of real time information. Rapid data transfer showcases the strength of the MES/APS integration. Strong integration provides for high levels of responsiveness within the systems' rescheduling when a change is required in the existing production schedule.

MRPII benefits greatly from a fully implemented MES. Most companies looking to implement a MES already have well-established MRPII systems. Although MRPII systems provide a phenomenal planning discipline that combats classic reactionary management culture, they lack the feedback and knowledge of actual execution. The three core functions of MRPII systems, product definition, material control, and material planning serve to develop ideal schedules. MESA International stated in 1997, "Where MRPII has fallen short is in the development of a realistic schedule for the shop tied to a factory communication and tracking network. Dispatch lists produced by MRPII systems are rarely followed" (Functionalities, 1997). MES seeks to alleviate this issue with data collect and real time feedback.

MRPII and MES work as a team. MRPII plans and MES executes. This collaboration requires a circular information flow between both segments. The most important information that the MRPII systems provide to the manufacturing environment and MES are forecasting and demand requirements, bill of material

(BOM) structures, resource levels, routing requirements, and standard operating procedures (SOP). This information flows from MRPII to MES. MES employs this grouping of information to properly execute the required demand.

Throughout the manufacturing process MES collects vital information, which it then passes back to MRPII. The principal data that flows from MES to MRPII are actual start/end times, actual resource/labor usage, true routing processes, genealogy and serialization, and actual build configuration and BOM structure. This information flow between entities provides for a continual improvement of forecasting by MRPII.

Manufacturing execution systems define the communication between manufacturing planning systems (MRP, MRPII, ERP, etc.) and the shop floor control systems used to moderate production. Before MES this gap in knowledge was bridged by numerous people and countless paper documents that lead to great inaccuracies. Data collected in the manufacturing environment was never current or fully accurate. The sheer quantity of data available was difficult if not impossible to amass and never fully comprehensive. A MES system provides a complete solution to this archaic methodology of production execution.

The data collected from MES and transferred to MRPII provides MRPII with an evaluation of the forecast. The analysis of 'actuals' or what really happened is used to develop accurate and realistic process models, completion times, lead times as well as to identify precise capacity. The process will then repeat with more accurate information embodying the sense of continual improvement.

Well-implemented MES, APS and MRPII systems that collaboratively seek to forecast, schedule, and execute in the manufacturing environment provide for excellent manufacturing operations. Reduced cycle times and work in process (WIP) coupled with increased time in value adding activities, maximizes return on assets as well as improves productivity and customer satisfaction. With successful implementation a new or strengthened competitive advantage will emerge, and continued benefits throughout the company will be realized.

2.5 System Architecture of MES

Due to the incredible array of possible applications, MES system architecture varies dramatically. Systems range from a single computer within a department to many computers across departments across plants in numerous countries. No matter the structure and depth of the system the core functionality remains the same. To provide for this functionality, MES embodies on-line transaction processing (OLTP). This system design provides for immediate data transfer and availability. Fast response times in a highly automated system where data is continuously created and updated describe MES and OLTP. With OLTP multiple users can access data simultaneously.

The size of the manufacturing environment and associated number of data collection points proves one of the strongest constraints on system architecture. When numerous workstations, machining devices, printers, suppliers, data libraries, etc. are connected through MES the complexity of design grows dramatically. Not one of these processes much less all can be frozen in time as MES runs. This requires MES to calculate continually and provide up to date, real time information as defined by its OLTP system design.

Decision makers often undervalue the importance of hardware in a successful MES system. The biggest issue facing hardware design is integration. The concept of 'plug and play' devices that collaborate on Windows machines without any extra programming are becoming more and more prevalent, but this is still a major consideration. Another major consideration is sizing. As mentioned previously, size correlates with complexity. Data storage capacity, peripheral connections (workstations, machines, printers, etc.), and computational requirements provide metrics for establishing the specific hardware necessary to support the desired specifications of the MES system to be implemented.

The need for reliability within hardware requirements must be factored in as well. Such an integral system cannot 'go down' without great ramifications.

The risk associated with operation and heavy reliance on this system is often mitigated through running parallel components within the system, and having data centers that temporarily store information passed to the program if it is momentarily unable to accept. Such a design provides for operation during scheduled maintenance as well.

Connections between devices play a vital role in the caliber of the system as a whole. Devices usually connect via local area networks (LAN). The basic premise of LAN networks is to provide connection between all devices at the lowest cost. Various methods of layout design exist that connect devices in series, parallel, or a combination. All layouts communicate through connection points called nodes and controls for data integrity are implemented as well. The most common cable for such connections is coaxial as it provides high data transfer rates, strength in the manufacturing environment, and relatively inexpensive pricing. Depending on the system requirements, fiber optic cables provide the best solution on the market, but at a cost. Cables are not required for every device as seen when a connection must be made to MES, but is too mobile or inaccessible. Solutions, such as wireless networks, exist and have been successfully implemented for communication with almost any device enabling full interaction with MES.

Lastly, the devices themselves affect the speed, reliability, and overall performance of the system. The term device seems quite broad as it refers to any source or sink of data whether human or machine. When comparing a human or machine data source, automated data collection should be given priority over human input. Set forms and specific controls on a computer best accomplish human entry, but only as a last resort. Strong data integrity and timeliness, provided by automated entry, greatly improve the quality of the system as a whole. Various devices such as barcode, RFID, smart machines, and computer vision among many others are interfaced with MES and provide real time data correctly. A robust and capable system relies heavily on the foundation supplied by proficient hardware.

2.6 Current Out of Box (OOB) MES

Manufacturing Execution Systems vary widely in functionality and combination with other systems under the ERP umbrella. Numerous types of MES have been developed based off the needs of the company attempting to implement the system. MES systems exist in two main categories, homegrown and purchased. The purchased category offers a myriad of software for a vast array of companies all offering differing functionality and toting great user interface.

Homegrown systems are relatively rare, and are generally implemented in industries that cannot interface with standard OOB MES. These internally developed systems were common when the term MES arrived in the early 1990's in one form or another. Throughout the last two decades numerous have been scrapped and replaced with a purchased system.

Purchased MES systems are as varied as the industries they seek to represent. Often MES are specialized to interface with the characteristics represented by a larger pool of companies. For example, HYDRA specializes in plastics, rubber, mold making, and automotive whereas Interax works in aerospace and defense, electronics, and industrial machinery. Some MES packages come with other modules such as customer relation's management (CRM) or asset management and occasionally with an integrated MRPII component such as Exact JobBOSS. For a smaller company with little existing computerized production management Exact JobBOSS would be an ideal purchase because of the small-scale integration with MES and MRPII among other components and financial modules.

Within the purchased systems category arrive huge ERP systems for equally huge companies on a global scale. These systems are generally provided by ORACLE or SAP. Both boast MES systems that work seamlessly with their existing ERP packages and associated modules. With enough funding these MES modules can be fully customized to the industry needs and manufacturing characteristics. These will be the MES systems of focus in the

development of this thesis due to their overarching functionality and wide adoption.

As a purchasable and configurable software package, MES systems can be implemented following a systems engineering approach. Not all aspects of this broad field are employed, but the strengths provided systems engineering aid in properly managing such a complex implementation. In an essence, utilizing systems engineering attempts to discover MES implementation in a holistic view. Utilizing standard tools within systems engineering such as project and complexity management, optimization, and risk management functions streamlines the implementation process. Systems engineering places emphasis up front on design in order to minimize issues encountered downstream. Numerous interpretations of systems engineering exist. This versatile and powerful topic is considered in the development of a systematic engineering approach to MES implementation.

2.7 Cost/Reward of MES

From the analysis of the benefits provided, and solutions to existing problems, the reward for successful implementation should be great. Quantifying the returns in time and money are not too difficult, but identifying all of the direct and indirect benefits of a fully implemented MES system prove to be the most challenging aspect of assigning an accurate return on investment. Kai-Ying Chen in 2006 from National Taipei University of Technology has developed a “performance measurement of implementing MES from several quantitative and qualitative aspects by analyzing the basic functions and objectives of MES and interviewing with some senior consultants and MES relates working staff.” His paper displays a careful analytic hierarchy process (AHP), which is used to prioritize the performance measurement indices. With around forty different indices AHP was employed to identify the most influential of the candidates. In conclusion Chen reports, “The main benefits of implanting MES are process

improvement and quality improvement.” To limit the influence to direct benefits that can be quantified monetarily would be at great loss to the true value.

MESA International a well-established association of MES developers and vendors provides another look at the value attained from implementing a full MES system. Through industry surveys MESA has developed an expected outcome for MES implementation. MESA International reports some impressive statistics for direct benefits of MES.

Sixty-six percent (66%) of the manufacturers responding reported a reduction in manufacturing time of 45% or greater. Sixty-six percent (66%) of the manufacturers responding reported a reduction in entry time of 75% or better. Fifty-seven percent (57%) of the manufacturers responding reported a reduction in WIP of 25% or better. Sixty-three percent (63%) of the manufacturers responding reported a reduction in paperwork between shifts of 50% or better. Sixty-three percent (63%) of the manufacturers responding reported reduction in lead time of 35% or better.

All of these figures are merely some of the direct benefits of MES, and do not include any indirect. With this in mind MESA International reports their most indelible fact, “Return On Investment/Payback Period (14 Months Average).” This is truly impressive because for the initial investment of an MES system can be enormous depending on complexity and size.

Chapter 3 - Thesis Work and Validation

As seen, a fully integrated MES system will greatly benefit a company from numerous angles. Implementation practices and common knowledge although are much more difficult to acquire. Numerous small to medium paper driven companies could benefit from a manufacturing execution system. Unfortunately, a lack of understanding of how to simultaneously shape the existing manufacturing environment into one compatible with MES and control its implementation is missing. Throughout all literature reviewed, none specifically identified a successful plan for implementing MES. Many benefits and case studies summarizing an implementation exist, as well as occasional identification of issues and stakeholders, but no roadmap for systematic implementation planning tool can be found. This thesis seeks to fulfill this important missing aspect.

The construction of this tool requires complete understanding of MES and its implementation. This problem is two faced. First, there exists a general lack of understanding of a generic manufacturing environment ideally interfaced with such an MES system, and how to carefully define the processes within. This involves many issues including facility layout, process design and interaction, and resource management. The second issue, the heaviest focus of this thesis, is the lack of information regarding the actual implementation plan. The developed implementation plan will precisely lay out stages and strategies necessary to bring a company's manufacturing environment from their current state into a digital one interfaced with a manufacturing execution system.

The conglomeration of information presented in this thesis will provide companies with valuable information to affordably and successfully control the implementation a basic MES system. In the definition of processes and design of a manufacturing environment based purely off the mandatory inputs to a MES system, a visibility into the structure of an ideal manufacturing system interface with a MES system will be exposed. The insights presented by this design will be used to develop stages, measurable by percent of total implementation, and

strategies used to move a company's manufacturing system through the process of basic MES implementation to a fully integrated system.

The execution of the research requires a multiple stage analysis and trial implementation. This process will involve the evaluation and understanding of multiple out of box MES systems available for purchase. This analysis will also provide the identification of multiple inputs into the system. Only when inputs are defined, can stages and strategies of implementation be examined.

Issues causing the inability of a small to medium paper driven company to implement a MES system will also be identified. Once these issues and inputs are characterized, the main creation of the thesis will begin. A systematic implementation planning strategy will be developed. Fourteen stages will be identified to determine the levels of development necessary to achieve MES implementation. Accompanying and summarizing these stages will be a chronological execution map and strategies that when enacted, will bring a company's manufacturing environment to one seamlessly interfaced and capable of reaping the benefits of a fully realized MES system.

The validity of the work accomplished by this thesis will be verified by a comprehensive case study. This case study will consist of a full analysis of the stages and implementation of the execution maps. Upon the completion of alterations to the existing manufacturing environment, the full implementation and effects of the MES system will be recognized by a medium sized satellite communications company and the thesis work successfully validated.

Chapter 4 – MES as a System

Three main topics comprise this thesis. First, general concepts and premises of MES as well as inputs into an out of box MES will be defined. Also, recommended adaptations of the manufacturing environment based on these inputs will be portrayed. Next, general issues facing small to medium sized businesses when looking to implement an MES system will be addressed. These issues will be overcome by a specific identification of stages defined by levels of functionality of MES implementation, and strategies to best move from one to the next, the main focus of this body of literature. The end result is the presenting of a fourteen stage systematic planning approach for MES implementation. Ultimately, this thesis will examine the effectiveness of this proposed systematic implementation strategy with a specific company. Conclusions will be made and a summary of the work written.

4.1 General Concepts

Have you have heard that no two snowflakes share the same physical configuration? Well, the same theory holds true for manufacturing execution systems. Therefore, an attempt to quantify MES and standardize the exact concepts of the program across all businesses and industries would be futile. The only definition that holds true in any scenario follows, “A manufacturing execution system (MES) is an online *integrated* computer system that is the accumulation of the methods and tools used to accomplish production.” (McCellan, 1997, p.56) Essentially, two words can always be used in any successful MES implementation: *execution* and *integration*. We will focus on these two concepts as we move throughout this work.

4.2 Premises

Execution, as the main premise of MES, can be defined as the bridge between planning and control. Planning seen in the various functions of the MRP system. Control seen on the shop floor from humans, smart machines or programmable logic systems. The collaboration of information between the planning and control systems embodies the integration aspect of MES. These connections provide the basis of defining the inputs into an MES system.

The complexity and inconsistency of MES systems dictate a very specific program depending on each implementation scenario, but such wide variability can be attributed to the user interface and level of desired functionality. Out of box (OOB) MES systems are possible due to the development of standard reusable application software and extended entity-relationship (EER) modeling techniques. Use of these techniques is made possible from shared data control and analysis between systems.

With this in mind, to define the complex functionality of MES one must distil MES into its core functionalities. These functionalities must then be examined for specific inputs. Once the system is displayed in fundamental building blocks, it can then be recreated with a full understanding and a true implementation plan may be established. The fundamental elements are inputs.

4.3 Inputs

Inputs to MES form the strength of the program. Execution cannot be possible without proper awareness of the entire situation provided by the ERP umbrella. The MES's main source of information is the planning or MRP II system, but the feedback loop from the control system also provides crucial input. The planning device provides the constructs by which the MES system defines the activities required for production and the control layer returns actual results and continually refines the manufacturing process. The primary aspects of focus when identifying inputs into such an OOB MES are the planning and control layers.

Inputs into an OOB MES system can be broken down into ten specific concepts. Numerous other elements are interfaced under the ERP umbrella, but for a basic functionality of MES to be realized, these ten inputs are mandatory.

Functionalities and major inputs can be seen in figure 3 above. The first and most apparent input into MES comes directly from the planning level. This is demand. Demand sets the fundamental requirements that drive the MRP II schedule, which the MES system must attempt to fulfill. This basic input drives many of the MES functionalities including scheduling and inventory management.

The second input, scheduling, is also of great importance. High level scheduling and due dates are direct inputs into the MES system from the planning layer (MRP II). The basic schedule will provide MES with the start and end goals and provide it with the established guidelines by which to pilot production.

Figure 3: MES Planning and Control Inputs

Inventory takes next of these concepts. As the most crucial aspect of manufacturing, the planning and MES systems carefully control raw goods. In the planning level, on hand totals of product are maintained by triggering purchase orders. The planning level provides MES with initial inventory levels, but as the system executes, data is returned to the planning level as actuals are realized. As work in process (WIP) moves or supplies consumed, MES tracks detailed data of inventory levels, location, and availability. This is usually done automatically via flagging successful completion of stages and using other input elements such as the bill of materials or routing to make calculations of inventory usage. Any exceptions or rework can be directly accounted for by inputs from operators on the floor. The control layer either a material handling system, in a highly advanced manufacturing environment, or merely the operator retrieves inventory based off the MES system's execution outputs. Planning, execution, and control layers all require and collectively maintain inventory data.

Inventory data cannot be calculated without another mandatory input, bill of material (BOM). Bill of material data, comprised of name, quantity, lead time, etc. resides under the ERP umbrella most likely in a computer aided manufacturing database, and is a mandatory input to planning and execution levels. The planning level essentially relies on BOM data for all of its calculations, which are in turn inputs to MES. As a direct input into MES, BOM and routing information are referenced when inventory is assigned to a specific production station. MES relies on the integrity of BOM quantities to maintain accurate inventory levels.

Routing information provides the map with which MES navigates WIP through the manufacturing floor. As BOM information is held under the ERP umbrella in a database so are routings. The planning level will utilize routing information as well as time standards for high-level feasibility and capacity planning. As an input to MES, routing information structures the backbone. The execution level relies on routing information to construct finite schedules per manufacturing operation. Routing information allows for the development of

potential schedules based off the priority and workload per operation. MES analyzes these potential schedules by time, cost, labor, etc. to determine the most desirable then implements the chosen agenda accordingly. If the factory includes a material handling system, MES will use the routings to manage the physical movement of the system and inventory within the system. The operator is passed routing information by MES in the form of location of the product's next stage of manufacturing and associated directions. Routing information is the core of MES. With more complex and interconnected routing of products through the manufacturing floor, the more beneficial MES.

Process data, sixth, is not a traditional input to MES. MES does not synthesize any data or make any calculations based off this input. Instead, it acts as a transfer medium between the ERP cloud database holding this process data and the control layer/operator. Highly automated machines could be setup by this transfer of data, or at minimum, the operator could see a particular set of tasks required for the specific product at his or her workstation. Process data is not limited to instructions or settings. BOM and routing information is often included in this transfer of information. The MES system provides for maximum knowledge at the operators fingertips.

Capacity planning continues to build the mathematical model of the factory floor in the eyes of MES. The planning layer conducts total capacity planning which is input into the execution layer. Once in the MES layer, capacity planning is broken down further into finite and actual real time capacity for every manufacturing operation. This data is continually refined from actuals gathered from the control layer. MES builds its scheduling models accurately reflecting capacity planning data.

Inputs and outputs into the standard manufacturing environment must be accounted for as well. The receiving of purchased goods into the system, their inventory location, and any quality control or other data accompanying the shipment is carefully documented by the MES system. These inputs are used in inventory calculations and the accompanying data is used in metric generation and quality control. Receiving quantities are also input into the planning layer

where they are assigned to purchase orders. This data is then passed to the MES system to be executed.

The ninth input to MES is the only to come entirely from the control level. Operational data comprises much of the information input used in reporting from the MES system. With wide variability, operational data consists of the actuals seen on the shop floor. From serialization, completion times, rework measures, setup time, or throughput, this information is held in the MES system and uploaded to other ERP modules. In the MES layer, operational data is used for reporting purposes as well as refining the mathematical model of the shop floor. MES collects this data by either automated machine upload or manual input by the operator. Under the distinction of operational data, quality control and testing data is also collected.

Lastly MES provides for the execution of engineering change orders (ECO). This input is held in a database under the ERP umbrella, and passed to the MES system. New production items will be logged with the required ECO. MES will also identify and execute any repair items in need of ECO service.

The main issue in collaborating these inputs in a manner capable of interfacing with an out of box MES system is process definition. The hardest part of MES implementation is definition. The precise defining of both the specification of desired functionality of software as well as actual manufacturing processes to be input into the system challenges small to medium size companies to carefully examine and standardize their processes.

With these inputs a more precise definition of purpose of MES comes to light. Beyond basic execution MES also seeks to answer real time problems affecting the processes on the manufacturing floor. With such a complete knowledge base, MES maintains real-time insight into the status of operations and feeds carefully synthesized information to management.

MES assists production management throughout its entire lifecycle. The first phase implementation of MES is never the last. This means that MES also serves as a tool for continual improvement when developed over the entire manufacturing environment and evolved to include all functionality.

As the focus of this endeavor surrounds small to medium sized businesses, the ideal level of implementation varies. General issues include funding availability, interest of stakeholders, and time. These issues along with inputs will be analyzed in Chapter 5 in the development of a systematic planning approach to successful MES implementation.

4.4 Adapting the Manufacturing Environment

The manufacturing environment of a small to medium sized company often harbors more complexity than a fully flushed large-scale operation. This is due to the fact that the interworking of individuals is specific only to that person and task. The same task is more often than not done differently between operator and each view their way as correct. Without established processes an MES system cannot flourish.

Often times the adaptation required in a manufacturing environment proves not so much change as standardization. In the process of adjusting the system to fit MES, numerous other quality measures must be taken. This leads to concepts such total quality management, lean, and process improvement philosophies being introduced and simultaneously employed in a conjunctive effort to mold the manufacturing system to interface with MES.

The most common issue plaguing a small to medium sized company attempting to implement MES is established routing. A facilities design engineer has most likely never examined the physical movement of products through the manufacturing environment. With the definition of routing, processes, and resource centers the ideal floor layout can be identified. As mandatory inputs to the digital construction of the shop floor in MES established processes must be determined.

With the current understanding presented and understood, the ultimate creation of a systematic planning approach to successful MES implementation may be explored.

Chapter 5 – Systematic Planning Approach to MES Implementation

A systematic planning approach to successful MES implementation has been developed that provides for a visual understanding of the chronological implementation of MES. This graphical representation of the 14 stages of implementation can be utilized as a reference guide. Exit criteria defined for each stage provide the user with a strong understanding of the current progression and open action items. Successful implementation requires strong organization and planning facilitated by the execution tool seen on pages 28 and 29.

With this systematic tool in mind, the explanation and required execution will be explored for each stage. The best way to define the complex application of MES to a system is by quantifying the level of functionality incorporated in the design. From initial conception to steady state, monitoring the stages of MES implementation will define a road map capable of depicting the best path to successful rollout and reception throughout the company. To achieve such a successful product, careful consideration to all aspects and a system engineering mentality must be employed.

The V-Model, utilized in system engineering, provides an excellent portrayal of the high level processes by which the stages of implementation can be categorized. The V-Model in Figure 4 below serves as a graphical representation of the process of system development. Through delineating the phases of system development, the V-Model provides clarity by mandating completion of necessary documents to exit a phase. Numerous stages comprise most phases found in the V-Model.

Figure 4: V-Model of Systems Engineering

‘Concept of Operations’ is the first phase of the V-Model. This phase is entered with initial conception of MES. Generally, such a beginning stems from a need or deficiency in the current system. Numerous possibilities exist for the initial consideration of MES. Often times issues surrounding visibility into the

actual occurrences on the manufacturing floor are first realized by upper management. Without proper data collection and analysis mid-level management cannot answer questions regarding inventory, work in progress, historical records, and cycle times among others. After realizing this lack of control, MES is concluded to be the best opportunity for improvement.

5.1 Stage 1 – MES Explored

With this in mind Stage 1 is entered. In this stage the option of MES is explored. Often with little to no initial understanding of MES, management begins to reveal this option through personal research and possibly a consultant. The strengths of MES defined previously entice the decision makers with promises of great improvements. As the layers of MES are peeled back, the complexity arises and costs come into play. The exit criteria for Stage 1 are the simple research into MES, and the desire to examine the possibility.

5.2 Stage 2 – MES Project Feasibility

Here stage 2 begins. More evolved, the actual means of executing this drastic project are first explored. The beginning components of a statement of work are proposed. The scope of the project is investigated. As the solutions provided by MES systems are varied and not all required, defining requirements and involving stakeholders proves the main focus of Stage 2. The process of requirements definition also marks the beginning of the second phase of the V-Model. Requirements definition for specific applications will change the stages of implementation actually used from this work, but in order to maintain generality, the assumption of a complete MES system will be upheld throughout. In the process of requirements planning many inputs must be gathered. For the successful adoption of MES, all stakeholders that stand to gain or be affected by this software, must be involved. This in itself proves a massive undertaking as

expectation management and viability must be balanced by cost and time constraints. Simultaneously, project feasibility emerges.

In Stage 2, in accordance with the V-Model theory, much thought is placed into detailed design at the beginning of the project in order to reduce uncertainty and risk throughout. As a strongly requirements-driven software that is highly variable, the concept of mining for desired functionality, and flushing out any potential issues is of utmost importance. This proves to be an ongoing process. The exit criteria for Stage 2 are as follows: involvement of all stakeholders, initial feature discussion and primary feature identification, established project feasibility most importantly in terms of cost and time constraints.

5.3 Stage 3 – Project Analysis

As stage 3 commences the project begins to evolve and becomes much more involved. The main focus of this stage is the “gap analysis.” The analysis itself cannot be done at this stage, and probably not even by the company itself, but in this analysis the understanding of the current state and the future state is flushed out. With beginning and end states defined, the decision makers can then set about in determining how the transition will be made and define deliverables along a timeline. At this stage the company actively pursues the assistance of an outside consultant/vendor. Stage 3 serves to solidify the envisioned MES system, and the exit criterion is an almost complete high-level understanding and associated documentation of the project process and deliverables.

5.4 Stage 4 – Decision Strategies

Stage 4 is characterized by the ‘make versus buy’ decision. With a strong understanding of requirements, analyses of current out of box (OOB) and potential build to suit options may be explored. Each with their own set of costs and benefits, a side-by-side comparison is made. Often in this process the assistance of a professional consultant versed in the intricacies of MES will assist the decision makers. With general lines defined, request for proposals (RFP’s) are generated and sent along these channels. A few important considerations are taken into play at this stage.

In determining the make versus buy decision, a fully informed decision is critical. With current knowledge of the manufacturing environment, desired functionality, and available systems the best decision can be made. Another significant factor lies in the consideration of the existing enterprise resource planning (ERP) system. The ERP system and its modules interact closely with the proposed MES system as previously described. Due to this data intensive relationship the selected MES system must interface with minimal issues with the existing systems. With all influences documented and measured the best course of action may be chosen.

In analysis of the existing solutions across the MES board, the best solution varies. For a discrete manufacturing company with a relatively high product variability and volume an OOB MES system should be chosen. This is due to the fact that there are numerous MES systems for this type of manufacturing environment that most likely specialized to the company’s field. This is the ideal company for OOB MES implementation due to the ability to leverage all components an MES system has to offer. Companies with low product variability and high or low volume should also choose an OOB MES, and will realize similar returns though possibly not utilize all available features. OOB MES systems are the most common as they are a cost effective and provide an established system. The only time a built to suit MES outweighs an OOB solution is when the product or manufacturing environment is very obscure and

highly individualized. The costs of time, money, and knowledge required to design from the ground up prove OOB solutions the most attractive.

With little other consideration, a MES system provided by overarching ERP packages such as Oracle or SAP should be chosen providing the associated ERP system is already in place. The potential to interface, with little or no added development, to modules across the business provides an incredible cost benefit ratio. Selecting this option minimizes additional software architecture. Such an implementation will be an ideal case study as described later in this work. Phase two of the V-Model comes to a close in this stage as the high-level system requirements are all met, and the basic design has been established. The exit criterion for stage 4 is assimilation of previous stage's information in completed RFP's.

5.5 Stage 5 – Choosing a Vendor

Stage 5 begins with proposals in hand from on average between two and five organizations; the final decision can now be made. Using decision making tools such as the analytical hierarchy process (AHP) or paired comparison analysis the various options may be scrutinized. Through identifying relative importance of features, timeline, cost, etc. as well as qualitative analysis of desired factors, the strengths of the models may be compared. For this decision, the AHP process works wonders as the major factors of the models may be directly compared on a quantitative level. The AHP decision compares important issues on a deeper level that include user interface, functionality, time for implementation, change management, and risk among many others. These factors are all identified and qualitatively measured for each proposal. Then the factors themselves are qualitatively measured against one another regardless of proposal. Ultimately, using matrix calculations, the proposal with the highest score is identified. Stage 5 is exited when a specific proposal is chosen.

5.6 Stage 6 – Statement of Work (SOW)

A statement of work (SOW) to be signed by both the company adopting MES as well as the vendor company dominates stage 6. In stage 6 many issues that have been touched upon in the previous stages are solidified. A statement of work will dictate the responsibilities between each company. Often this includes a solution plan, project schedule, resource plan, project budget, risk assessment, and a training plan. With these documents defined and the acceptance criteria set the project can be easily visualized. In a statement of work the features desired are also somewhat set in stone. Communication protocols and resource expectations from both companies are established. One of the largest aspects included in a SOW concerns the pilot implementation plan.

The pilot plan remains crucial to the successful adoption of MES throughout the process. To begin a pilot plan the first decision arrives with the identification of a product line that will serve as the original product supported by MES. This is a difficult decision and is comprised of three main characteristics. First, the choice must be made of a product that embodies many if not all of the manufacturing processes of the company. Second, to select an ideal product, the product flow diagram must be scrutinized to identify all modes of data collection. Lastly, this product should have a large financial impact within the company so that the financial analyses presented along with the program are strong as well. With a product that contains all of the aforementioned characteristics, a well-built pilot program may be conducted. This program will serve as a strong proof of concept. Addressing all possible issues and conditions throughout the manufacturing process, such a proof of concept stands against the most difficult criticisms.

The decisions made concerning the pilot program are reflected and built upon in the various other aspects of a complete SOW. An effective SOW dictates the need for a solution plan that describes the setup of the application and any software or hardware necessary to implement the pilot program. Project schedules often completed in Microsoft Project lay out project deliverables,

resources, and durations. Assembled from actions defined in the schedule as well as resource plans accurate project costing and budgets are built to specifications from the initial proposals. The SOW also requires risk identification, impact, and mitigation strategies are to be compiled in a risk matrix document. Ultimately, a training plan is requested, as the consultant group must transfer their knowledge of operations to the company once MES is implemented. Stage 6 concludes with a SOW complete and a team of resources selected.

5.7 Stage 7 – Gap Analysis

Now that the project has been fully defined, and the first two phases of the V-Model completed, stage 7 commences. The third and last phase of the project definition leg of the V-model is ‘detailed design.’ Detailed design is a complicated stage. To begin this stage the gap analysis previously begun in stage 3 must be completed. From stage 3 the current and future states have been defined. The gap analysis requires examining the actual information available in the current system and identifying the missing or incorrect format for integration with MES. This information is varied, and depends on the desired functionality within the MES system.

Information held within the current system is broad. Routing, BOM, work centers, resources, capacity data among much more are generally held in databases under the ERP umbrella. The existing data, its current state, and its storage mechanisms must be understood. Such understanding will be utilized in the implementation process to identify issues so that the pilot program may be successfully run. As the main focus of the gap analysis is determining the steps necessary to implement MES, a logical construction must be followed. The foundation must be established. Data provides the groundwork, which all other functions require for performance. The depth and strength of the data, both in content and storage, dictates the success of the program as a whole. Next, the constructs or walls must be built. The constructs can be defined as the actual

shop floor modeling and definition within the system. This also refers to interface with other systems throughout the ERP umbrella. Ultimately, the roof or 'outside' is implemented. This is the actual user interface. Whether this refers to the form by which the operator inputs data, or the display the shop manager reads in order to expedite an order, the user interface proves the ultimate goal and the end all evaluation criteria for success.

A complete gap analysis also provides both the adopting and consultant companies with a clear understanding of the work necessary to implement MES. At this point, statements of work and their associated schedule, resource, and budget may have to be reworked even though this is not favorable. The exit criterion for stage 7 is a completed gap analysis and the assimilation of understanding of all steps required for integration.

5.8 Stage 8 – System Architecture

Stage 8 truly showcases the detailed design of the system. System architecture is the main focus during this stage. Two main concentrations exist during this stage: software and hardware. Hardware specifications must be determined based on the previously defined system requirements. As earlier stated, size of the system defines complexity, and complexity delineates the requirements of the hardware. Higher levels of complexity necessitate better hardware in terms of data storage capacity, peripheral connections (workstations, machines, printers, etc.), local networks, and computational requirements. The exact hardware will be determined and supplied by the vendor identified in stage 5.

One of the biggest costs and most controllable from careful early stage design is software architecture. This software performs beside MES to facilitate the data flow to and from MES. Essentially data can be stored in various formats or arrive packaged in numerous formats from any device within the system. Any additional software's main purpose would be to synthesize this data for its usage within MES. Complexity of the system, requirements of other software with

which MES communicates, and variability of data collection devices define the extent of additional programming architecture necessary to seamlessly implement MES.

Software architecture can also be required within MES. Occasionally, with specific requirements, OOB MES systems lack certain reporting functionality or other such services desired by the implementation team. This generally occurs within a very specific manufacturing environment or implementation scenario. Such additional software development is entirely possible, and will have been defined in the statement of work completed in stage 6. This is not an issue with built to suit MES systems as the entirety of its functional design arrives within this stage as well as a vast majority of cost. Detailed design goes beyond system architecture. The exit criteria for stage 8 are completed documents graphically and verbally defining system communication, layout, and architecture as well as a clear understanding of the exact hardware components to be purchased.

5.9 Stage 9 – Pilot Program

Stage 9 solidifies the functionalities desired within MES specific for the pilot program, and determines data collection methods. In this stage sufficient knowledge of MES has been obtained to facilitate the development of an actual working pilot program. Previously identified functionalities must be aligned with the pilot program. In this stage a company may scale back initial requirements of the MES system in order to progress the chosen product through the MES implementation. Basic functionality and successful operation of MES serves as a strong proof of concept that provides for the continued integration and ultimate scaling to the entire manufacturing environment across all product lines.

Data collection points for the pilot program are also defined in accordance to desired functionality. To accomplish this, all aspects involved in the manufacturing of the product previously chosen for the pilot study must be understood. Often, this is achieved by developing a process flow chart if not already in existence. Determining the flow defines the workstations, operations,

machines, quality measures, transportation, and storage locations with which the item interacts. These are the essential data collection points necessary to implement basic MES functionality. Exit criteria for stage 9 are completed documents detailing the elements of manufacturing for the pilot project as well as the data collection points necessary to facilitate implementation.

5.10 Stage 10 – Implementation

In stage 10 implementation begins. The implementation phase lies at the bottom of the V-Model. This phase provides the methodology with which the consulting company develops the first iteration of MES. Stage 10 will focus on implementing an out of box (OOB) MES system. To begin implementing functionality, the fundamental operations must first be defined in MES.

The manufacturing system specific to the pilot product must be delineated in MES. The defining of operations necessary to manufacture the pilot product dominates the beginning of the implementation phase. Each operation must be defined and stored for reference within MES. Labor and machine resources and credentials as well as time and material requirements must be defined for each specific operation. Once operations are defined, the flow or order must be established. Here, operations are labeled to occur in series or parallel. MES utilizes the breakdown of detail to specific operations to construct ideal schedules for expeditious execution. Operation definition proves critical to the implementation of MES.

Storage and inventory also must be defined for MES to fully define the manufacturing environment. Capacity must be identified for each storage location for both long term and work in progress. Existing inventory levels must be input for each location as well.

Perhaps the most important aspect of MES is the defined scheduling system. This user specific method of scheduling can be as simple as a chronological series of operations, but is always complicated with numerous constraints. Many theories and scheduling practices may be selected for this

operation. OOB MES systems begin with basic demand based scheduling. MES fulfills basic scheduling by examining capacity of the manufacturing floor and lead times. Some systems are configured for more complex scheduling including kanban, level loading, or even drum-buffer-rope. The exact scheduling component of MES varies by system.

With a simulated manufacturing environment defined in MES, operations may be run off its structure. These operations are the functionalities promised by MES implementation. Basic functionalities of MES generally identified in the pilot project as described previously include:

- Dispatch driven execution
- Display of work content and instructions
- Clock in/out functionality
- Transaction reporting and controls
- Exception management
- Serialization
- Shop floor device and test equipment integration
- Automated printing of travelers and labels
- Labor skills validation
- Supervisor dashboard

With successful implementation of the above functionality, a working MES pilot program can be realized. For an OOB MES, implementation of functional parts of the system is best described as ‘turning on’ certain elements. To accomplish this, each element requires specific data collection and input points to facilitate proper operation.

The data required for the dispatch driven execution functionality of MES to be activated is a schedule input from the planning system (MRPII), resource information, capacity, and current status. The timeliness and format of the data transfer is paramount, and the vendor will determine exact details. MES then

controls the execution of this plan, and reschedules if any issues or alterations arise. Dispatch driven execution serves the operator as the stepping off point for all actions. Besides displaying work orders by priority, it provides ability for recording work related transactions. These transaction reports include start and finish times, work in progress movement, scrap, and exceptions. This user-generated data is then fed back to MES, synthesized, and schedule changes are made accordingly. With this data structure in place dispatch driven execution may be implemented.

Much data is necessary to implement the display of work content and instructions on the operator's terminal. The specific details previously outlined for each operation form the fundamental information passed to the employee's terminal. This information can include sequential tasks, information on children, and routing information. Display of work content proves one of the strongest drivers in eliminating the traveler, and striving for a paperless manufacturing environment.

For MES to support clocking in or out makes perfect sense. In line with the focus of an ERP system, the operator would have to record this information manually. Since the MES system provides tracking for start and stop times for a specific job, calculations for total time spent on a certain project, and throughout the day are simplified. Such reporting removes non-value added activities from the machinist. This functionality requires no extra data configuration as the job number is already defined by the work order the operator is fulfilling. Time capture is a prime example of MES interface with the greater ERP system. Actuals are passed into the ERP databases and are referenced throughout manufacturing, but also by payroll and finances.

Transaction reporting and controls provide the structure by which the operator moves the product through the manufacturing floor. A component of other functionalities, transaction reporting comprises much of the data generation on the shop floor. Solid user interface prepares the machinist with the ability to simultaneously report multiple movements, time expenditures, quality results, or many other transactions. The control portion refers to the required data to

progress to the next stage or operation according to the flow of the product. By controlling how transactions are processed, MES monitors the actions of the shop floor. Here, logic gates are defined that govern the shop floor activities. Operations definition, flow, and logic criterion data is required to implement this functionality.

Exception management forms the source of many strengths associated with MES. With exception management, operators can report events such as missing/unfit components, inoperable machines, fatal quality problems, or missing operators. This information is used to alert supervisors, but also to avoid missed production quotas. Once MES is informed of an issue it undergoes rescheduling of operations and reevaluation of priorities. This minimizes the detriment caused by the fault in the production line. To enable this functionality, possible exceptions must be defined and stored in MES databases. MES measures and seeks to minimize the effect on the system by removing possible operations from the rescheduling.

Serialization exists as a rather simple task in MES when compared to paper controlled systems. Much of the serialization data is input along the way as subassemblies are constructed or purchase orders received, and predetermined by naming algorithms that exist in other modules under the ERP umbrella. MES utilizes the predetermined serial numbers to compile, store, and recover historical records. This includes more than just transactions, and is most valuable for determining child serial numbers from a parent. Well-integrated MES systems occasionally interface with supplier information. This provides ability to track production to its origin. Serialization provides for the ability to assign certain production to work orders, and maintain control of specific items throughout production.

Shop floor device and test equipment integration delivers vast quantities of data to MES. With similar purpose as transaction reporting, device and test equipment provide automated responses to actions on the shop floor. As expected, smart machines provide for higher caliber and faster transaction reporting. Much of the work to integrate these machines into MES has been

previously described in system architecture. Implementation of this functionality requires no other data development or structure, but rather data management in order to properly transfer, interpret, and store information.

Ideally, a company's manufacturing floor would be completely paperless, but many factors dictate the need for paper travelers. MES provides automated printing of travelers and labels seeded with information already within MES. Operators may print from their workstation to remote printers set up during the device integration stage. Beyond traveler printing, label printing also benefits the company greatly. Label selection, sizing, and printing often prove difficult and faulty. With MES previously defined labels are seeded and printed with the push of a button. Therefore, for this functionality to be leveraged, data structures must be developed before they may be seeded with information within MES. Label printing is often more complex as different material and sizes are required forcing the utilization of multiple printers. Traveler generation generally works with one or a few templates based off product line or work center.

Companies with highly trained human resources rely on labor skills validation. With MES, records may be stored that evaluate the ability of the operator to perform a task. If an operator is not qualified to transact an operation, MES will alert the operator and prohibit the action. Training records may be incorporated from other modules of the ERP umbrella. Otherwise, data must be generated that list the qualifications of a specific operator and their ability to fulfill a required operation. When this functionality has been turned on, MES schedules with adherence to labor qualifications. ISO standards are upheld with implementation of labor skills validation.

Ultimately, the supervisor dashboard will be implemented. This user interface provides for more complex interaction with MES. In this application, jobs may be expedited, priorities assigned, and exceptions resolved. This level of control allows for the streamlining of decision making required for maximized productivity and seamless operations. The manager is equipped with a tool that provides insight into the exact operations of the shop floor.

The value of collecting such vast quantities of data would be lost if metrics were not generated. With great knowledge, great understanding may be achieved. The supervisor dashboard pulls from all data collected to provide managers with real time insight into the actions of the shop floor. Key metrics include:

- Production to plan – Determines progression according to schedule
- Work order shortages – Identifies missing resources or capacity
- Labor performance metrics – Quantifies labor efficiency
- First pass yield – Alerts to quality of product

Many other metrics are produced from the data generated within MES. Perhaps one of the most valuable is the work order shortage as it provides a look into the future and preventatively alerts the supervisor to an issue that will occur with the current schedule. Overall, the supervisor dashboard provides a clear understanding into the manufacturing environment in real time.

Stage 10 proves long and complex. The vendor company will accomplish most of the work. Intermittent signoffs of progression should be established as the project develops. Complete implementation will come eventually, but this stage provides a working proof of concept. Exit criterion for stage 10 is a working prototype of the MES system specific to the pilot product.

5.11 Stage 11 – Test Prototype MES

With implementation complete, the final leg of the V-Model begins. In stage 11 the prototype MES system is put through rigorous testing. Numerous users exercise all functionalities of MES from every angle. Such testing begins with the high-level stakeholders in a ‘conference room’ pilot. These individuals sit around a table and assign theoretical roles and ‘move’ product through the system. In an effort to highlight any issues the proof of concept MES must

perform to expectations. During this exercise, the vendor is simultaneously teaching the users how to interact and control the system.

Once satisfied with performance on a theoretical level, the MES system will be tested in the actual manufacturing environment. Once installed on the operator's respective terminals, operators will be trained and expected to interact with MES. Shop floor supervisors must also be trained for their role in MES. They too will be required to employ the supervisor dashboard for completion of daily activities. Integrated into the manufacturing floor and the daily activities of the operators, the pilot MES may be evaluated for influence. For exit criterion to be met, the MES system must be in place and successfully used by both operator and supervisor roles. Stage 11 concludes once the exit criterion has been fulfilled.

5.12 Stage 12 – Verification and Validation

Stage 12 begins once sufficient data has been collected to perform comparison calculations between the before and after states. This is the next phase of the V-Model. During this phase the MES system's success is verified and validated. Validation is accomplished by calculations that attempt to assign cost to both direct and indirect benefits. Time saved for required operations prove the easiest direct benefit to quantify. Hopefully, in a controlled system, the previous time required to perform each element of production was recorded. With a new system, time studies for each element must be reevaluated. The reduction or elimination of data entry presents one of the largest time savings. With a very tangible difference in time, multiplied by the cost per hour of the operator, a dollar value of direct time savings may be presented. Another direct benefit can be seen with increased throughput. Decreased cycle times and reduction of non-value added activities lead to higher productivity. The previous production quantities per shift can be compared to the new. Decreased carrying costs due to minimized inventory levels can be presented in dollar format as well.

Direct benefits are easy to quantify and are represented in dollars off the bottom line.

Indirect benefits far outweigh direct benefits and are much more difficult to quantify. Such benefits include increased customer satisfaction, increased employee responsibility and communication, more accurate reporting and historical record keeping, increased visibility into operations and associated quality, and higher award potential for new contracts. Portions of these benefits may be captured when measuring direct, but not all. Unmeasured portions of indirect benefits are difficult to quantify with a dollar amount. Savings here are gradually realized over extended periods of time. Such ongoing indirect benefits generally outweigh direct benefits. Overall, cost rewards of implementing MES depend on the size of the system and extent of leverage.

System validation looks to ensure that the implemented software has indeed met desired levels of functionality. This is accomplished by testing of operational abilities, and comparison to characteristics predetermined in the statement of work. Such analyses determine the completeness of the system and its adherence to the initial design concepts. Cost savings and benefits, completeness of implementation, and acceptance within shop floor weigh the heaviest in determining overall success of implementation. Stage 12 terminates when the exit criterion, completion of metrics as well as system verification and validation, have been finished.

5.13 Stage 13 – Full Scale Implementation

Implementation across the manufacturing environment in stage 13 follows the previous phases. With the pilot program in place the steady state of operation is defined and set as a standard for shop floor wide implementation. For full scale rollout to be accomplished, all actions must be repeated for each product line as functionality is rolled out. Full scale operation proves much more intricate as numerous complexities arise when product lines share labor, machines, and raw material. Expansion across product lines is streamlined

providing similar steps are taken such as the deconstruction of them manufacturing environment into specific operations, storage locations, etc. and systems and practices across product lines are upheld. Large scale MES operation comes much more easily when a solid proof of concept has been implemented because all data structures, lines of communication, operations, and user interfaces already exist. Metrics must again be imposed on the new system in an effort to verify and validate the system. Rollout of MES to the entire manufacturing floor gains traction the more product lines involved, and the level of success dramatically increases.

5.14 Stage 14 – Monitor and Maintain

Stage 14 commences when integration is complete. During this stage the system is monitored and maintained. This is the final aspect of the V-Model. During this phase, day-to-day operation is maintained. Any adjustments or feature additions that occur during the extended operation stage will cause a reexamination and utilization of the aforementioned stages. Stage 14 endures along with MES. Adding or removing product lines, devices, and functionality seems inevitable as the nature of MES is constantly changing to adapt and best serve the manufacturing environment. Stage 14 is ongoing for the lifecycle of MES.

With these stages developed, a systematic planning approach to successful MES implementation can be presented that provides for a visual understanding of the chronological implementation of MES. This graphical representation of the 14 stages of implementation will be utilized as a reference guide for planning and control of MES implementation. Exit criteria defined for each stage provide the user with a strong understanding of the current progression and open action items. Successful implementation requires strong organization and planning facilitated by the work presented in this thesis.

Chapter 6 – Case Study

A case study utilizing the systematic planning approach to successful MES implementation presented in chapter 5 has been accomplished by an undisclosed company. This company is in the process of transitioning through the MES planning tool. Verification and validation measures have been defined in the process of quantifying benefits. MES implementation had been considered for numerous years, but was only accomplished with a new and clear perspective on the situation facilitated by the information on hand. At the time of this analysis, a prototype MES system for a pilot product is being developed. Proposed metrics have also been identified.

As a medium size company with a discrete manufacturing environment this company was able to leverage the full extent of the MES road map/planning tool presented above. This company began with an existing ERP system established. The selected OOB solution was provided by Oracle, the same platform as the ERP. This solution required minimal software integration to collaborate with the other modules under the ERP umbrella. Oracle was chosen due to the fact that it provided all functionality desired for a competitive price. When MES was first considered, a best of breed software was examined for its improved functionality. Once a cost benefit analysis was performed it was clear that the large expenses incurred with integrating the system into the existing ERP would be more timely and costly than possible. Oracle was selected due to the fact that the integration was seamless to the existing Oracle ERP and because the core desired functionality existed.

This company began with many opportunities for improvement from MES implementation. Predominately paper driven, the manufacturing environment had been well defined and flow charts existed for each of the products to be incorporated into MES. Thorough shop floor definition provided for ease of operations definition and routing. The major issues plaguing the implementation were data structures and vendor commitment.

The statement of work signed by the vendor and the company thoroughly outlined the expected product and deliverables. The project was streamlined by thorough high level and detail design. Gap analysis for the prototype project returned numerous missing data fields within the established data structure. This was addressed for each functionality, and established in the database structure by a combination of vendor and internal information technology resources. This blend of labor capital also provided for the definition and implementation of system architecture. Additional software was developed for interface with testing devices on the shop floor. Hardware requirements have been established for full rollout, but have yet to be implemented, as the existing system is sufficient to support the pilot project.

The pilot project was chosen for various reasons that made it a high profile product. The manufacturing process includes numerous buy items and subassemblies, internal purchases from other divisions, production and assembly in different locations, and quality control through all testing equipment. The pilot product exemplifies all aspects of manufacturing found throughout the manufacturing floor.

The implementation phase of this project is ongoing. Operations are defined and data structures necessary to store the vital information have been developed. Accomplished by identifying data collection points and breaking the system down into components or operations small enough to facilitate data capture at transactions. Workstations and flow have been input into the MES databases and can be readily referenced for routing and scheduling purposes. Functionality expected for the pilot project has defined all aspects of development so far and includes the following:

- Configurable work list driven shop floor execution
- Configurable work content and sequential display of instructions
- Clock-In/Clock-Out for time capture
- Shop floor transaction processing
- Integrated material transactions with lot and serial number entry

- Shop floor exception processing
- Seeded traveler printing
- Supervisor level exception summary with drill down to details
- Exception impact assessment
- Capacity and/or resource shortages
- Current state view of entire shop floor
- Views by project, product, item, department, operation, etc.
- Expediting of work orders
- Work order transaction histories/product sterilization
- Labor reporting
- Labor skills validation
- Serial number management on parents and children
- Enforce updates to operations before moving
- Integration with standard Oracle quality

Implementation of such requirements will serve as a strong proof of concept. Once the determined functionality is in place, conference room pilot testing will take place and metrics will be developed. Metrics will ultimately be recorded in this thesis at a later date.

6.1 MES Metrics

Metrics for grading the success of an MES system are varied. The strongest measure of success is direct time savings. Time is shaved off many activities including data entry, prioritization, decrease in rework, and decreased need for physical communication among many others. The best method of quantifying such improvements is through time studies. Each operation will be timed once MES is implemented and a cost will be totaled for hours of labor saved. Time savings generally has the greatest monetary value due to the fact that it is comprised of numerous benefits from MES implementation.

Increased efficiencies such as adherence to production schedule, preemptive solution of resource or capacity shortages, and higher quality lead to increased throughput. This too will be quantified. The company has in place a clear understanding of current production volume. With MES implemented before and after volumes will be compared and quantified in dollars. This company will show higher revenue due to increased capacity now able to fulfill previously unfulfilled demand.

Another major factor in gauging the success of MES is examination of lead times. MES implementation provides for more streamlined operation and a clear understanding of lead times. With successful implementation this company will be able to fully comprehend the reduction of lead times provided by the improved control of the manufacturing environment.

Decreased work in progress forms another quantifiable cost savings. With vastly improved control and visibility on the shop floor inventory levels can be safely reduced. Lower inventory levels bring lower carrying costs. Funds previously tied up in inventory or spent on storage, record keeping, obsolescence, etc. can be used to reinvest in the companies continued growth.

Overall, the pilot program will provide drastically decreased operating expenses. Benefits of implementing MES go beyond operating costs. Increased levels of quality, serialization, responsiveness, communication, etc. will position the company more aggressively as they bid for contracts. Improved communication between modules under the ERP umbrella provide for continued feedback constantly updating forecasting systems with actuals. Such indirect benefits are to be examined and eventually realized on a longer-term scale.

Chapter 7 - Conclusion

This master's thesis presents a well-defined systematic planning approach to successful MES implementation. The strengths of MES are presented as well as the emerging trends within the technology. Explained through integration with the enterprise resource system, current options are explored and value propositions described. System aspects, connections, and operation are defined and used to identify specific inputs as well as data flow. Issues surrounding implementation are also explored. Ultimately, a 14 stage planning tool/road map verbally and graphically depicts the required path for implementation.

MES proves applicable to numerous manufacturing instances regardless of size, industry, or manufacturing environment. Companies stand to realize an attractive cost to benefit ratio upon implementation. With the 14 stage systematic planning approach to successful MES implementation proposed, the average small to medium sized company is armed with sufficient knowledge of the implementation process to achieve success. Overall, the benefits provided by implementing MES, as demonstrated in this thesis, provide sufficient evidence for its consideration. MES proves its strength in the world of information systems, and will soon be mandatory in highly competitive manufacturing industries.

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