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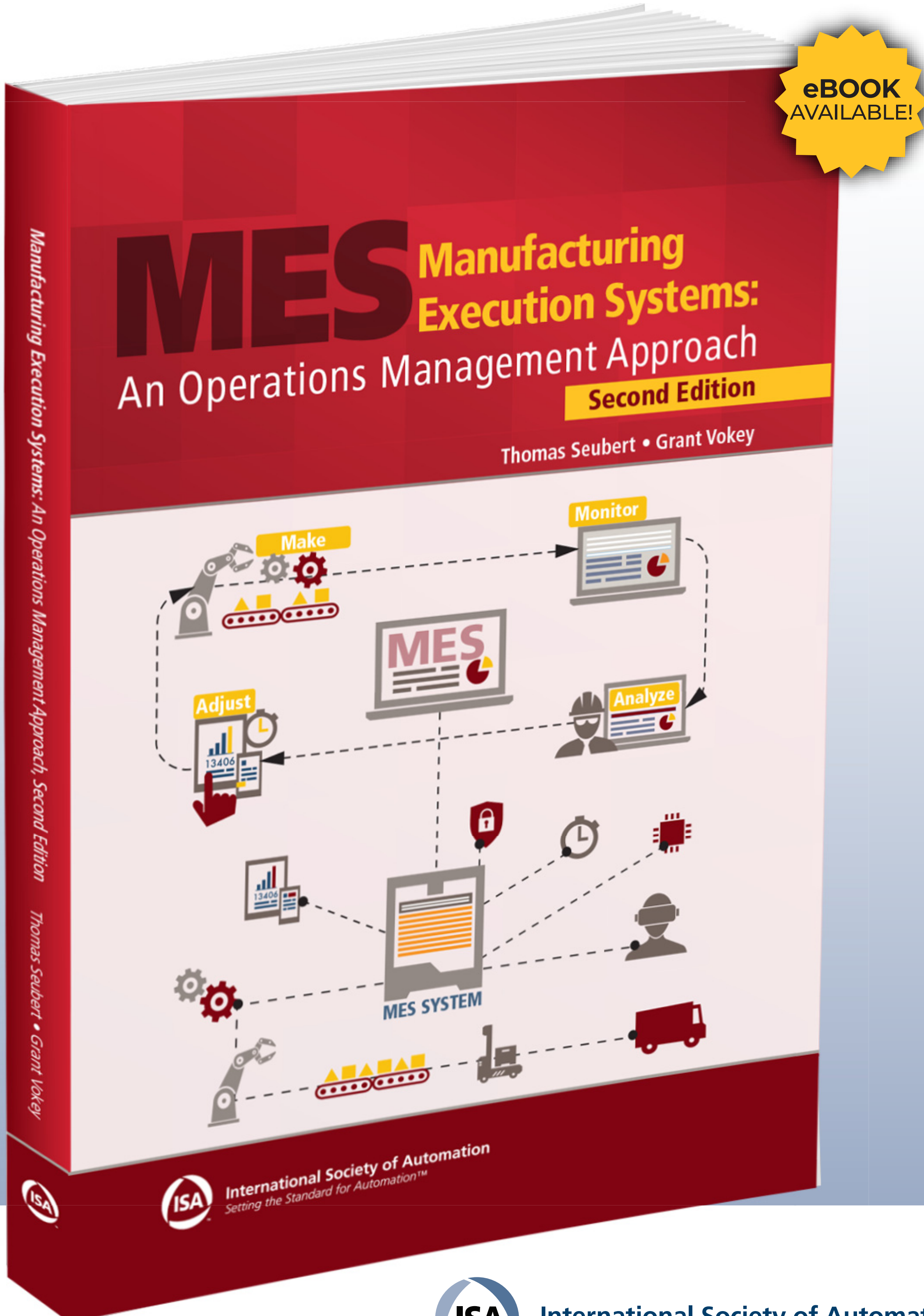

International Society of Automation
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Manufacturing Execution Systems

An Operations Management Approach

Second Edition

Thomas Seubert
Grant Vokey

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Preface

In the manufacturing industry, the main focus of operations personnel has been to make products as effectively as possible and to better understand the characteristics of their processes. This has resulted in the development of several methodologies to plan and schedule production and to continuously improve the product and the process of making it.

However, most manufacturing engineers and operations managers still rely on physically observing each operation with stopwatches and various sensors to build a characterization of their processes, operation by operation. Although these are the tried and true methods of the industry, they are cumbersome and slow to produce results. Even in the most recognized improvement methodologies of Lean and Six Sigma, many practitioners still rely on these practiced methods for understanding the details of a company's internal processes.

Although manufacturing execution systems (MES) were first introduced in the late 1990s, adoption of these applications has been slow and, in some cases, hotly resisted. In investigating why, it was discovered that it is mostly due to (1) a lack of understanding of how to apply MES to manufacturing operations and (2) a considerable amount of broken promises from MES vendors about delivering the silver bullet that will make everyone's jobs easier and provide more than enough return on investment (ROI) to make it worthwhile.

The missing link to vendor promotions is that, like any enterprise system, the installation alone does not make a company run better. It is in using the system that Operations benefits. First, by helping Operations to understand the processes holistically, thereby allowing them to make the best decisions, and then by updating the application to help stabilize the processes as quickly as possible. This enables a company to gain the expected ROI. An MES does this by providing production operators with the correct guidance to do their work (this stabilizes processes quicker and helps remove the "noise" that makes process analysis more difficult). Second, it provides the information that manufacturing engineers and operations managers need to correct issues that arise, and it provides that information quicker and more reliably than any other enterprise-level application.

However, most vendors (and implementation consultants) either do not have the knowledge to guide manufacturing operations properly or are not in a company long enough to provide that knowledge, even if they have it.

This book was written to help manufacturing operations people properly understand what an MES application does and to provide guidance on how to use it from a manufacturing operations perspective.

In this book, we break down the processes of a manufacturing business into generic sections and discuss how MES can help in these sections. We look at various manufacturing sectors to understand their primary characteristics and which MES functionality is needed to support them. We review the available methodology tools (e.g., ISA-95, Lean, Six Sigma) and how they are applied using MES. And further, we show the distinction between MES and MOM and how MES enables MOM.

This book was written by manufacturing operations people, for manufacturing operations people, to help them better understand how to get the most out of this specialized enterprise application called an MES.

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About the Authors

Grant Vokey

Grant Vokey is the principal consultant for Vokey Consulting. With 20 years of diverse manufacturing operations experience and an additional 15 years of integrating information technology (IT) systems into the manufacturing floor, Grant has developed a strong understanding of how manufacturing companies work and the information needed to operate at world-class levels.

Grant's experience, coupled with continuous training and 10 years as a Certified Operations Manager, has also provided him with an excellent understanding of industry best practices and best-in-class utilization of manufacturing execution systems (MES). Using this knowledge, he has been a subject matter expert for developing industry-leading MES applications/solutions, a program manager for multiple MES programs, and a lead consultant on implementations of MES in various verticals (electronics, industrial equipment, automotive manufacturing, and metal fabrication).

Grant has developed a reputation for providing sound, practical advice and direction that make a difference to his clients and the MES industry as a whole.

Thomas Seubert

Thomas Seubert is currently a project manager for an MES development project. Previously he worked as an MES consultant and an MES delivery and presales manager. Before that, he worked on several shop floor and MES projects going back to the year 2000 when General Motors/Electronic Data Systems were developing MES solutions.

Tom has more than 25 years of experience with manufacturing processes and controls, 18 years of experience with IT, and 17 years of experience with MES. He has consulted on MES solutions for the multitiered automotive market, as well as the aerospace, plastics and steel, tire, food and beverage, and pharmaceutical industries. He also helps instruct adults and youth in learning leadership skills within the Boy Scouts of America.

Tom was a keynote speaker at the Industrial Engineering and Operations Management Society International Conference in Orlando, Florida, in September 2015 and a recipient of their Distinguished Service Award the same year. He was also the recipient of the 2014 Boy Scouts of America District Award of Merit. He earned his BS in electrical engineering from Lawrence Technological University in Southfield, Michigan.

1 Introduction, Overview, and the Current State of Manufacturing

1.1 Introduction

Before we can discuss manufacturing execution systems (MES), we must examine the manufacturing enterprise and operation as a whole to understand how these systems fit into the big picture.

Let us start with the scope of manufacturing. Simply put, it is the entire process from procuring, receiving, and storing materials in the plant (or a nearby warehouse) to the fabrication (or assembly) and quality assurance of the manufactured part, which may include limited storage of intermediate-level parts or finished goods until they are needed, and possibly shipping the product to the first-level customer.

Manufacturing, which includes all activity within the plant, is illustrated in Figure 1-1.

It takes considerable coordination to properly manufacture a product. The following is a list of the high-level processes within the scope of manufacturing:

- **Material procurement** – When, how much, and from whom
- **Material receipt (including incoming inspection) and storage** – Frequency of delivery, where to place the delivery once it is in-house, and verification of material quality

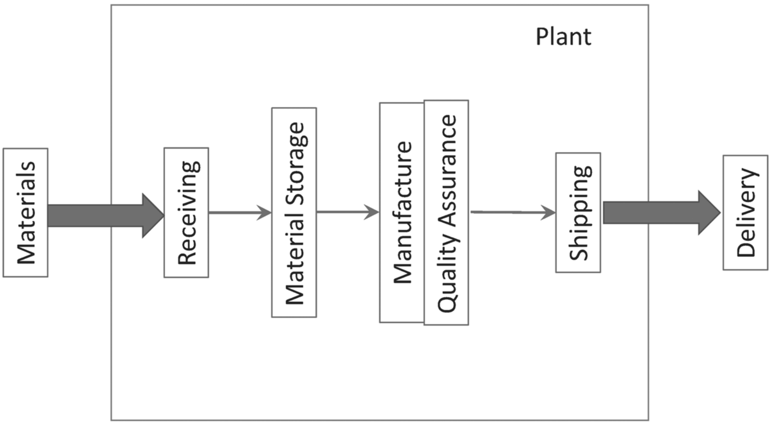

Figure 1-1. Manufacturing scope.

- **Material and product inventory management** – All material movement and storage of finished goods within the plant
- **Production planning and scheduling** – When to produce and how much, which includes sequencing the manufacturing processes for the product or subassembly at both the subassembly line level and the final assembly level
- **Maintenance and readiness of tooling and conveyance systems** – Ongoing maintenance and calibration to keep the tooling and conveyance available when needed
- **Training and readiness of operators, supervisors, and other staff** – Having both the knowledge to perform the work and the right skills available when they are needed while minimizing cost
- **Product quality assurance** – When tests should be performed on products or materials to check the product's quality while reducing potential waste if something goes wrong
- **Shipping scheduling and coordination** – Ensuring the product is shipped with enough time to deliver on time and minimizing shipping costs

These processes require the careful coordination of material, resources, and information to make and deliver the product efficiently. As such, operations must recognize that any work performed toward the fabrication or assembly of a production unit is an investment that is not recovered until the product is sold, and operations costs for producing finished goods (including scrap, direct labor, and material) must be recovered in the sales price of the product. As with any investment, Operations must try to reduce the investment needed to make each sellable product.

2 A Functional Overview of MES

To understand manufacturing execution systems (MES), the first question to ask is, "What is an MES?" The answer is best understood in context with the ISA-95 Series of Standards. Figure 2-1 presents an activity diagram of all the activities needed within a manufacturing company. The diagram also highlights the activities that are directly associated with manufacturing operations management (MOM) and includes the operations management of production, quality, inventory (materials and finished goods), and production maintenance. These highlighted activities are primarily managed at the plant level within a company. Activities that are outside the highlighted area are considered enterprise-level activities that are common across all plants.

Recall the ISA-95 hierarchy model from Figure 1-5 that shows the enterprise activities at Level 4 and MOM as primarily the activities within Level 3. As it turns out, MES applications have been designed to support most of the activities within Level 3. This concept is so embedded in industry that Level 3 is frequently referred to as the *MES layer*. Supporting this layer requires systems to maintain a record of the detailed workflow of the production process for each product being manufactured, all major equipment and/or workstations on the production floor, and all operators engaged in production activity. Additionally, Level 3 systems must record the detailed activities performed by production for each production unit during manufacturing.

As we discuss MES, it is important to note that a full discussion on ISA-95 is outside the scope of this book. Many good books have already been published on the standard. References to the standard in this book only serve to provide context to the activity

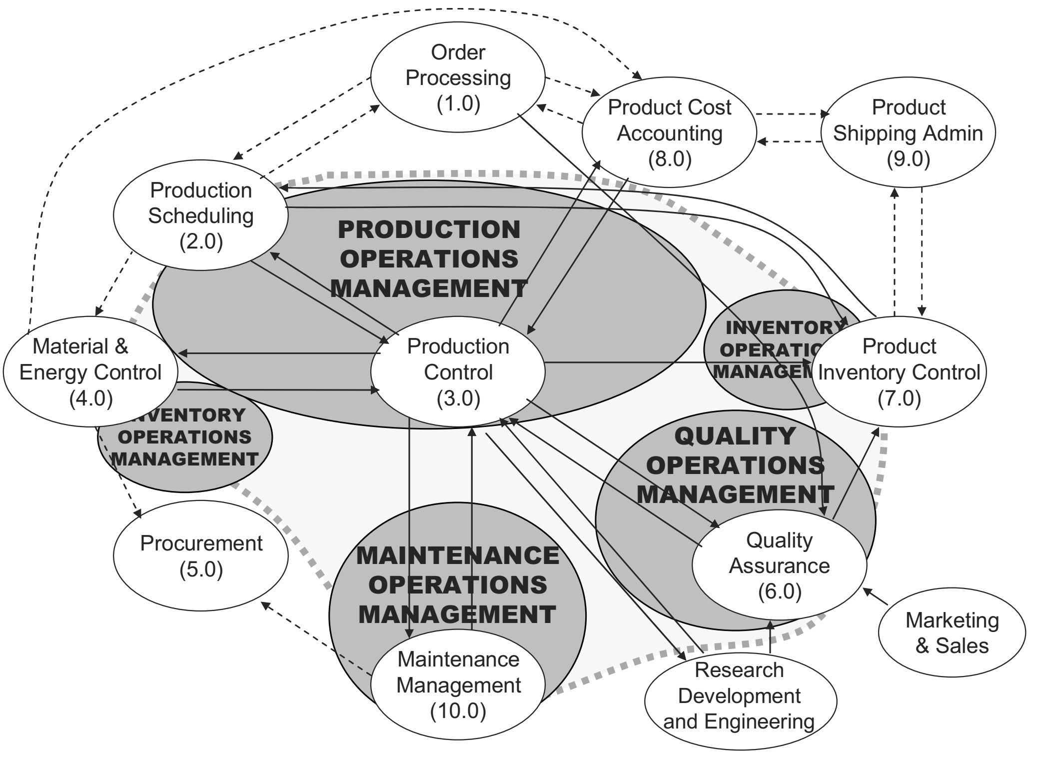

Figure 2-1. Manufacturing activities highlighting manufacturing operations management (MOM). *Source:* ANSI/ISA-95.00.01-2010 (IEC 62264-1 Mod), *Enterprise-Control System Integration – Part 1: Models and Terminology*, Figure 8, Reprinted with permission from the International Society of Automation.

and data models that are used within the MES scope of functionality. For additional information on ISA-95, please see https://www.isa.org/isa95.

The ISA-95 Series explores the functional activities that should happen at each level in the hierarchy. It also defines the structure of data that should be used at each level and exchanged between levels.

Figure 2-2 shows the types of transactions that take place at Level 4 and the resulting data that is part of the integration between Levels 3 and 4. In the ISA-95 hierarchy model, the data and transactions at each level do not necessarily come from enterprise resource planning (ERP) and MES; however, they are the typical applications supporting these transactions. The ISA-95 standards also prescribe a data model for each of the integration branches between Levels 3 and 4. In practice, these data models vary from company to company as a result of the differences among industries, products, and business practices.

Similarly, Figure 2-3 shows the types of transactions that take place at Level 3 with the resulting integration between Levels 2 and 3. Parts 4 through 6 of the ISA-95 Series

3 Order Execution Management: Details and Benefits

3.1 Introduction of Order Planning and Execution

A major activity for managing manufacturing companies is determining which products to make, how many, and when they are going to be available. This process starts at the executive level with the rough-cut planning necessary for sales and operations planning (S&OP) and is performed a year or more in advance. Then, for the most part, the process ends with scheduling the correct sequence of products to make the most effective use of resources on the production floor and is determined at the level of products per shift. This planning function is further complicated due to recent trends of mass customization and the demand for shorter delivery times.

Consider the automotive industry as an example. As part of an order planning process called *in-sequence*, suppliers of parts to the original equipment manufacturer (OEM) manufacturing lines are expected to have the capability to receive a schedule for a product of a specific configuration (color, optional features, etc.) within a week of the expected delivery, deliver a set of semi-assembled parts to an exact location on the OEM production line within a half-hour window, and deliver the set in the correct sequence required by the OEM. The supplier must schedule the receipt of materials and resources to the production floor and load the delivery truck in enough time for it to drive to the OEM location and deliver the material within the prescribed window regardless of local traffic and weather conditions. In many circumstances, the end customer can change their mind about certain options as close to 24 hours before delivery to the OEM assembly line. If the supplier gets the configuration or sequence wrong or if there is a nonconformance on delivery, the supplier then faces significant fines from the OEM to correct the problem.

Most manufacturing sectors are not as tightly scheduled as the automotive industry, but all industries have their own constraints and problems. Planning and scheduling for a manufacturing floor can be a stressful activity, considering the scheduling, logistics, unexpected events due to materials not conforming to expectations, and equipment performance deviation or failure that can occur. Planning departments struggle with keeping production flowing, and information that identifies a potential issue is best provided to the department as soon as possible. In many cases, seconds can make the difference between a successful shipment and a major failure. The recent push by Industry 4.0 and Smart Manufacturing initiatives is an effort to (1) keep unexpected events from happening and (2) provide notice of events that happen (and the effects) to the entire length of the supply chain. In this chapter, we will discuss the data and information needed to keep things moving on time and how a manufacturing execution system (MES) can help achieve this goal.

3.2 Order Execution before MES

To understand the benefits of having an MES in order management, take a step back and look at order management issues before the advent of MES. Many companies still work in this environment, and if a company has well-defined business-level processes and relatively simple product order management, this scenario may be acceptable. In this section, we will review the planning process at a high level and provide input on the issues that MES helps to solve.

Figure 3-1 illustrates the planning process for order management:

1. Determine the current capacity of the manufacturing environment and compare it to the marketing plan as the initial S&OP, which is needed to determine the master production schedule (MPS). Part of the concern of S&OP is a result of the *hidden factory*, where up to 30% of the capacity is consumed by repair, rework, and expediting processes that are not tracked within enterprise resource planning (ERP).

4 Material Management: Details and Benefits

Another key component in manufacturing is *materials management*. This refers to the raw materials and parts used to make the end product that must be ordered, delivered, and managed by the plant. Management includes not only ensuring that the parts are delivered to the proper production line station at the right time and in the right order so that production is not affected but also managing the part or material inventory. Without this process, ensuring that the right material is at the right place at the right time in order to fulfill the production schedule becomes a difficult task and will lead to production delays or surplus parts inventory (and the excessive cost of carrying inventory).

4.1 Material Management Business Process

4.1.1 Overall Process

Material management is executed through supply chain management (SCM) processes. This means that before the material or parts can be managed within the plant environment, certain business transactions must occur between the manufacturer and its parts and material suppliers. Figure 4-1 shows an overview of the SCM processes that occur before the material arrives at the plant location. Depending on the industry,

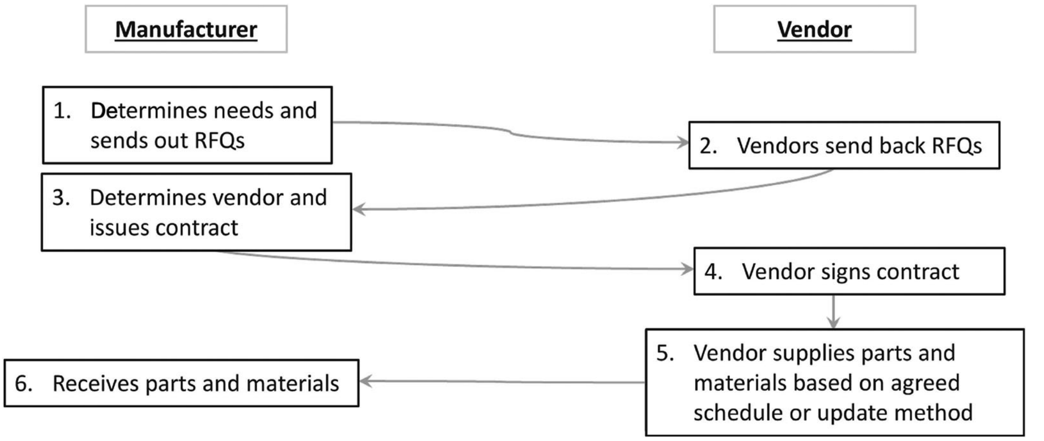

Figure 4-1. Supply contract process.

these processes may vary; however, a discussion of such differences is beyond the scope of this book.

4.1.2 Material Management before MES

To understand the benefits of having a manufacturing execution system (MES) in material management, we will take a step back and look at an example (in discrete manufacturing) of the issues in material management before MES was used. It should not be surprising that before MES, all material management was conducted manually and usually monitored at the enterprise resource planning (ERP) level in aggregate quantities. To follow the lifecycle of a subpart or raw material in the plant, every status check in the process must be manually updated.

Starting with the plant receiving the part or material, the inventory must be manually updated, typically on a hard copy checklist. When the part or material is physically transferred (or moved) to the bulk storage or warehouse area, the inventory must be manually updated in ERP. Parts or materials typically are not transferred to the part pick or staging area until the inventory there drops below a certain threshold and must be replenished to its maximum threshold. This also must be manually monitored, and again the inventory must be manually updated. Operations methodology like kanban has been implemented to try to make this easier. Parts and materials leave the part pick area either when a manual pick list is generated or when a manual replenishment is triggered from the production line workstation. Throughout this process, inventory must be up to date so that when the next order for parts or materials must be sent to the vendor, it can be triggered at the proper time.

All manual triggers mentioned depend on a person being designated to trigger the event at the proper time, which is when the inventory for that specific workstation hits

5 Quality and Traceability: Details and Benefits

5.1 Introduction to Quality and Traceability

Imagine that you are a customer of a manufactured part, such as a car, a hot tub, or some other product that has a significant price tag. You have had this product for a few months and things are going well. Then, you see in the news that the company that made your product is announcing a recall for a quality problem. A couple of days later, you receive a letter stating the product you purchased is related to this problem. The letter asks you to call your local service depot to arrange for the product to be reworked to fix the issue. If you closely read the letter, it generally says one of two things:

1. Your product is *suspected* to have the problem, and the service center must verify and fix it.
2. Your product *does* have the problem, and the service center knows what to replace or fix. They just need you to schedule the repair/rework.

The difference between these two scenarios is a function of the level of quality assurance that the manufacturing company has engaged in and, more particularly, the level of traceability that is used during manufacturing. Believe it or not, most companies put a lot of effort into ensuring that the material used during production is of good quality and that the product has been manufactured the right way. How *effective* the company is greatly depends on the use of technology and, frequently, on the use of a manufacturing execution system (MES) as a primary component of that technology. In this chapter, we will look at the broad range of quality activities within manufacturing and detail how MES supports those activities.

5.2 Quality Assurance or Quality Control

There was a time when quality was only concerned with answering the question, "Was it built correctly?" Manufacturers engaged in activities during or after the manufacturing process to verify the product *was* built correctly, or they helped establish processes during manufacturing to ensure it *is going to be* built correctly. The scope of quality has expanded considerably since then, but as far as the manufacturing floor is concerned, these questions are still the primary concern. The field of quality includes functions such as various types of inspection, functional or performance testing, statistical process control (SPC), and continuous improvement activities. It also includes quality functions on the production floor such as equipment calibration, user certification, and documentation control for work instructions. All these activities can still be brought back to the original two questions: (1) Was the product built correctly (frequently referred to as *quality control*)? (2) Is the process understood enough to ensure that the product will be built correctly (also referred to as *quality assurance*)?

If the Quality Control team determines that the product has not been built correctly (which is referred to as a *nonconformance*), then steps are required to repair the product or scrap the nonconforming product and replace it. In some industries, the nonconforming product may also be downgraded to a lower level of acceptance (a product of lower quality), but for all intents and purposes, it is still being removed from the order as part of the intended product quantity. Downgrades are simply a means of recovering the costs of scrapped products.

Part of the quality assurance (QA) team's role is to analyze the failures and nonconformances that occur to determine how to prevent them from happening again, all as part of a program of continuous improvement. There has been a considerable amount of growth in this area with the development of methodologies like Lean Manufacturing (Lean) and Six Sigma. The quality function of continuous improvement and MES is an expansive subject that will be covered in greater detail in Chapter 7, "Continuous Improvement: Details and Benefits."

6 Production Monitoring: Details and Benefits

6.1 Introduction to Production Monitoring

In the previous chapters, we covered how a manufacturing execution system (MES) brings value to order execution, quality assurance, and material management activities and processes. All these business processes share in the benefit provided by the ability to monitor, annunciate, and trend actual manufacturing activities and events that can directly affect the efficiency of the manufacturing process. Especially in a just-in-time manufacturing environment, any amount of time that production is scheduled and cannot be met becomes an issue, and risks must be minimized. In this manufacturing environment, everything that interrupts the production schedule must be annunciated, acknowledged, and corrected in the shortest amount of time possible. Process-critical parameters, like the temperature of an oven drifting out of the range of product requirements or manufacturing equipment being down due to an unscheduled repair, can have a major impact on the on-time delivery of an order and the *cost-effective* delivery of that order. Without the capability to respond immediately, the whole manufacturing process will not be able to meet the demands of the production schedule. An MES provides these monitoring functions in support of plant operations.

An MES brings efficiencies to the production monitoring process because of its ability to detect and annunciate faults and other concerns in real time over a large geographical area as well as some remote areas. This helps speed up resolution responsiveness, provides deeper details into these concerns (and the impact of the concerns on products), and provides real-time analytics and trending functions. Without these production management functions provided by an MES, direct management of production is based on experienced guesswork or isolated pockets of information without the holistic visibility of the impact on the entire production process.

Production monitoring includes the following areas, which we will explore in this chapter:

- Equipment warnings and faults
- Production faults
- Quality faults
- Throughput and cycle time monitoring
- Overall equipment effectiveness (OEE)
- Andon
- Trending
- Process failure mode and effects analysis (PFMEA)
- Six Sigma
- Preventive/predictive maintenance (advanced)

6.2 Production Monitoring before MES

Before MES, there was production monitoring, but the annunciation of different events was limited to physical devices. Some smaller manufacturers still use this process because it provides a cost-effective annunciation in a small environment. As shown in Figure 6-1, these devices range from a stack light that signals a green (bottom), yellow

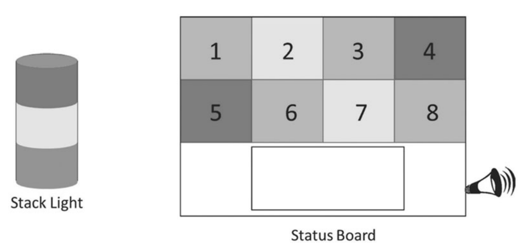

Figure 6-1. Device-based production event annunciations.

7 Continuous Improvement: Details and Benefits

7.1 Introduction to Continuous Improvement

There are those who would use the cliché that *continuous improvement* (CI) is about the journey, not the destination, and to some extent, this is true. A line of thought that goes along with the journey concept is that the level of improvement obtained by each step must always be worth the expense to achieve that step. This is where Quality and Operations management frequently collide. Those who are *Deming purists* will state that the benefit will always outweigh the input because of *nonmeasurable customer satisfaction* characteristics. From an operations management viewpoint, if you cannot measure it, how do you know you have improved it? The bottom line is that the cost of the improvement for a product/process combination *must* be recoverable within the life of the product, or it will result in a net loss for the company.

It can be argued that changes in product characteristics can improve the desirability of the product from the customer's perspective, but these issues are under the control of Product Design and Marketing. Therefore, these aspects are outside the scope of this book. From a manufacturing perspective, the only aspects of improvement controlled by operations are the efficiency and the ease with which the product can be made. The ease of making the product is the primary driver for the initiatives of design for manufacturing (DFM) and is a collaboration between Manufacturing and Product engineering. There will be more on this later in the chapter.

In the aspect of process efficiency, you must *standardize, standardize, standardize*. In the context of the value gained by any improvement, you must know your costs. In a cost/benefit analysis, as previously mentioned in this section, if the cost of the improvement is greater than the benefit, then the improvement should probably be avoided and a mitigation strategy should be used instead. The only caveat is the need for a clear understanding of the benefit to be achieved.

By now, you are probably thinking, "What does this have to do with MES?"

This chapter discusses the aspects of a good CI program and how MES can be of value to CI initiatives. Regarding the issues we just raised, this chapter will highlight some high-level concepts that will keep the CI program on track and provide input on observations we have made over the years.

7.2 Brief Introduction to MES Configuration to Support CI

One of the key factors to a successful CI program using an MES is how the virtual production environment is configured within the MES database. When the MES is first implemented, not all the data needed to manage the process or for data mining will be known. As such, it is important to configure the MES environment during the initial setup to provide the most flexible configuration possible. Failing to provide a flexible MES environment from a data configuration perspective can limit the visibility that companies have into the root cause of a problem. In this section, we give a quick example of a typical configuration concern.

In Figure 7-1, a simple process of four operations has been set up. The figure displays a common configuration error implemented by teams that are highly enterprise resource planning (ERP)-centric. In this system, the implementation team has chosen

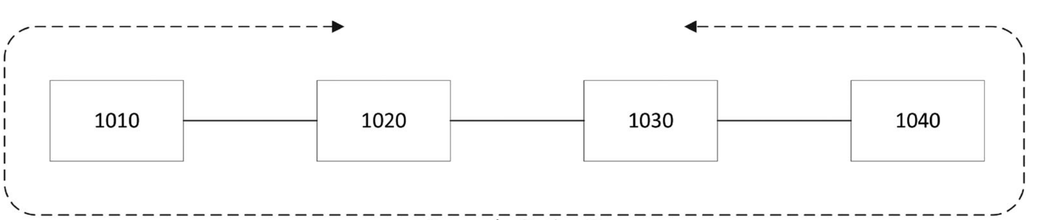

Figure 7-1. Process labeling by station ID.

8 New Product Introduction: Details and Benefits

8.1 Overview of New Product Introduction

It is important to understand that the new product introduction (NPI) environment is a function that includes just about all aspects of the company. Product Engineering, Marketing, Finance, Sales, and Manufacturing all have a stake in a product that is going through the NPI process.

Questions that Operations should answer include:

- What will the unit cost of the product be?
- What is the demand-to-capacity ratio of the company's production or the production of one plant?
- How fast can the product be available to the market, or what is the *time to market*?

Even if the NPI process is just handling a new revision of a product, all these questions still apply. Costs may change, which provides a better price point within the market, or capacity may change, which provides greater fulfillment of demand and is possibly tied with marketing to increase market share. Many of these factors are also directly related to decreasing a product's time to market.

One of the greatest problems with NPI is having the product ready for initial shipment reliably. Significant preparation goes into launching a new product (or a new revision of a product), and planning the first shipments when marketing gets started is very important in any market. As is evident in the smartphone industry, some companies delayed the initial release of a product and lost considerable market share, while other companies released a product that had problems, knowing that the issues would be found, but at the consumer's expense.

As a result, it is critical that a company has the tools to move a product through the development phase as quickly and reliably as possible. Although most of the management of product and process design information is handled by product lifecycle management (PLM) during the NPI process, there are specific concerns regarding managing the process when products and processes are evaluated on the production floor.

During the design phase, it is important for materials to be tested to ensure performance characteristics are met and to make design and supplier decisions. In some industries (e.g., the automotive industry), many materials must meet regulatory requirements before being considered for use within a product.

Preparing for material tests may include partial or complete builds of the product at its current level of design in order to perform statistical testing. In these scenarios, the product build must be highly controlled because any deviation in the build process between materials or designs being analyzed can affect the testing of the product or material. This can cause the product engineer to analyze skewed data or a product that has built-in, hidden inconsistencies that may affect the evaluation. In many cases, the skewed results may not be detected until late in the product development phase (if at all before product release) and cause unexpected delays in the release date, or worse yet, a company may release the product anyway and suffer the consequences to their reputation.

Anyone familiar with design for manufacturing (DFM) principles understands that Manufacturing Engineering must be involved in the design to (1) ensure the product can be manufactured efficiently and (2) prepare the manufacturing line to build the product at an acceptable rate of production to supply the expected demand. The preparation of the line may include the design and build of production-level test capabilities and the creation of assembly jigs that will be used to ensure repeatable manufacturing.

9 MES Architectural Concepts

9.1 Introduction

Over the past several chapters, we have reviewed various business processes and the data required to develop efficiencies within the manufacturing enterprise. This is the reason *why* a manufacturing execution system (MES) is valuable. However, we have not yet reviewed the *how* of MES—how does Operations use an MES to execute the functionality of each process and provide these efficiencies? This chapter will cover these items.

The following topics will be covered in this chapter:

- General architecture (programmable logic controllers—PLCs, servers, databases, supervisory control and data acquisition—SCADA, applications, etc.)
  - Plant-floor devices (scanners, sensors, etc.)
  - PLCs and data concentrators
  - Plant-floor human-machine interfaces (HMIs)
  - Servers, clients, and distributed computing
  - Cloud, edge, and fog computing (all external to the plant)
- Industry 4.0 and the Industrial Internet of Things (IIoT)
- In-plant (internal hosting) computing with edge versus cloud versus fog solutions
- Autonomous MES

While it will not be possible to cover all the possible permutations of architectural solutions, the basics will be covered so that system architectural details are understandable.

9.2 General Architecture

Most MES architectures follow the ISA-95 hierarchy model (covered in Chapter 2) on the different levels of manufacturing activity (see Figure 9-1). In breaking down the levels into system architectural elements, Figure 9-2 becomes clearer.

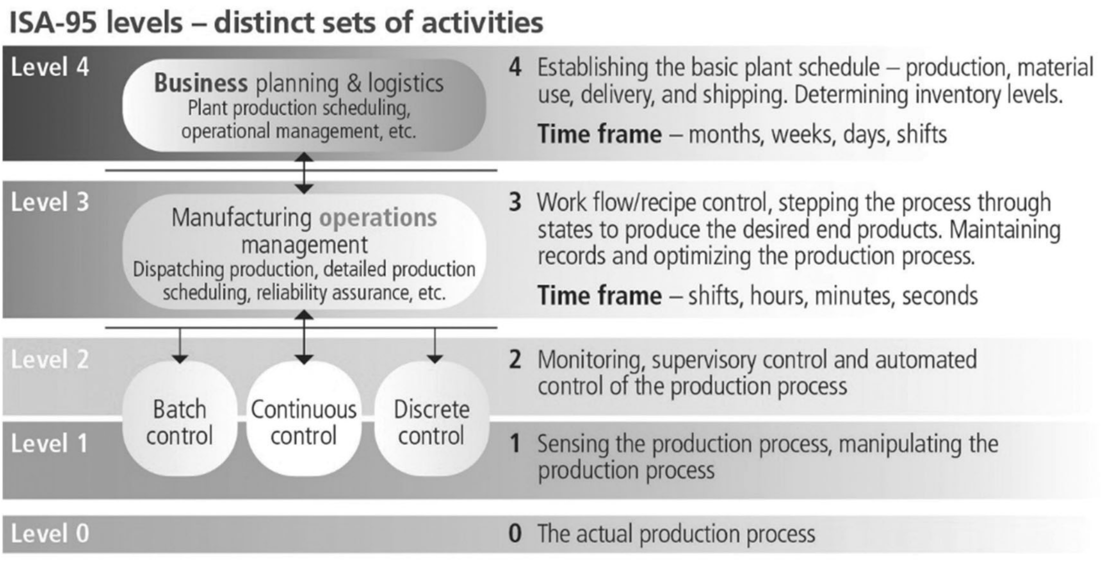

Figure 9-1. ISA-95 hierarchy model levels.

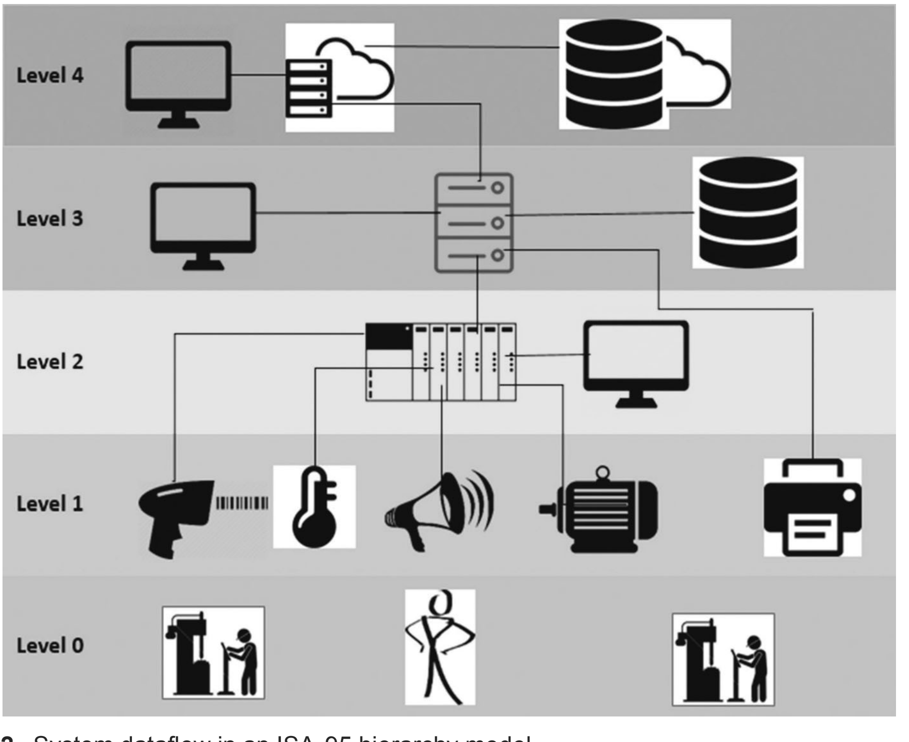

Figure 9-2. System dataflow in an ISA-95 hierarchy model.

10

Differences in Manufacturing Models and Their Impact on MES

10.1 Introduction

Now that we have covered the *why* of manufacturing execution systems (MES) through the review of business processes and the *how* of information technology (IT) solutions, we must review the different models of manufacturing to best understand how each type has its own MES characteristics. Without doing so, it would be difficult to configure an MES properly. In this chapter, we will cover these differences and how they shape MES operations. First, we will cover the different types of manufacturing and explain their characteristics:

- Discrete
- Batch
- Continuous
- Hybrid

We will then apply the manufacturing types to examples of manufacturing models and explore the main manufacturing industries and their primary requirements for an MES:

- Automotive
- Aerospace
- Food and beverage
- Metallurgy (aluminum, steel, etc.) and plastics/polymers
- Pharmaceutical
- Others, including tires and general consumer goods

We will then align the main MES functional areas to the industries to complete the picture.

10.2 Manufacturing Models

In the following sections, we will review some characteristics of various manufacturing models and provide an overview of important MES functionality that is required to support these models. This will provide guidelines on what functionality to look for when investigating MES solutions.

10.2.1 Discrete

In manufacturing, *discrete* means that each production unit produced is independent of the others process-wise, and there is no real connection between one unit being produced, its predecessor, or the unit that comes after it. Therefore, each production unit can have its own specific path through the manufacturing process. As a result, the production tracking and management must recognize each production unit as its own distinct entity within the MES and must use a serialized unit identifier.

Because each production unit may not exactly match another unit, all elements of the MES (i.e., product scheduling, subpart sequencing and line delivery, quality assurance, and production monitoring) must recognize and handle each production unit independently.

When process management can reach high levels of first-pass yield (the ultimate target is a Six Sigma process capability), it then becomes possible to test and inspect production units at audit levels instead of 100% of the units in process. When this level of

11 Developing an MES Strategy

11.1 Introduction

To determine the direction for a manufacturing execution system (MES), several topics must be examined to ensure the right decision has been made at the corporate level. For companies that have multiple plants, getting this decision right can make the difference between satisfying the needs at the plant level with a total cost of ownership (TCO) that is effective at the corporate level or having pockets of effective MES use with an astronomical TCO without the benefits of a corporate-wide knowledge base. In many cases, the MES investigation starts with a single plant that is *ahead of the game*, but as each plant moves to MES implementation, it goes through the investigation phase on its own and with only the single plant's requirements in mind.

The cost of the first implementation is always the greatest as several initial interfaces must be developed and customizations are inevitable. In the situations previously mentioned, the implementations are scoped to support only one plant, and knowledge of using the MES is restricted to pockets at the plant level. In addition, each plant will frequently implement its own MES application (or develop its own), resulting in multiple MES applications being used, and configurations that should be common over several implementations must be designed and reconfigured in each separate plant. This also applies to customizations that should be common. Many large companies in the auto industry, for example, have already fallen into this predicament with the point of view that each plant is exclusively responsible for its own profit and loss and, therefore, its own investments in an MES.

Without an overall MES strategy, lessons learned are not easily transferable because each implementation is unique and may even be on a unique application, making it necessary for each plant to *relearn* how to solve problems that arise. Each time a plant must determine a solution to a quality or process issue, the solution analysis must start from scratch.

An outcome of this method of MES implementation is that plants that have independent MES strategies will not deliver products or information to the customer consistently, causing frustration when these customers are supplied by multiple plants. In one situation, a customer was receiving the same product from three different plants (all plants of the same supplier), and the customer's major complaint was that there was no coordination within the supplier's manufacturing organization. There were significant differences in product delivery that resulted in considerable frustration on the customer's part because issues that were solved in one plant needed to be revisited and investigated by the customer in another plant.

When a corporate strategy is put into place, benefits can be achieved by collectively determining requirements and implementing common and repeatable solutions. In this chapter, we will review many subjects that should be included as part of a full MES strategy. Even in situations where an MES is being implemented in only one plant, many of these suggestions still apply.

11.2 A Refresher on the Benefits of an MES

For manufacturing companies, there are three primary benefits to using an MES. The first is to provide a platform that gives companies the ability to stabilize their processes and provide work instructions that are needed by a production operator at the right time during the production process. This stabilization helps reduce variation and increase repeatability to prevent human error. When a solution has been determined, an MES provides a platform that permits changes to a process to be normalized faster. This helps speed up the implementation of continuous improvement initiatives. If a company has multiple plants that make similar products, an MES enables the company to develop and implement best practices across the entire enterprise.

The second benefit is that all activities in the production environment are recorded within a relational database. This makes it possible for quality and process engineers (and, in some cases, product engineers) to review what has happened on the production floor before having to go there to see it. When analyzing a problem, there is nothing better than actually seeing a problem in person (in Lean terms, "going to gemba"), but by using the database information, it is possible to narrow down where the potential

12 Current Manufacturing Challenges and Trends

We have reviewed aspects of the business process information, technology influences, and manufacturing types in this book to determine how a manufacturing execution system (MES) has been developed and how it can be configured and operated. So, what is left to review? There are a few current challenges to manufacturing that we must understand in terms of their impact.

This chapter will explore the following challenges and their impact on an MES:

- Aging assets and brownfield maintenance
- The challenges of greenfield plants
- Globalization
- Standards, or lack thereof
- The need for simulation
- Implementing other manufacturing operations management (MOM) concepts
- Trends

12.1 Maintenance of Brownfield Plants and Aging Assets

Brownfield plants are plants that already have a defined manufacturing capability and hardware and are either currently producing products or have recently produced products. Inevitably, these brownfield plants need an overhaul. In many cases, Operations will plan these overhauls to be managed in reasonably small chunks, but often there is a need for a major redo of the entire manufacturing model.

Any changes to the manufacturing environment—be it updating the aging assets by replacing obsolete equipment, improving the manufacturing technology (or operational technology—OT) capability, or taking on a major manufacturing process change—require careful planning and can incur significant costs.

Because the layouts of most plants have been designed for a particular set of processes, the challenge in regard to any brownfield upkeep or improvement activities is to first ensure that all the business processes are properly documented. In many cases, the business processes have morphed over time and are no longer comparable to the original implementation. Preventing this difference between the documented process and the current actual process has been a significant focus of quality initiatives such as Six Sigma, Lean, and the Theory of Constraints. The next challenge is to fully understand what must be replaced or improved and to have a clear plan for implementing the change and ensuring that the company avoids a situation where an extraordinarily large CapEx (capital expenditure) is needed to maintain or improve performance. All these changes must happen without negatively affecting the production schedule, and significant changes usually require training activities regardless of whether the change is in assets or processes. These plans and costs can be significant, and the rationale for the change must be justified by the program, including the need for a time-efficient return on investment (ROI). Otherwise, the activity will be a detriment to the company's financial performance. However, the need to avoid obsolescence should be included in the rationale, not just the cost and ROI. It is well understood that information technology (IT) assets must be replaced over time, and most companies have an active plan to replace aging IT infrastructure. Because most OT assets are designed to operate for a longer period, the aspect of obsolescence must include a review of IT/OT convergence and the impact of interfacing on OT assets.

The investment in the hardware necessary to operate manufacturing is significant—especially in controls, programmable logic controllers (PLCs), networks, devices, and other automated equipment—both in initial investment and in ongoing support. As the technology continues to evolve, these equipment assets start aging rapidly; what

13 Bringing It All Together and Selecting a Solution

We have discussed many concepts related to the different aspects of operations management, such as continuous improvement, capacity planning, facilities management, and others. We have shown different ways that a manufacturing execution system (MES) can help with each of these areas of manufacturing operations management (MOM).

We have also covered several process and quality management methodologies and shown ways in which MES can help with them.

We have presented the information technology (IT) side of an MES in a manner that is relatable to an operations point of view and provided guidance on how to use the data from an MES to help many of the enterprise-level business processes perform better.

In this chapter, we will summarize some of the concepts from other chapters and relate them to the bigger picture of an MES program. Additionally, we will present some final feedback on implementing MES in general.

13.1 Supporting MOM

Within the activities of MOM that we have discussed so far, two aspects of operations management are important.

The first aspect is understanding the actual capacity and the requirements for estimating the support of customer demand and then ensuring that the actual delivery meets the actual demand. The issue MOM managers must deal with is that depending on the situation, there are several things that can cause variance in the ability to deliver, and unexpected variances of significant magnitude can be highly detrimental to the planning and management of delivering on that demand. These variances are the pain points that frustrate MOM managers and leaders and cause them to lose sleep (and sometimes their jobs).

The other aspect of operations management that is important in MOM is locating the problems that cause variances within the processes (i.e., manufacturing and business processes) that are a plant's pain points and determining just how big of a problem these pain points really are.

Sometimes these pain points are caused by a high volume of small variances as a result of manufacturing operator errors, and although each problem may not cause considerable concern in and of itself, the volume of issues can still result in considerable costs to operations. These issues are collectively categorized as *common cause* quality issues, and they are problematic not only because of the cost associated with them but also because they create a lot of "noise" for quality management programs and make it difficult to analyze and quantify major issues. In this case, MOM leaders and managers require assistance to stabilize these operational activities and invoke a serious process management program. In these situations, using an MES to ensure repeatability and consistency in a production operator's performance is very helpful. This is also part of the focus of initiatives such as Lean and Six Sigma. This activity is covered in detail in Chapter 5 and Chapter 7.

When the volume of variation has been reduced, Operations can turn their focus to the issues that fall under special cause variations. These are issues that have specific causes that may or may not be known. After the common cause variation (the noise) has been reduced, it becomes easier to characterize processes, analyze the root causes, and take action to prevent these special cause issues. This is also covered in Chapter 7.

The staff's availability to identify the root causes of these problems and then develop a solution to resolve them is often limited due to time constraints. Because of this, it

Appendix: Introduction to Autonomous MES Computing

Introduction

This appendix introduces the concept of an autonomous MES architecture. An autonomous MES is not a proven concept, and the white paper will be updated as the concept becomes better defined through discussion streams via social media. The goal of this document is to aid in the development of the autonomous MES concept and to provide a sounding board for the development of an open-source standard communication protocol that can be used as the basis of a "services"-based MES.

Problem Statement

Many manufacturing companies use several IT systems that collect, aggregate, and process data and transactions to keep track of sales, inventory, and shipments, as well as a whole host of other data objects, and then generate reports for information that enables companies to understand their current performance. One of these systems is a manufacturing execution system, an MES.

The MES is designed to lead production operators through the manufacturing process as production units or work-in-process (WIP) move through that same process as defined by a company's manufacturing engineering. As part of the function of an MES application, the system records all activity that was performed on each unit of WIP and maintains the complete as-built history or device history report (DHR) of each unit of WIP. All of this data is maintained in central databases in order to provide the reports and information that people need from the system and to provide guidance to production staff related to the up-to-the-second status of the production floor. In most cases, MES databases must accurately record and provide feedback on transactions to the latest second (sometimes even into the millisecond range).

An MES is also "aware" of what the process should be and what components should be used to build the product. In many implementations of an MES, the system is required to verify many (if not all) of the steps needed to manufacture a product before each step is actually performed. The system also must take into account what equipment is being used at that moment in time, the current state of process conformance for any particular production unit, and the "up-to-the-second" current state of material availability. The result of this verification by an MES is that every transaction (i.e., every operation performed, component assembled, and test performed) must be verified as the correct action at that moment in time before that transaction is to be performed.

The outcome of all of this verification is that all data and transactions must be transmitted, verified, and recorded in the central database in real time.

With a small production demand of a 20-step process, 100 components to assemble at a line rate of 1000 units per hour comes down to about 40 transactions per second for that line. Within each production transaction, the MES will perform three to four verifications, giving 120 to 160 application transactions per second per line. This does not include the movement of data that is generated by any of these transactions. In an environment such as this, a conventional MES has no problem maintaining that rate of production. However, when production areas have 25 or more lines with greater than 50 steps and hundreds of components, the demand for communication can grow very rapidly.

If you were to take a look at the data traffic from a networking perspective, as the segments of data (called *packets*) move through the network, the closer the packets get to the main MES server (or cluster of servers), the more each transaction must compete with other transactions to be completed in the required second to subsecond time frame (packets communication becomes denser the closer you get to the target server).

In the manufacturing sector, the Industrial Internet of Things (IIoT) is on the rise as more equipment used in production is machine-to-machine (M2M) enabled (i.e., the equipment has a considerable capability to perform computational transactions and provide greater granularity of process characteristic-data to the MES environment). As this trend in data and information availability grows, it places more and more demand on the MES infrastructure to receive, process, and act/report on the current status of production. It is conceivable that this demand can and probably will create

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Glossary

blue printing. The part of an implementation project that analyzes the current state of a manufacturing plant's operation and determines the vision of a future state. It compares the current state to the vision of the future state and creates a roadmap of changes to achieve the future state.

BoL: bill of lading. A shipping document used to describe the contents of a truck or other shipping container and the formal document of receipt for the carrier.

BOM: bill of material. A list of materials and the quantity of each that are used to make one unit of a product.

BOP: bill of process. A list of operations and/or tasks that must be performed to make a production unit.

computing node (node). A small hardware-computing device that is implemented as an integral part of the manufacturing equipment in production and used for specific application support.

computing service (service). A small software application designed to operate within a node or on some other computing device that operates as an integral part of the autonomous operating infrastructure.

CRM: customer relationship management. The aggregate of processes, systems, and data used to manage the ongoing relationship between a company and its customers.

DFM: design for manufacturing. A design methodology that focuses on designing a product in a manner that optimizes the capability to manufacture the product.

ERP: enterprise resource planning. The aggregate of processes, systems, and data used to manage the ongoing capabilities of a company as a whole (or enterprise).

GMP (cGMP): (current) good manufacturing practice. A prescribed set of manufacturing methods and practices used by several industries (medical devices, food and beverage, cosmetics, pharmaceuticals, and health supplements) to ensure the quality standards of the product and provide regulatory traceability.

IIoT: Industrial Internet of Things. The interconnection of sensors, instruments, and other devices networked together with industrial applications running on various computing devices to support manufacturing, energy management, and other industrial purposes.

IoT: Internet of Things. An extension of Internet connectivity into physical devices and everyday objects (cyber-physical devices). These devices are embedded with electronics, Internet connectivity, and other forms of hardware (such as sensors); they can communicate and interact with other devices over the Internet and can possibly be remotely monitored and/or controlled.

ISA-95: International Society of Automation ISA-95 Series of Standards. These standards contain an IT model linking the processes of the shop floor to the top floor of manufacturing.

JIT: just-in-time. A process in which manufacturing scheduling is tightly managed to minimize any gaps in time from the launch of production and delivery of any unit to the expected demand of the end product.

LSS: line-side stocking. An inventory stocking methodology that places small quantities of material stock at a workstation-level inventory location. It is used to ensure easy access to material that will be needed within a short time window.

M2M: machine-to-machine. Early concepts of IIoT used to reference communication events directly between two or more machines without a central database system.

mBOM: manufacturing bill of material. A list of the raw material (components) required to manufacture a single unit of the product including data that is important to the manufacturing process such as operation of consumption, process, or genealogy data to be collected.

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