Manufacturing Execution Systems: An Operations Management Approach

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

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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, and possibly the shipment of 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

• **Material and product inventory management** – All material movement 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 keeps 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.

Beyond the full scope of manufacturing, the scope of an MES is generally from the point of goods issue to the production floor (material moved from inventory to local holding on the production floor), through the process of fabrication and/or assembly, to the point of goods receipt from the production floor (movement of completed products back into inventory ready for the next stage of production or sales).

All this processing is based on the current status and ongoing updates to the product design as well as updates to valid materials used during the product’s life cycle. Additionally, demand must account for variations in the product to be delivered to the end customer as the consumer goods industry moves toward mass customization, which will potentially increase manufacturing costs. Making and delivering a product at the lowest possible price is ultimately what manufacturing operations management (MOM) is all about. To understand how an MES affects the efficiency of producing a product, we must understand how it fits into the MOM model (see Figure 1-2).

MOM refers to the processes and procedures that plan, deliver, and support the manufacturing of products with most of that activity creating interaction between enterprise resource planning (ERP), product life-cycle management (PLM), and MES.

Figure 1-2. Simplified MOM diagram.
In order to understand MES, the first question to ask is, “What is an MES?” The answer is best understood in context with the ISA-95 Series. Recall the ISA-95 hierarchy model from Figure 1-5 that shows the scope of the MES is to support the activities within Level 3 of the hierarchy model. This concept is so embedded into the industry that Level 3 is frequently referred to as the MES layer. Supporting this layer requires systems to have a record of the detailed workflow of the production process for each product being manufactured and a record of all major equipment and/or workstations on the production floor and all operators engaged in production activity.

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. The reference to the standard in this book only serves to provide context to the activity 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. It also defines the structure of data that should be used at each level and exchanged between levels.

Figure 2-1 shows the type 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 ERP and the 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 will vary from company to company as a result of the differences between industries, products, and business practices.

Similarly, Figure 2-2 shows the type of transactions that take place at Level 3 with the resulting integration between Levels 2 and 3. Once again, the ISA-95 Series describes the data models at these levels, however, there is considerably more variation at these levels as a result of differences in manufacturing processes, products, and equipment.

Using the ISA-95 Series and MES, manufacturing companies can build on the knowledge and development of best practices to better understand the activity of the production floor.

Any activity performed on the production floor to fulfill a production order must be configured to be recognized, recorded, and potentially controlled by the MES. For the MES to support these activities, all data recording and control must be executed in real time (as the activity is happening). To better understand this concept of real time as it pertains to the MES, we must compare the transaction processing of the MES to a system like ERP.
2.1 Differences between an MES and Other Enterprise Systems

As shown in Figure 2-3, when a transaction for ERP is performed (such as an inventory movement), the operator tells the system (via a data entry screen) which material is going to be moved, where it is moving from and where to, and how much is moving. Once this data has been entered, the operator selects the **go** button to initiate the transaction. The ERP system then verifies that the data has been entered correctly, places the transaction onto a processing queue to be completed, and acknowledges to the operator that the transaction “has been accepted.” Depending on the volume of activity the system is handling, this transaction may be completed in seconds or minutes, but the operator is not expected to wait for the transaction to be completed before starting the next one. As a result, if there is a problem with the transaction, an error message will be placed into a message log; the transaction will be delayed; and at a later time, an operator will be required to review the log and correct the problem, leading to the completion of the transaction after the problem is rectified. If there is additional processing required for that transaction (e.g., financials), the ERP system will automatically create an additional transaction and place it in the queue to repeat the flow. Other than an initial message that
3.1 Introduction of Order Planning and Execution

A major activity for manufacturing companies is to determine which products to make, how many, and when they are going to be available. This process starts at the executive level with 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 by fairly recent trends of mass customization and the demand for shorter delivery times.

Take 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 receive a schedule for a product of a specific configuration (color, optional features, etc.) within a week of expected delivery, to deliver a set of semi-assembled parts to the exact location needed on the OEM production line within a half-hour window, and to have the set delivered in the correct sequence as needed 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. Oh, and by the way, 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. The planning and scheduling function 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 MES can help achieve this goal.

### 3.2 Order Execution before MES

In order to understand the benefits of having an MES in order management, take a step back and look at the issues of order management before the advent of MES. Many companies still work in this environment, and if the 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 shows a model of the planning process.

Figure 3-1 illustrates the steps for creating an order:

1. Determine the current capacity of the manufacturing environment and compare it to the marketing plan as the initial sales and operations plan (S&OP), which is needed to determine the master production schedule (MPS). Part of the concern of S&OP is as 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 ERP.
2. From the sales estimate, determine the MPS; in some cases, the MPS may be partially replaced by actual customer orders.

3. Run material resource planning (MRP) in order to determine (1) what material is needed and when to fulfill the plan and (2) when the order must be released to Production to deliver (or have finished goods in inventory) at the right time.

4. When the timing is right, release the purchase orders for materials and/or production orders for manufacturing to initiate the delivery of finished goods to the warehouse (or the retail outlet) by the expected delivery date.

The timing of the order release is based on (1) the lead time to receive the material and manufacture the product and (2) when the product is expected to be in finished goods. Then, with this information, the planner can simply select the “Release” button on the ERP screen at the right time. The material will arrive right on time, the manufacturing floor will make the product when needed, and the finished goods will end up on the shelf right when they are needed—right? (Ya, right, this is the way it happens all the time.)

### 3.2.1 Determining the Lead Time

Before MES, manufacturing engineers had to perform a trial order (or periodic sample order) to calculate and verify the lead time of a product. The problem with this method is that each product has its own lead time that is subject to change whenever there is a change in the product or in the process for the product. Each time there is a change, the manufacturing engineer should requalify the new lead time. However, this procedure is time-consuming, and as a result, it is typically not maintained enough to provide meaningful data for the planning group.
Another key component in the execution of manufacturing is the management of materials. This refers to the raw materials and parts that must be ordered, delivered, and managed by the plant that are used to make the end product. 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, these processes may vary, however, a discussion of such differences is beyond the scope of this book.
4.1.2 Material Management before MES

In order to understand the benefits of having an MES in material management, we will take a step back again and look at the issues of 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 ERP level in aggregate quantities. To follow the life cycle 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 are typically 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 there is a manual pick list generated or when there is a manual replenishment 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 are dependent on a person being designated to trigger the event at the proper time, when the inventory for that specific workstation hits its threshold. This leaves a significant opportunity for error, not only for replenishment triggers but also for accurate inventory updates. The consequences of improper replenishment triggers or inaccurate inventory levels include the line
workstation running out of parts during production, which shuts down the line, or the plant running out of parts, which shuts down much larger aspects of production. In a manufacturing environment where the delivery of the end product is just-in-time, these production stoppage events must be minimized as much as possible or the company may face stockout fines from its customers.

Another consideration in this manual material management support model is that certain material management activities such as part kitting or subassembly management are more difficult to manage because all data points are tracked and managed (i.e., organized, collated, and reviewed) manually. Depending on the amount of data required, this takes a considerable amount of time and labor to accomplish. In an effort to prevent stockouts, manufacturers will maintain considerable levels of inventory and set the trigger levels high enough to provide for delivery lead time, and/or the manufacturer will implement methodologies such as inventory cycle counting, which also require considerable labor. This costs the company both the money invested in the inventory (which consumes cash flow) and the real estate for storage (which consumes production floor space).

In addition to this discrete manufacturing example, material management in process manufacturing had its own issues prior to the use of MES. In many instances, the raw material used for process manufacturing (pharmaceutical, chemical, etc.) required specific batches of material for a particular production run. Operations had to ensure that the correct batch of material was used for a specific order, and depending on the size of the order, they may have needed multiple batches to complete the order. Batch details, including which batches were used, how much of each batch was used, and batch characteristics, should be tracked based on process and end-product requirements. To complicate matters even more, batches of material may have expiration dates that must be managed. Not managing these batches properly could result in scrapping entire production runs.

4.1.3 ERP and SCM

The business process of material management begins with ERP and SCM. This means that the contracts with the material and part vendors must be in place first. These contracts must include the following information:

- Production schedule
- Quantity required
- Delivery schedule
5.1 Introduction to Quality and Traceability

Imagine that you are a customer of a manufactured part; let it be 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 an MES as a primary component of that technology. In this chapter, we will look at the broad range of quality activities within manufacturing and take a detailed look at 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 right?” They engaged in activities during or after the manufacturing process to verify the product was built right or helped establish processes during manufacturing to ensure it was built right. The scope of quality has expanded considerably since then, but as far as the manufacturing floor is concerned, these questions are still the primary concerns. The field of quality includes functions like various types of inspection, functional or performance testing, statistical process control (SPC), and continuous improvement activities. However, 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 as the intended shippable product. 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.”

Throughout this chapter, we will discuss the issues that are related to the activities just described and how MES has helped improve the field of quality within the factory
floor. Finally, we will discuss traceability and the extended benefits of using MES for traceability.

5.3 Quality Assurance

The driving force behind QA is that it is far more reliable to prevent problems from happening than it is to detect and correct problems. As a result, most of the quality activities have moved toward preventing defects instead of trying to efficiently detect and fix them. In fact, many companies have realized that trying to improve the repair process so that products get back into mainstream production quickly can actually be detrimental to process improvement as it removes the opportunity to collect data to determine the root cause of the defect. The only time that defects should be repaired and moved back into production quickly is when the root cause of the issue is already known and the extra data collection can provide no additional insight.

In the next few sections, we will cover many aspects of QA, the issues that are faced by Operations during the production process, and the way MES has helped resolve those issues.

5.3.1 Calibration of Tools and Equipment

One key facet of QA is to ensure that equipment and tools are in a known good state of operability. In addition, QA calls for operations to be aware of the most up-to-date performance characteristics of the equipment and tools. In most cases, the quality team will highlight and audit the need for the implementation of a management program for calibration or preventive maintenance, and the maintenance activities will be carried out by Plant Maintenance or Manufacturing Engineering staff.

As part of a typical quality management program, the quality team is frequently the owner of the calibration lab with support from manufacturing engineering. The program keeps test and manufacturing equipment in a state of known calibration compared to national standards and establishes the calibration policies and procedures. To do so, it is necessary to maintain a record of when tools and equipment require calibration (or maintenance) and where the equipment is located on the production floor at that time. Large pieces of equipment are relatively easy to track, but small tools and pieces of equipment are often moved by Operations personnel to where they are needed, making them more difficult to track. In some cases, the whereabouts of the tools or pieces of equipment are not known until someone is using them in production, only to discover that the calibration was due earlier in the week.
6.1 Introduction to Production Monitoring

In the previous chapters, we covered how an 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, announce, 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 being 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. Without the capability to immediately respond, 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 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
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 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 (middle), or red (top) status, to an overhead board that signals specific workstation operations (green for 1, 3, 6, and 8; yellow for 2 and 7; and red for 4 and 5). Some of these devices even play a specific musical tune to alert the right team to respond to the manufacturing event.

At first, these devices were physically wired to the programmable logic controller (PLC) running the operation, whether it was a tooling or conveyance system. While this solution works in small manufacturing plants to respond to events quickly, it lacks any analytics, historical functionality (once the event is done, the data cannot be recalled), or trending functionality. It is also limited to the actual physical placement.
of the annunciation hardware and cannot leverage any functionality that would provide remote notifications of events. In addition, it can only signal that there was a type of fault, it cannot provide real details about the fault. Additional research would be required to determine the root cause of the fault.

6.3 Monitoring Area Details

Before we get into the different areas within production monitoring, it is useful to cover the planning of production monitoring and the level of detail it necessitates. This planning has a direct effect on how an MES will be configured and how it will operate. First, when it comes to monitoring, planning, and determining the equipment failure modes, the faults are usually listed first by the equipment vendor because they must know the operational details of their equipment. Additional equipment faults can be added through planning activities between the plant and the vendor, especially for faults in which the plant floor equipment loses communication with the higher-level MES. Some equipment, especially conveyance systems, has programming that supports production metrics and faults, which can then be easily added to the MES configuration. Once the failure modes are determined, it is up to the plant to determine how the MES will be configured to annunciate to the proper response team and what preliminary action must be taken. The annunciation solutions available, depend on the defined process of the response team and on the system’s functionality. Solutions can include local PC clients, smart device texting, smart device apps, and emails.

The planning for equipment monitoring also includes the ability to use the data to provide useful analytics and trending functions. While these functions are not
necessarily related to faults, they can provide significant insight by delivering the data through organized displays like dashboards and reports or through similar distribution methods. The delivery of data in this way supports continuous improvement and provides visibility of long-term trends in production events.

6.3.1 Equipment Faults

The first and foremost concern in production monitoring is the ability to know the health of all production equipment in real time and to be able to correct faults in such a way as to minimize production downtime. Every minute that production is down due to an equipment fault is time lost in the fulfillment of the production schedule. This includes every piece of equipment that helps produce the end product, including all tooling, conveyance systems (horizontal and vertical lifting systems), robots, PLCs, operator-assisting equipment like lift assists, and any other piece of equipment that directly supports production. Equipment health is really based on the detail of the faults of that subsystem. The more detailed the fault notifications can be, the easier it is to determine the root cause of the fault and thus be able to correct the fault quickly.

Equipment faults are classified into three main prioritized categories:

1. **Production critical** – Production cannot continue until the root cause is fixed. This requires immediate attention and resolution (e.g., a motor drive overload that has stopped a conveyor or tooling with an electrical welder over-current).

2. **Production major** – Production can only continue because there is a defined work-around. Production throughput and data collection are usually negatively impacted. While this does not require immediate attention, it does require quick attention and root cause resolution (e.g., a conveyor nonoperational position sensor or tooling’s operational temperature drifting outside the normal zone, but has been confirmed to not cause a quality issue for this instance).

3. **Production minor** – Production can continue, but at some point in the future, the root cause will become either major or critical (e.g., a conveyor drive motor bearing over temperature or a tooling temperature sensor requiring a calibration check).

It is essential for equipment faults to have a shop floor maintenance team that is responsible for responding to all these faults. This is a dedicated team. Therefore, all
7
Continuous Improvement: Details and Benefits

7.1 Introduction to Continuous Improvement

There are those who would use the often-stated 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 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 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, if the cost of 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 have just raised, this chapter will highlight some high-level concepts that will keep the CI program on track and provide input on observations that 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 with the use of 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 ERP-centric. In this system, the implementation team has chosen to define the operations within the process according to the station identification that is performing

![Figure 7-1. Process labeling by station ID.](image)
the work (which is usually derived from the ERP configuration). It considers the operation identification and the workstation identification as a single data element. Another common implementation concept that accompanies this mind-set is that the station identification is also used as the ERP reporting step ID that is set up to record consumption in the ERP system (e.g., station 1010 in the process is related to ERP reporting step 1010 in the ERP consumption routing). The problem with this configuration is that it fails to recognize that the workstation layout on the floor may change, and if the creation of another line is needed (regardless of whether or not it is in the same plant), the configuration requires the definition of a whole new routing.

Conceptually from the perspective of ERP, the example in Figure 7-2 is acceptable, as consumption from either of the workstations labeled 1020 would probably report the same data. However, the additional workstation 1020 may have different performance characteristics that Operations would need to reconcile (e.g., the additional station may have performance issues that would be hidden at the data level). Additionally, having two operations on the MES routing with the same identification would cause other concerns from a data integrity perspective.

An easy fix for this problem would be simply to rename the additional workstation; however, this would require a change in the routing in both the MES and ERP and would create reporting issues within the ERP structure (see Figure 7-3). In addition, because of the different station identifications, when investigating an issue with the second step in the process, the solution would probably require the use of something called substring searches in the data mining, which would make the reporting extremely slow.

A follow-on problem to this would occur if there was an additional workstation required in the future, which would complicate this issue even more.

Figure 7-2. Example 1 configuration problems.
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.

Some questions that should be answered by operations include:

- What will be the unit cost of the product?
- 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 in 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. There is significant preparation that goes into the launch of a new product (or a new revision of a product), and the planning of first shipments when marketing gets started is very important in any market. As is evident in the smartphone industry, some companies have delayed the initial release of a product and lost considerable market share, while other companies have released a product that has problems, knowing that the issues will 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. While most of the management of product and process design information is handled by product life-cycle management (PLM) during the NPI process, there are specific concerns regarding the management of this process once products and processes are evaluated on the production floor.

When a company’s product is manufactured, considerable time is spent during the design phase that manufacturing contributes to. In addition, having manufacturing ready to produce the product in expected quantities is critical to the successful launch of the product (or revision).

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 (such as 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 build of the product must be highly controlled as any deviation in the build process between materials or designs being analyzed can impact the testing of the product or material. This can cause the product engineer to perform analysis on skewed data or on a product that has hidden inconsistencies built into it that may impact 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 who is familiar with design for manufacturing (DFM) principles understands that it is necessary for manufacturing engineering to get 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. If the product assembly is highly automated (as is the case with many components in the automotive industry), it is not just the jigs that must be built but the automated fabrication tools as well.

Getting the timing right when introducing a product can make the difference between a successful launch and capturing a major segment of the market and an unsuccessful launch that misses a marketing opportunity completely, potentially causing a company to go out of business. The high-tech industry has some excellent examples of the ramifications of having troubles during NPI.

In the next few sections, we investigate the areas of NPI, how an MES can help bring products to market faster, and how getting the configuration of the MES correct is crucial to an effective NPI business process.

8.2 The Operations Processes of NPI

Within the scope of operations, a manufacturing facility must develop an understanding of several issues as early as possible in an NPI project. Some issues include the cost of the product, the supply of material, and the capacity of the available manufacturing facilities, all of which must be forecasted well in advance. In addition, each of these areas of concern contains multiple subissues.

8.2.1 Material Cost

Although the cost of the components sometimes makes up a significant percentage of the product cost, most of the component cost tracking is managed by the supply chain or procurement as part of a vendor management program. Using an MES provides visibility to the components that are being used in the build process. In many cases, the bill of material (BOM) does not contain all the data on what was consumed. Material will not only be consumed as part of the build process but also as repair and rework is performed. As products are sometimes processed and reprocessed through operations, an MES clearly tracks all steps executed and maintains a record for product and process engineers to use when evaluating new designs. An MES can provide a clear understanding of the additional material that was consumed during these processes.
It is important for any vendor management program to include input from an MES to get a clear profile of a supplier’s performance. Product engineers can use MES reports to highlight components and subassemblies that require more work to increase reliability. The next section discusses this further.

### 8.2.2 Transformation Cost

The goal of manufacturing (or transformation) is to convert the raw material into the product by following a fabrication/assembly process. The more efficient the process is at transformation, the lower the cost. This enables a company to lower prices in a highly competitive market or increase profit in markets that are less competitive. For efficiency, the process is designed to have only the steps required for assembly (i.e., operations that add value), making instructions visible for assembly and the controls to ensure the operations are followed correctly. To decrease the time to market, the process development function must complete the design in as little time as possible and the design must be lean in order to maximize the yield and minimize the amount of repair or rework required.

If you look at the process of product development, there are prominent functions in the product development life cycle wherein MES can be of significant value. Once the product engineer understands the information that an MES provides, he or she can use the system to quickly verify a component fit for use and recognize product features that make it difficult to manufacture. Adjustments in product design can then significantly reduce the manufacturing lead time of a product. For more information, investigate the subject design for manufacturability.

### 8.2.3 Material Evaluation

As part of the product evaluation, using components that are known to be reliable can greatly reduce the touch time and wait time (waiting for repair/rework) to manufacture a product. Ensuring a supplier is delivering good components is the responsibility of the supplier relationship function.

Best-in-class supplier relationships will minimize the number of suppliers used by a company to gain the best price and provide the most consistent forecast for your suppliers to plan against. The problem is determining which suppliers to use. Some of the information used to determine a good supplier comes from the audits of received goods. If a good incoming material audit program is in place, a company has all the information required to make that decision, right? Well, not quite.

Material and components from suppliers may be received in good condition but may not be capable of surviving the production process. These failures may be due
MES Architectural Concepts

9.1 Introduction

Over the past several chapters, we have reviewed various business processes and their need for data to develop efficiencies within the manufacturing enterprise. This is the why of what makes MES valuable. However, we have not yet reviewed the how of MES—how does operations use MES to execute their functionality 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, sharing with SCADA, apps, 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 earlier in Chapter 2) on the different levels of manufacturing activity (see Figure 9-1).

In Chapter 2, “A Functional Overview of MES,” we covered ISA-95. In breaking down the levels into system architectural elements, Figure 9-2 becomes clearer.

Now the following becomes apparent:

• **Level 0** – This level represents the actual work being performed. This includes the tools and automation that act on the product itself. Examples include inserting components and bending tubes, shafts, or presses.

• **Level 1** – This is the first layer of monitoring that senses the actual product manipulation, so scanners and annunciators are Level 1 devices. They are used to generate the data for SCADA machines.

![ISA-95 levels – distinct sets of activities](image)

Figure 9-1. ISA-95 levels of the hierarchy model.
• **Level 2** – This is the controls layer. It is made up of PLCs, data concentrators and other data computational devices, and system monitors used to provide supervisory controls or to display automated controls of the manufacturing process. This includes any dedicated closed-loop or small process controllers (not shown in Figure 9-2). This level requires Levels 0 and 1 to control the process.

• **Level 3** – This is the operations layer. All supporting processes required in managing the control of the manufacturing process in general are located here. Servers, relational databases, and workstation clients are located here. They help manage the process through screens, reports, and other business functions directly associated with manufacturing. Real-time interactions that occur between multiple operations within a process are frequently managed at this level. Most of the business logic that is used to maintain the integrity of both the processes and the product being manufactured is managed at this level. Manufacturing data is provided to this level from Level 2 or directly from operator screens at this level.

• **Level 4** – This is the business planning and logistics layer. All long-term analytics and production planning are done here. All data is provided from Level 3. This includes all business functions that support but are not directly part of manufacturing, such as customer relationship management (CRM), supply chain management (SCM), and other functions. This is the level that cloud-based solutions can help support.
10
Differences in Manufacturing Models and Their Impact on MES

10.1 Introduction

Now that we have covered the why of MES through the review of business processes and the how of 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 very 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 different industries in order to complete the picture.

### 10.2 Manufacturing Models

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

#### 10.2.1 Discrete

In manufacturing, *discrete* means that each production unit being produced is independent of each other and there is no real connection between one product being produced, its predecessor, or the product 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 as part of this production management.

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 process capability is achieved, production units can be arranged into groups called process lots according to their similar process characteristics (e.g., same material, equipment, and operators). The process lot is then sample tested to determine the fit for use status. This is very similar to batch management with the exception that the process lot is only managed for the length of the testing cycle for a particular process lot. Companies that are targeting this level of production management should look for an MES capable of handling process lots.

10.2.2 Batch
The batch manufacturing model is used when many production units follow almost exactly the same process and use exactly the same material. As a result, there is very little variation in quality and handling from unit to unit. In this model, frequently the processes for manufacturing a product are either very simple from a management perspective or each production unit is so inexpensive that it is not worth managing at a per unit level (there are, of course, exceptions such as pharmaceuticals, where the unit price within a batch of drugs can still cost thousands of dollars). In these circumstances, the manufacturing schedule is set up to produce a relatively large number of units that are all almost exactly the same, and all units produced at that time are all identified by the same batch or lot ID. Because the entire batch of production units has similar quality characteristics, each batch is usually sample tested to determine its conformity to requirements, and the quality and processing records are recorded for the entire batch instead of at the individual unit level.

In process manufacturing, a batch (or lot) would be determined by the number of production units that are all made from the same batch of raw materials and by the same set of equipment and production operators.

From an MES perspective, the application must be configured to handle multiple units of a product under the same production unit identifier (batch ID) and have the capability to process partial quantities of units distributed across the entire process. In this model, the inputs into the production run (process, equipment, and material) are usually controlled to define a change in the batch ID (if any of the inputs change, then the batch ID must change). If a subquantity of the batch is redirected because of nonconformance or special processing, the application must be able to separate that number of units and re-identify them as a batch variation by changing the batch ID representing that number of units.

In this model, the data collection, quality control/assurance, and reporting of characteristics of the batch are usually performed by statistical representation and
11 Developing an MES Strategy

11.1 Introduction

For determining an MES direction, several topics must be examined to ensure the right decision has been made corporately. 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 started with a single plant that is ahead of the game, but as each plant moves into 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 there are several initial interfaces that must be developed and customizations that 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 into an MES.

Without an overall MES strategy, because each implementation is unique and may even be on a unique application, lessons learned are not easily transferable, 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 exact 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, there are benefits that 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. Once 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, as previously mentioned, 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 issues are that are causing problems and reduce the number of gemba walks required to fully analyze these problems. Also, with the relational database of an MES, there is the added benefit of having the statistical data readily available to determine just how much of a problem the issue really is (a major consideration for Six Sigma projects). These benefits improve the rate at which issues are pinpointed and isolated and provide for the development of specific solutions that resolve the root cause.

The third benefit (by no means the last) is that the relational database provides visibility of issues across the entire production environment. Many continuous improvement (CI) initiatives focus on improving a single operation and/or a single issue. One of the faults of CI initiatives that are managed this way is the inability to recognize that improvements in one area (or operation) may, in fact, cause problems at another. As an MES records the entire history of all production units, the impact of one change at an operation is easily seen in the output of another operation. Once again, this helps speed up the implementation of CI initiatives. If a company produces product over the same multiple plants as previously described, and they are on the same MES, this provides excellent insight and support for centralized improvement programs. Once again, this enables companies to develop and implement best practices across the entire enterprise.

It is possible to accomplish these benefits without an MES, but it is highly likely that they will not be accomplished at anything near the same rate as when an MES is used. Any quality or process issue that is not captured will continue to cost the company money (a direct load on profit) for as long as the issue exists. As a result, although a company can run a CI initiative or plan production without an MES, the ease of pinpointing the root cause of an issue and implementing a stable solution will likely be orders of magnitude faster with an MES, provided that it is selected, configured, and supported properly. The remainder of this chapter provides guidance on doing just that.

11.3 What Are Your Business and Manufacturing Models?

Many of the decisions that must be made with an MES initiative will depend greatly on the type of businesses that a company engages in and the different manufacturing models that exist within the enterprise (discussed in Chapter 10, “Differences in Manufacturing Models and Their Impact on MES”). These key points will drive
We have reviewed aspects of the business process information, technology influences, and manufacturing types in this book to determine how an 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 all quality initiatives like Six Sigma, Lean, or the Theory of Constraints. The next challenge is to clearly understand what must be replaced or improved and to have a clear plan on how to implement the change and make sure that the company avoids a situation where there is an extraordinarily large capex (capital expenditure) needed to maintain or improve performance (similar to IT resources, replacement and upgrades must happen regularly). All of these changes must happen without negatively affecting the production schedule, and significant changes will usually require training activities regardless of the change being 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 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 of time, 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 as well as in ongoing support. As the technology continues to evolve, these equipment assets start
aging rapidly; what is now available through the innovation of Industry 4.0 and the Industrial Internet of Things (IIoT) capability of equipment (as discussed in Chapter 9, “MES Architectural Concepts”) was not available in the early 2000s. At some point, these aging assets will not be able to support some of the changes and abilities offered by the functions provided by the newer enterprise solutions. Additionally, replacement parts for outdated equipment is often not available or very expensive. As such, aging equipment assets can become a significant cost when they must be replaced or at least retrofitted. Much of the older controls assets are still functional for the actual production capability they were built for, and some were made to function for decades; however, they are often either void of communication capability outside of the PLC system or their communications capability is quickly becoming obsolete and difficult to retrofit unless upgraded with a custom designed integration package. The cost and planning to upgrade is not only for the acquisition and installation of new technology, but also for training to support the new asset and the removal of the old asset. This includes replacing controls assets that have become obsolete on the market and the replacement parts that are either very expensive or no longer available. Therefore, the life cycle of manufacturing assets must also be planned for, which includes the retirement of the assets once they reach the end of their useful functionality.

In some cases, for OT upgrades, there are retrofit kits designed to easily add to equipment that will provide at least some communication/data acquisition functionality. These kits can provide relatively inexpensive upgrade capability and extend the usable life of the equipment for several years.

12.2 The Challenge of Greenfield Plants

Greenfield plants, alternatively, are new manufacturing facilities, which may even include a new building. These plants have no manufacturing assets or processes set up. In planning the project for manufacturing start-up, the manufacturing processes must be sketched out and approved for all the plant functions first. This may include integrating the greenfield plant into business processes that already exist from previous plants or defining processes from scratch as the plant is being built. The main challenge here is the undocumented business processes, as these processes are sometimes missed. When a process is missed, the omission may not be determined until late in the project and will probably cause difficulty in including that business process into the support systems (e.g., IT, enterprise systems, or business models). As solutions are created to try and include these undocumented processes, most of the solutions will be developed ad hoc, and they will likely not easily fit into the overall process flow. These ad hoc solutions will usually manifest themselves as unplanned costs, as well as schedule delays. In addition, the support of these solutions (as stated in previous chapters) can be difficult in the long-term.
Getting to the end of this book, there are a lot of concepts that have been covered in relation to the different aspects of operations management, such as continuous improvement, capacity planning, facilities management, and others. We have seen the different ways that MES can help with each of these areas of manufacturing operations management (MOM).

Also, within this book, we have covered several process and quality management methodologies and have shown ways in which MES can help with them as well.

In some of the chapters, we have tried to present the IT side of MES in a manner that is relatable to an operations point of view and provide guidance on how to use the data from 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 Support of MOM

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

First, there is a need to understand the capacity requirements needed to estimate customer demand and ensure that the actual delivery meets actual demand requirements. The issue that MOM managers have to deal with is that 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 actual demand. These variances are the pain points that cause all MOM managers and leaders frustration and what they lose sleep over (and sometimes even their jobs).

The other aspect of data 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 high number of issues can still result in considerable costs to operations. These issues are collectively categorized as common cause quality issues, and this type of quality issue is a problem not only because of the cost associated with it, but also because it creates a lot of “noise” for quality management programs, making it very hard 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 would be very helpful. This is also part of the focus of initiatives like Lean and Six Sigma. This activity is covered in detail in Chapter 5, “Quality and Traceability: Details and Benefits,” and in Chapter 7, “Continuous Improvement: Details and Benefits.”

Once the volume of variation has been reduced, Operations will be able to turn their focus to the issues that fall under special cause variations. These are issues that have very specific causes that may or may not be known. Once 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.

Because the staff’s availability to identify the root causes for these problems and then develop a solution to resolve them is often limited due to time constraints, it is
important for the managers and leaders in MOM to focus continuous improvement activities on resolving the costliest pain points, invest in solutions that provide the “biggest bang for their buck,” and ensure that the root cause of the problem is actually being focused on rather than a symptom of the problem.

As part of the *gaining the greatest impact* concept introduced in Chapter 5, the Theory of Constraints (TOC) philosophy is that if a solution does not improve the capacity of the constraint and/or improve the delivery rate of good product (thereby improving the ability to sell more product), then MOM improvements are not really improving things (or at least the improvement has minimal effect). Whether you subscribe to the TOC in particular or not is irrelevant. Making the investment that provides the greatest return is always just good management.

In the previous chapters, we have shown that an MES, when used as the central point of record for manufacturing, can provide valuable insight into the real characteristics of the plant. This includes the business and manufacturing processes (cycle time, yields, and, of course, throughput of the right product to be manufactured), equipment and operator capacity (a product of the process measurements when focused on a specific piece of equipment and product combination), and the operational costs related to cost of goods sold. In the next few sections, we will summarize many of the concepts from previous chapters and highlight what is important regarding MES.

### 13.1.1 Summary of Supporting Processes

In managing a manufacturing plant, there are some key points that must be clear. When it comes to forecasting sales (independent demand) and the markets that are sold to, Operations will have very little that can contribute to the accuracy of the demand side estimations, and Operations should not try to impose on this part of the business. However, both Operations and Sales should keep an eye on the consumption of the forecast for any variance that is happening to both the actual demand coming in as sales and to the delivery to sales. This is important to ensure that (1) Operations has visibility of issues that will affect their capacity to deliver and (2) Sales understands what is contributing to the variance in sales demand in an effort of create better forecasts. There is no greater contributor to errors in manufacturing than to have Operations surprised by an unexpected increase (or decrease) in demand.

The part of the demand/delivery equation that Manufacturing Operations does have control over is in the planning and execution of product delivery. As with all planning activities, there is an understanding that once the execution of a plan starts, it is going to have variances.
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 to generate reports for information that enables companies to understand their current performance. One of these systems is a manufacturing execution system, or 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 to
each unit of WIP and therefore 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 approximately 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 bottlenecks (as shown in Figure A-1) in the communication between the MES server(s), the workstations, and the operators performing the work. This bottleneck would then create delays in the processing of MES transactions in an environment where true real-time communication has been proven critical to providing information to the production operator at a rate that does not slow the operator down. As MES are implemented, many consulting companies are already finding it difficult to provide a system response that does not impede the speed of production.

In an attempt to resolve this problem, many application developers are implementing applications using cloud computing systems. This method of implementation can provide some relief but does not actually resolve the bandwidth constraint issue. In many implementations, it is the network infrastructure that causes delays and not the MES application itself. The MES can be the fastest in the world and still be limited by the bandwidth of the network. In order to resolve the communication constraint, a new infrastructure for the MES must be developed.
**BoL**: bill of lading. A shipping document used to describe the content 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.

**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 then compares that current state to the vision of the future state and creates a roadmap of changes to achieve the future state.

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

**computing service (service)**. A small software application designed to operate within a node or on some other computing device design to operate 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).

FIFO: first-in-first-out. An asset management system in which the products produced first are sold first. A FIFO feeder shelf dispenses the parts that were obtained or produced first to be used first.

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 devises). 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.
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