What Goes Where: Determining Most Effective Technologies for Real-Time Operations

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Table of Contents

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Introduction

Many organizations are struggling internally with decisions around technology use in the real-time operations space for applications that impact manufacturing, operations, and the plant-floor environment. In trying to determine which technologies should be used to enable real-time operations, execution and reporting, there are an abundance of solutions to pick from, and often confusing terminology to decipher from solution providers and system integrators. Moreover, organizations are implementing or rolling out big Enterprise Resource Planning (ERP) implementations and want to leverage this significant investment as much as possible across their enterprise.

With the growing convergence of the Information Technology and Engineering functions and responsibilities within many companies, it is critical to have a consistent vision and strategy for technology deployment. That does not mean, however, that one size fits all. Organizations who use technology for applications that are not fit-for-purpose often find themselves starting, stopping, re-grouping, and re-starting projects. This is particularly true when it comes to implementing real-time applications like Manufacturing Operations Management/Manufacturing Execution Systems (MOM/MES).

The purpose of this article is to demystify what goes where (ERP, MES/MOM, Controls) and provide some practical examples to guide companies through the decision making process.

Defining the Layers

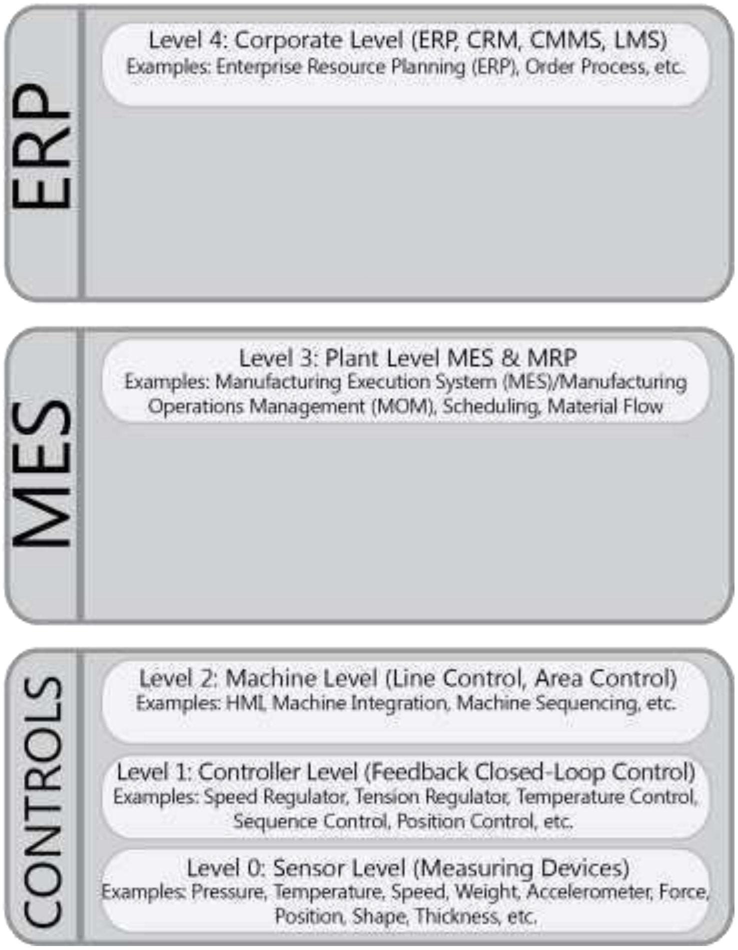
Before we can determine what goes where, let us start by defining the layers themselves.

ERP *(also referred to as Level 4: Corporate Functions – business planning and logistics)* - ERP systems are designed to: automate and support administrative, financial, and inventory processes, manage material planning (purchasing plans, manufacturing plans, costing), demand and supply planning, production planning, sales and delivery, HR and human capital management, supply chain coordination and visibility, corporate quality plans, enterprise/business KPIs, transactional driven, "business" user interface.

MOM/MES *(also referred to as Level 3: Plant MES Solutions*) – MES systems are designed to: manage work-in-progress, manage work orders, materials on the shop floor, report material consumption data and schedule attainment to enterprise systems, audit trails, early warning and manufacturing visibility, contextualization of real-time data for measurement of manufacturing performance, execution and sequencing of production builds and processes, work instructions, detailed track and trace/genealogy, "operations" user interface (appropriate for people working at a distance from a computer screen, on machines, or wearing gloves), direct connections to shop floor controls, enforcement of operator certifications, and manufacturing compliance.

Controls *(referred to as Level 0, 1, 2: Plant Control Layer)* – Controls systems are designed to: provide deterministic real-time control of shop floor devices, manage machine I/O, provide safety logic and functionality, execute batch sequences and machine steps, buffer for communication to higher level systems, and deliver basic logic to operate the facility (includes Supervisory Control and Data Acquisition [SCADA] systems and detailed historians).

Figure 1: Defining the Layers



The Concept of "Drawing the Line"

After looking at the different layers and respective roles, some functions are clear-cut fits for certain layers. For instance, financial data is easily mapped to ERP, and safety-critical real-time plant floor control fits clearly in the Controls layer. What about MES? Since MES is sandwiched between ERP and Controls, it shares some functional overlap with each layer. Nomenclature used in each layer can take on different meanings to the users (i.e. Production Order means a different level of detail to a production planner looking at scheduling for a site versus an operator looking at executing a specific order on a specific machine or line).

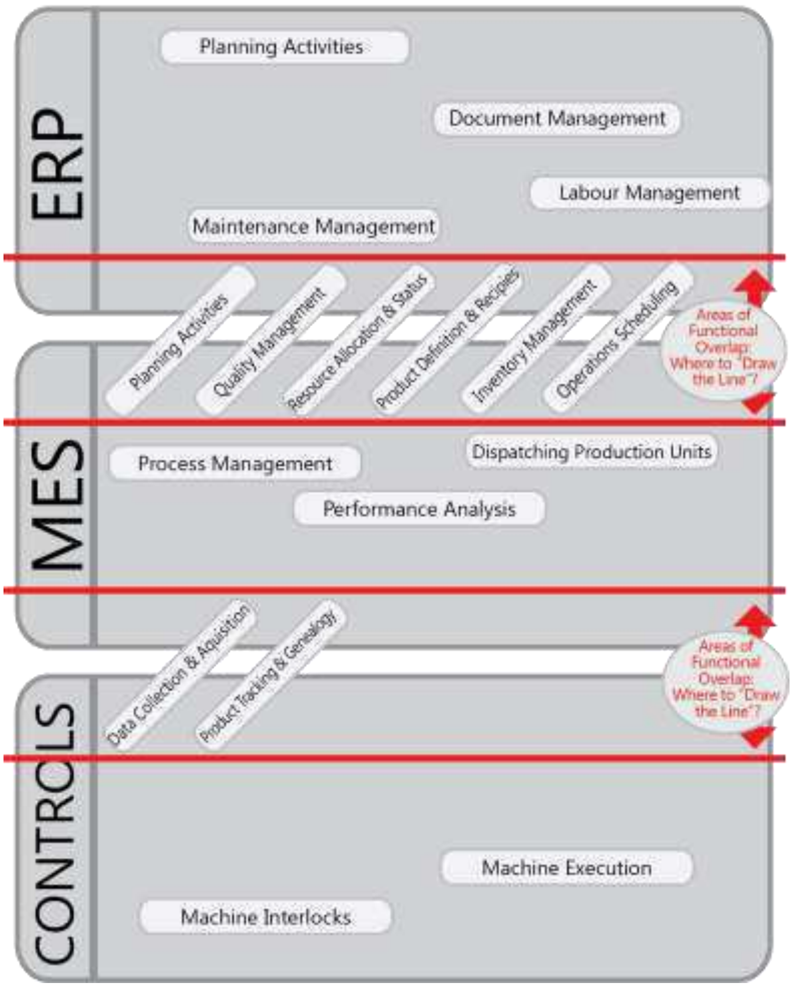
To make it even more complicated, even if there is agreement on functionality, it is often difficult to map the functions to technology. How do we "draw the line" between these other layers?

How do we determine what goes where? Well, it depends on some of the following considerations:

- ***Data Transaction Rates*** **–** Processes that require very high rates of transactions (Ex. 1-100 transactions per second) are most often captured and aggregated in the Controls layer and stored in MES. MES interacts directly with the data in a control system and is optimized to store production data efficiently. Lower rates of transactions (Ex. 1 transaction summarizing production per hour or shift) are often more suited in the ERP system. Frequently, data is aggregated in lower level systems and passed up, providing it is relevant for storage in that particular layer.
- ***Data Relevancy*** **–** Not all data is relevant to each layer. The users of each system have different needs. For example, maintenance personnel typically work in the physical plant and often require detailed information regarding the process for troubleshooting and optimization of machines and maintenance schedules. In contrast, a corporate VP of Operations is based offsite and will likely be more concerned with the overall plant performance that is calculated based on summations of the detailed data. Granularity must be considered as the level of detail required will vary depending upon the layer and associated use cases.
- ***Need to Act*** **–** While some data is collected and stored, other data triggers a response for action. This response is often time critical (or safety-critical) where the input parameters are adjusted based on the current output parameters (Ex. process control PID loop). Time critical functions and interlocks are often handled in the Control layer, unless the data required to select the response is not available. If the decision requires data from other parts of the facility or the enterprise, such as verifying a material has not been placed on hold by the quality group, the function may reside in MES or ERP. The typical practice is to download the necessary data into a buffer from the master system (MES or ERP) so that it is pre-loaded in the control system to make a real-time decision. Nevertheless, pre-loading data is not always possible or practical due to large volumes or dynamically changing data.

- ***Functional Uses* –** The intended use of the functionality and the technology that is currently integrated into the targeted role and physical location will contribute to deciding the most appropriate layer. For example, a function that is contained to a particular cell is a candidate for storage in the controls system, whereas a function that will span multiple cells and areas (i.e. WIP track & trace, genealogy) would likely be stored in MES, and functions or data that requires access to multiple plants would reside in ERP. It makes sense to continue to build functions into systems that are already integrated into a particular role instead of adding many different systems to a job stream and requiring users to inefficiently switch focus between them or between systems.
- ***Standardization* –** In order to efficiently integrate ERP and MES systems, there is a need to standardize the interface with the layer below. For example, imagine an ERP rollout of 50 plants that all have different MES systems requiring 50 unique interfaces. The effort required to build and maintain these separate interfaces in ERP could be tremendous. If instead a standard interface could be used from ERP so that each plant was a black-box that behaved consistently, only one variation of ERP interface would need to be built and maintained. Likewise in MES communicating to the plant floor automation systems, there are techniques to make each machine interface consistent so that unique interfaces are not required for each piece of equipment in the plant. Standardization is a critical consideration for "drawing the line" and if placing a function in ERP or MES will require detailed knowledge and customization to interact with the layer below, it is often a clue that the function should be moved down to a lower layer.

Figure 2: Deciding Where to Draw the Line



Architecture

Determining the most suitable location goes beyond the specific functions offered by technologies at each layer, but is equally a matter of architecture. In fact, it is here where much of the debate occurs. Architecture is highly important for real-time operations to provide operational flexibility and robustness. Typical architectures of each layer are as follows:

- ***ERP has a centralized architecture*** – ERP systems are stored on corporate servers hosted in a company data center. The system is networked to each site to provide a central repository and system of control for the corporation. ERP is a central point of failure for the plant (e.g. loss of WAN connection) and the enterprise (system downtime).

- ***MES has a distributed architecture*** – a separate installation of MES is typically hosted in each plant and is connected to the plant floor over the local production LAN network. MES is a highly available central point of failure within the plant (system downtime). Note that as MES systems and architectures evolve they are starting to take on a centralized architecture. Some of the systems have accommodations for a store and forward approach with local components. For other systems an appropriate data buffering strategy such as the use of data concentrators should be applied.
- ***Controls has a distributed real-time deterministic architecture*** – the control system is connected directly to plant floor machines and distributed to each production area or cell. The control system is a localized point of failure for the particular production cell or area (system downtime). These systems are found to be highly reliable. Often the controls layer is run on an isolated or protected network from the rest of the business networks for both security concerns and performance requirements of the real-time control systems.

Architecture must be considered when mapping functions and "drawing the line" to ensure that production will continue when MES or ERP systems are not available. The question is: what is most effective for the task at hand? There are several techniques to buffer production data to allow the Controls layer to execute production and store results without MES or ERP as required. Production critical functions cannot live exclusively in the ERP or MES layer, but need to exist in the lower layers as functions that can continue to provide the services required to run the plant during network interruptions or system outages.

The following are some fit-for-purpose examples to consider between ERP and MES:

"Dock-to-Dock" Traceability – Ideally, MES handles the receiving and shipment of materials in and out of the plant as material movements often correspond to a large number of transactions and rates and it forms the starting point for traceability. ERP will typically treat the plant as a black-box and will be updated on lot creations and consumptions from the MES system. This allows MES to manage the details of material movements and genealogy, update the ERP system as shipping manifests are closed of the inventory changes, and ERP to manage the overall inventory levels and trigger material orders to maintain target inventory levels.

Transaction-Based Data **–** ERP is designed and optimized to handle transaction-based financial and corporate data. Some of these transactions may involve a very large amount of data, which would not be practical to store in an MES system. For instance, financial transactions may involve relating data to many different internal and external data objects including material, customer, financial, supply chain, maintenance, and human resources systems. Conversely, the ERP design would not suit storing frequent production floor data transactions associated with event driven execution as the typical ERP update rates are not appropriate to represent a dynamic real-time environment.

Corporate Master Data **–** Human resources, financial, materials, master product recipes, and corporate targets and information are best suited for ERP. A single-source of this data is maintained in the centralized architecture with necessary information pushed down to lower systems. Attempting to maintain the same data across distributed plants, such as recipes duplicated in each MES or Control System, would be more complicated, less standardized, and provide less governance over which plant system owns the data.

Plant-floor layout, data model, and equipment **–** Specific details regarding each plant such as lines, units, cells, and the breakdown in equipment and routings along those lines or cells, are most suited for MES. ERP will treat the details of the plant as a "black-box" and will let MES manage the flow of material throughout the plant's physical layout, equipment models and operating parameters.

Shop-Floor Awareness **–** MES provides equipment level shop floor awareness, allowing the system to know the status of all machines at any given time. This capability supports functions such as Overall Equipment Effectiveness (OEE), inline quality, and dynamic scheduling. While ERP does not provide the shop-floor awareness, it supports these functions from a planning perspective (i.e. planned schedule from ERP that can be adjusted by MES as required based on real-time conditions or the ERP system can schedule and send planned maintenance activities).

When functionality is properly balanced in the ERP, MES, and Controls layers, fit-for-purpose is considered and each system compliments the other and greater overall value is realized.

Practical Scenarios Demonstrating “What Goes Where”

The following scenarios are intended to clearly demonstrate, through practical examples, the design of real-time functional systems. In each example, all architectural layers co-operate to achieve a common goal. Requirements are subdivided into specific tasks that are assigned to the layer that represents the most effective technology to complete that particular task.

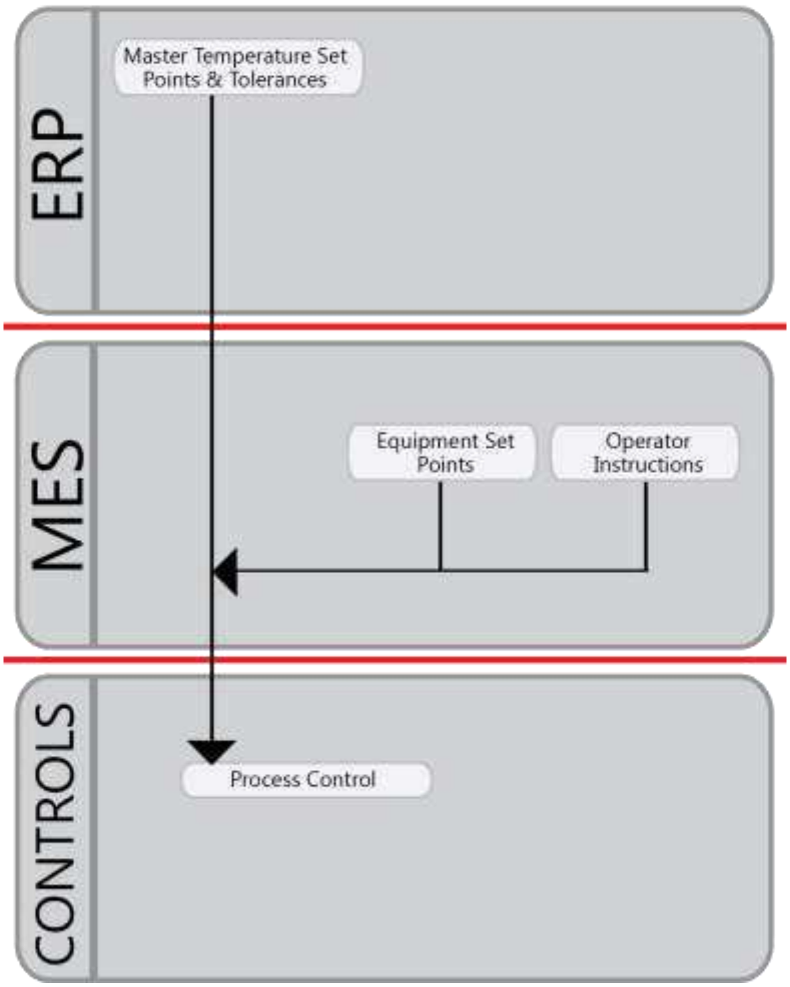
Scenario 1: Temperature Control

A chemical producer monitors and adjusts temperatures in real-time. As the temperature is measured, machine parameters are adjusted to heat the mixture if required to stay within tolerance.

Tolerances are maintained as part of the master quality data for the material specification in ERP and downloaded to MES as part of the recipe specification. A temperature tolerance defined in ERP (i.e. SAP QM) may represent a “corporate value”. The MES layer may need to “modify” this value because each plant, based on real equipment, might have its own tolerance that might differ from the “corporate” value. In addition to this, ERP will never define all parameters needed for production but will define only the common ones. MES will add for each plant the specific ones for that plant. When an order to produce the recipe is received, MES links the master recipe with the site or equipment specific recipe parameters, and then MES sends the controls specifications to the PLC. Within the controls system, a process uses the ERP master quality tolerances (passed in from MES) as parameters to determine the set points required to maintain temperature control of the process.

In this scenario, ERP maintains a centralized master data record for temperatures required in a recipe to produce a consistent product. MES contains the specific equipment parameters required in each plant to achieve those consistent temperatures. The controls system monitors the temperature in real-time and makes adjustments to the inputs as required. Each layer works within its role, in co-operation with other layers, to execute the standard process.

Figure 3: Scenario 1 - Temperature Control



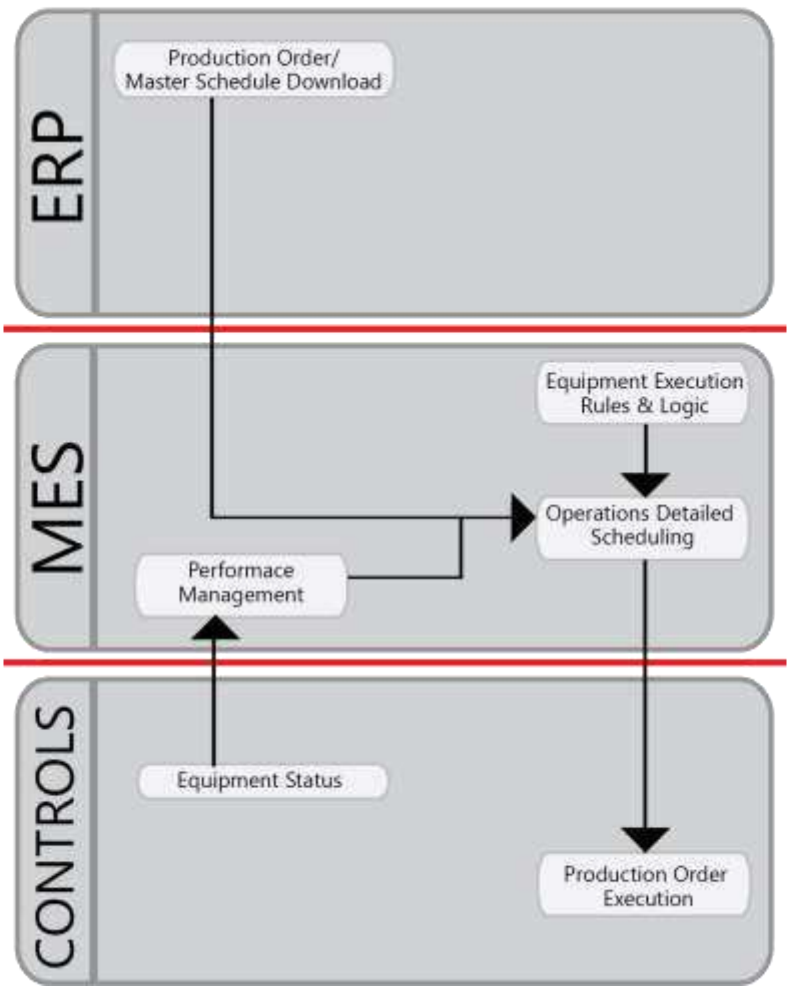
Scenario 2: Order Downloads to Execution Equipment

A beverage producer's ERP system provides a planned schedule of orders to be executed on the production floor for each plant in the enterprise. The schedule for the next two days of production is downloaded to Plant A. MES can automatically split the master production orders into sub-orders that correspond to the main physical areas of the plant (mixing, filling, and packaging). On the plant floor, the plant scheduler assigns each master order to a particular line in the Plant A MES system based on awareness of the current equipment statuses and conditions.

Since the order is split and assigned after the planning stage, ERP does not know which particular mixer will start the batch. Each mixer has unique set points, operator instructions, and operating parameters that are stored within MES and assigned to the batch instructions upon assignment to the actual mixer.

ERP and MES work together to execute orders efficiently – ERP can maintain a standard approach to production orders and material formulas across the enterprise, while the unique details within each plant and mixer are applied by the MES system.

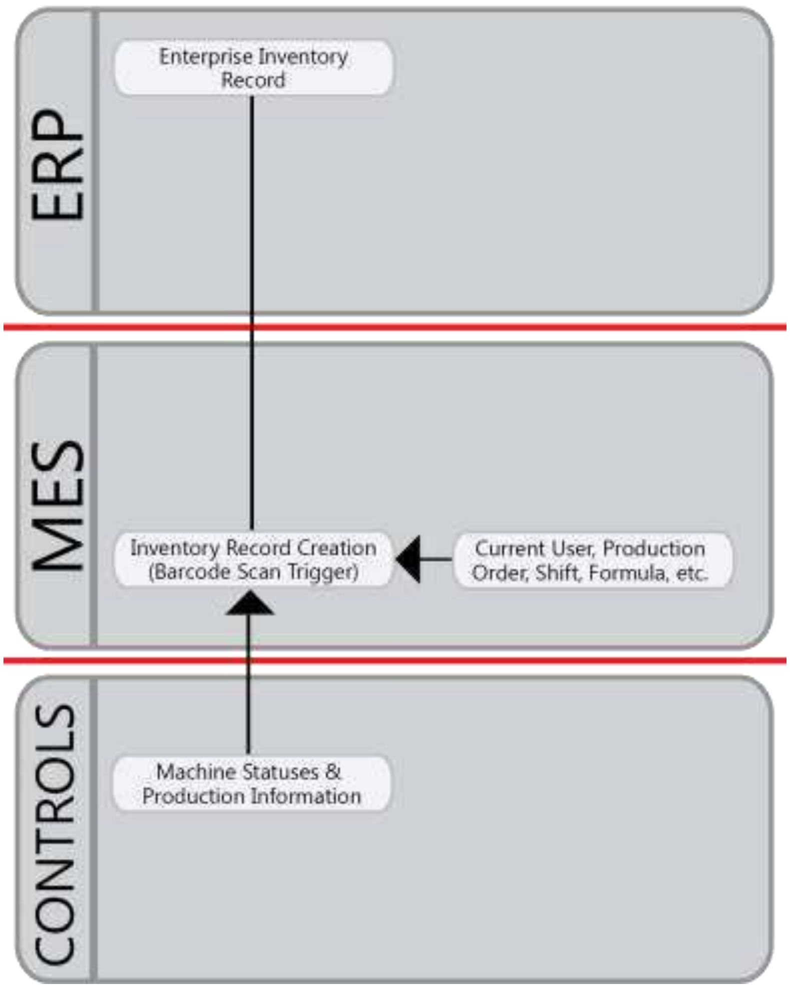
Figure 4: Scenario 2 - Order Downloads to Execution Equipment



Scenario 3: Container Shipping

A food producer configures a single barcode scan (lasting less than a second) to a container shipment transaction in MES in order to trigger each of the following: report production, declaration of inventory, load inventory into the shipment container, move it to shipment location, print a container label, back-flush the packaging material and finally, all of the labor reporting required through an instantaneous update to ERP. Because such data is captured based on "as-built" specifications, in real-time, MES can reduce operational mistakes by error proofing while establishing traceability of who does what process when, with which material, without further data entry. In addition, if this action occurs repeatedly for a group of products to the same shipment the MES system can be used to buffer the information and send the details in a batch update and/or summarized by material types.

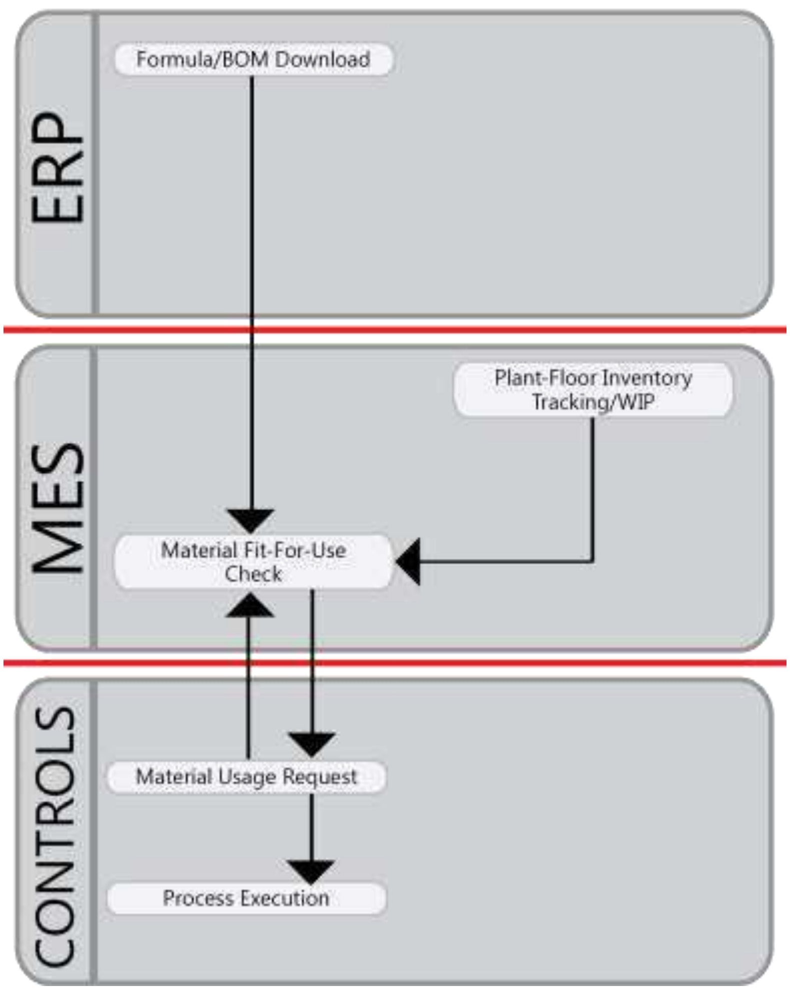
Figure 5: Scenario 3- Container Shipping



Scenario 4: Material Verification

ERP Bill of Materials (BOM) is downloaded into the MES system as part of the product formula. Many manufacturers use MES's robust traceability and real-time architecture to implement interlocking material verification of products and processes, where quality controls are integrated directly into manufacturing. MES can halt production if quality tolerances are out of acceptable boundaries or if a component type is not part of the BOM or cannot be added at a precise step of the process operation. As the actions happen, MES records and links the traceability to the genealogy of the product being produced. This traceability can be utilized in real-time or reviewed in a historical context. This capability allows MES customers to achieve cost effective compliance, while ensuring quality is maximized during every stage of manufacturing.

Figure 6: Scenario 4- Material Verification



How Should Companies Proceed?

Before we attempt to provide advice on how to define what should go where in your operation, we recommend that organizations ask themselves some fundamental questions:

- Do we understand how our operations run today? How are various systems used, what are their capabilities, and what processes are followed?
- What are the regulatory impacts?
- What is the quality, user understanding, and alignment of the architecture?
- Is there a clear understanding of value drivers and areas of risk?
- Are the solutions being deployed fit-for-purpose?
- How far down the path are we in our implementations?
- What level of standardization do we currently have in our work and operational processes?

Answers to these and other questions/issues raised in this article could result in the following course(s) of action:

- ***Education*** – The MES space can be difficult to define. Inconsistent nomenclature and various viewpoints can lead to confusion. Providing stakeholders with a common definition of MES terminology and a baseline of functional requirements is critical to achieve organizational alignment and developing high-level project objectives and success criteria.
- ***Workflow*** – A graphical representation to map detailed functions to each layer in the system architecture. Often a function will not be isolated to a single layer, but will require co-operation of several layers to share information and execute specific functional details. A workflow answers the question "What Goes Where?" and defines the role of each system in the architecture with a sufficient level of detail to provide time and cost estimates.
- ***Framework Study / Roadmap*** - The framework study derives the functional requirements (Workflow) by focusing on how to fulfill the business goals and objectives. Return on investment is calculated and project activities are phased and prioritized. A roadmap

provides the blueprint for the program and clearly defines the timing, level of investment, and expected return throughout the project.

There is considerable confusion in the market today. Technology is quickly evolving and expanding with new functionality that blurs the lines between the traditional roles of ERP, MES, and Controls layers. Nomenclature has been used inconsistently making it difficult to determine if functionality is redundant or adding new value. This paper was written as a guideline on how to deal with these challenges and effectively "draw the line" while designing your architecture. There are many examples of generic education and standards available, but they often generalize the issues without providing clear and specific suggestions and guidelines. By examining the mapping criteria, practical scenarios, and suggested steps described in this paper, organizations can have confidence that they are getting started on the right foot and avoiding the mistakes of customizing or stretching products for purposes beyond their intended use. The best possible integrations are architected and designed based on the concept of using the most effective technologies.

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John is a Co-CEO of Brock Solutions, a role he has held since 2006. Prior to joining Brock he was a partner at Deloitte Consulting where he held several executive leadership positions. He works directly with Brock's largest customers as a strategic advisor and executive sponsor, and directly participates on client steering committees for large-scale transformational real-time solution programs. John is active in many professional associations including the Manufacturing Enterprise Solutions Association (MESA) where he served as International Chair from 2011 - 2012, World Presidents Organization (WPO), and is an Advisory Board member at the Centre for Business, Entrepreneurship & Technology at the University of Waterloo.

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