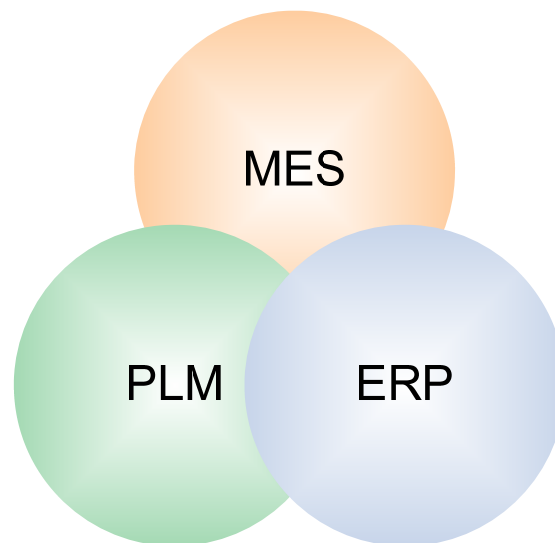




## Models for MES In an Enterprise Architecture



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**Applying Industry Models in a Discrete Manufacturing Environment**

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**May 12, 2011**

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## Executive Overview

This document describes the modeling techniques applied for the integration of a Manufacturing Execution System (MES) into enterprise architecture. The MES complements the enterprise resource planning system by providing essential production information in a fully integrated environment that reduces the dependence on manual data entry.

The implementation of a MES introduces actionable, real-time information into the paper-based shop floor environment and creates a “paperless shop floor”. This enables critical information to flow throughout the organization—including the once-forgotten areas of manufacturing. Collecting data from the shop floor and transacting in real time to other enterprise systems thereby replacing unnecessary and error-prone manual data entry systems. Having information about events as they occur allows planning departments to identify and prevent potential problems or bottlenecks.

MES subsumes fragmented shop floor applications deployed within manufacturing unifying the functions performed by these legacy systems. Avoiding and eliminating isolated knowledge pools by leveraging the intellectual property in current shop floor systems by mapping the data contents to the MES through electronic means. MES fulfills its enterprise mission through functional integration to other enterprise systems providing bidirectional synchronization of master data as well as the real time exchange of operational data.

Implementing MES by leveraging industry standards will reduce the cost to integrate MES to other enterprise applications. The integrated enterprise using XML, web services technology, and an Enterprise Service Bus (ESB), to interconnecting applications reduces the integration cost to less than half of the current typical point to point costs, and delivers the solution in a fraction of the time.

Ultimately, an MES implementation to the enterprise keeps costs in check, and production and shipments on schedule.

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# 1 The Manufacturing Domain

Organizations have been working for many years to bring into use commercial enterprise IT systems to standardize work processes and eliminate legacy, customized, and isolated systems to the greatest extent possible.

This goal, to standardize upper level business processes and communications, as well as streamline the processes utilized within the enterprise. Not intended to mandate all shop floor operations to operate in the same manner, in fact the diversity of types of manufacturing operations, products, equipment, labor, local codes, make it imperative that individual organizations have the freedom to organize their shop floor work operations in a manner consistent with past proven processes and policies.

What does need to be consistent throughout the manufacturing operations?

- The **type of data** which is transferred between the enterprise level systems and the individual manufacturing sites
- **How** this data is communicated across manufacturing operations
- **Quality** of product regardless of which facility in the enterprise produced or repaired the product.

## 1.1 Discrete Manufacturing Processes

The Manufacturing domain includes repair, maintenance and production enterprise that performs a very diverse number of manufacturing operations

Fabrication transforms raw materials into semi finished and final products through a series of manufacturing steps. Within the enterprise, locations act as original equipment manufacturers producing new product from raw material through foundry operations, forging, precision machining and welding, plating, finishing, painting, packaging, etc.

The enterprise also consists of Repair & Maintenance Operations where previously manufactured products are fully disassembled, reconditioned and reassembled with a combination of original components, reconditioned components and new parts.

Repair & Maintenance operations also reclaim (overhaul and return to service) many of the components and spare parts, provide refurbished spare parts into inventory for future maintenance. Many have the ability to produce hard to find parts needed to complete the repair and maintenance. The production of these parts may itself be equivalent to a commercial scale facility.

## 1.2 Characterizing the Manufacturing Processes

Process execution is the physical production of goods or the repair and maintenance of equipment. The physical activities take place on the shop floor where manufacturing technicians receive and consume materials to produce the end items. The nature of these activities at is very complex and varied.

The build work flow consumes raw materials, combined with sub assemblies to produce new end items. These processes utilize a bill of material (BOM) during production. The processes carried out at these facilities include Make to Order (MTO) or Engineer to Order (ETO).

The Repair and Maintenance process commonly referred to as (MRO) workflow is more complex. The end item is both the

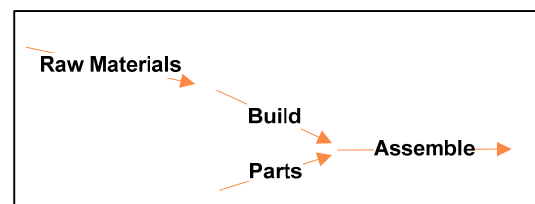


Figure 1-1 Manufacture

object of the order and a material component on the bill of materials (BOM). The process requires serialized tracking, often returning subcomponents to the original assembly).

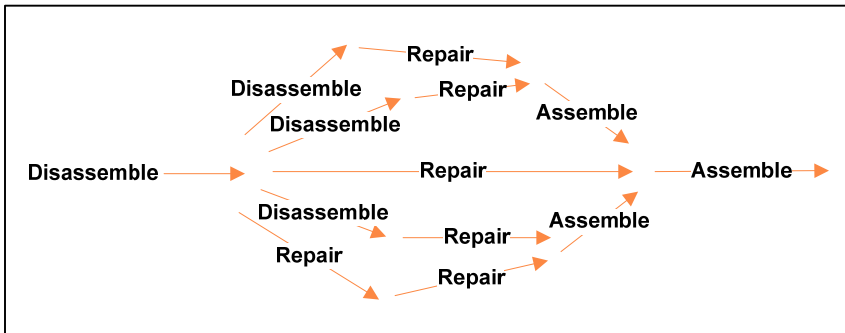
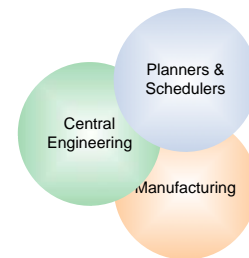


Figure 1-2 Repair and Maintenance

## 2 Enterprise Domain (Architecture)

The Enterprise relies on a variety of internal organizations with far reaching tasks to achieve their goals. These organizations include central engineering, schedule and planning, and manufacturing. These organizations feed information to each other to create, maintain, or repair products across the enterprise. Each has specific roles; but none of these groups can work efficiently without data from the others. Typically in small companies, engineering / planning & scheduling / manufacturing are within the same building or at a minimum within the same site, making communication between the groups easy to facilitate; however as the enterprise gets larger, with multiple sites, in multiple states, in multiple time zones, the amount of information to be managed grows and the ability to distribute and maintain information becomes increasingly difficult.



To control the information flow in commercial industries, engineering / planning & scheduling / manufacturing groups work with various vendors to deploy specialized software solutions for their specific functions within the enterprise; initially developed to help standardize data and communication within a particular group or organization. As these software solutions evolve standardized communication protocols are adopted greatly increasing efficiencies in transferring data between different enterprise groups.

Of the many enterprise level software solutions, this whitepaper focuses on the three functions that have a direct impact to the shop floor. The following sections contain a general description of these software categories.

### 2.1 Enterprise Resource Planning (ERP)

An ERP system typically integrates enterprise level information – i.e. financial, accounting, human resources, supply chain management, and customer information. The goal of ERP software is to mirror the business processes of the enterprise and help manage key parts of the business at an enterprise level.

Shop Floor activities supported by a typical ERP include:

- Order Tracking
- Maintaining Inventories
- Product Planning
- Supplier Interactions
- Parts Purchasing
- Customer Base

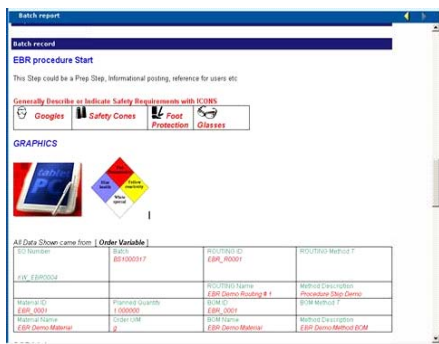
## 2.2 Product Life Cycle Management (PLM)

Both resource planning and manufacture within the manufacturing domain depends upon current product configuration information maintained by the engineering centers. In large enterprises, PLM is a software solution utilized primarily by the organizations to manage the entire product life cycle.



The content of PLM data includes eBOM (Engineering Bill of Material), technical data, as well as models from the OEM. From a factory floor perspective, PLM is an engineering system which maintains OEM data, Drawings, Models, Technical Data, etc. There are many other features offered by PLM systems but for purposes of this paper, it is the PLMs’ ability to manage engineering data.

## 2.3 Manufacturing Execution System (MES)



MES is the factory floor execution system. It is the MES layer in which the operators directly interact to step through the execution of the work flow to produce or repair product. The list of work to be performed, specific instructions to execute the work, data points to be collected, quality inspections of the work, sign off’s indicating the work is complete, are all performed within the MES layer.

Manufacturing Execution Systems (MES) provide the workflow, visibility and event notification required to ensure that manufacturing is meeting enterprise information demands. Simultaneously MES reduces non value-add activities, increases data accuracy and provides the ERP system with the real-time data needed to maximize enterprise

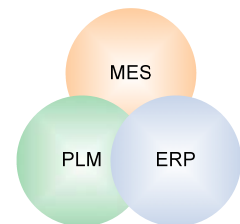
processing, planning and scheduling activities.

A MES system acts as a messenger between the factory floor, corporate engineering (PLM), and corporate planners / schedulers (ERP). When the operator requires data from the ERP or PLM: initiates the request within MES; the MES system then connects to the appropriate system to retrieve and display the information. In the ideal world, the fact that three different enterprise level systems exists is transparent to the shop floor.

## 2.4 Integrating Enterprise Systems

With this basic understanding of the enterprise systems, the next step is to determine the level of integration required with each system. In summary of above:

- ERP plans, schedules, and issues work to the factory floor.
- PLM provides the product standards and engineering data for development of the factory floor work processes.
- MES defines the factory floor work processes and executes the work.



Every enterprise uses these three systems, differing the emphasis placed on each system based on product mix; high volume, low variation place emphasis on ERP and MES, while small volume high variation emphasis on PLM over ERP and MES. The goal of every enterprise is to determine their organizational model and have the software support this model.

Whereas, it is possible to find ERP software which can perform PLM and MES functions, PLM software which does ERP and MES, and MES software which can do ERP and PLM; a single software package has yet to be

developed which can do all three functions well. An enterprise with the diverse products and types of manufacturing, the enterprise needs to utilize the individual strengths of the three independent systems and not try to make one or two systems cover the third.

### 3 Manufacturing Operations (Defining MES project)

Manufacturing operations encompass numerous plant level activities involving equipment (definition, usage, schedule, and maintenance), materials (identification, properties, location, and status), personnel (qualifications, availability, and schedule) and the interaction between these and the numerous systems that contains pieces of information. Defining the boundary of the MES system, and the interactions with user and other systems requires a reference framework. Bringing organization to this mix of functions, and to maximize the use of commercial MES software products, industry standards facilitate the MES design philosophy.

#### 3.1 Industry Standards – ANSI/ISA S95

There are numerous data models available for guidance on developing ‘computer aided manufacturing’ to more recent supply chain optimization plans. The primary reference used in developing this architecture is the five part standard by the International Society of Automation (ISA), entitled ISA S95 Enterprise – Control System Integration. This document uses the models and terminology defined within this standard. The ISA S95 standard defines a hierarchical systems model, which contains multiple levels of systems used within an enterprise. Level 4, Business Planning and Logistics, is the top level. Level 3, Manufacturing Operations and Control is the domain of commercial MES products.

As currently envisioned, ANSI/ISA-95 consists of the following parts under the general title Enterprise-Control System Integration:

- Part 1: Models and terminology
- Part 2: Objects and attributes for Enterprise-Control System Integration
- Part 3: Models of manufacturing operations management
- Part 4: Object models and attributes of manufacturing operations management
- Part 5: Business to manufacturing transactions

The defined manufacturing domain includes only production, quality and inventory functions; the maintenance function is wholly contained within a dedicated manufacturing maintenance software package, which remains an isolated operation within the model. The following are the components of part 3 of the S95 model identifying MES functions:

- **Production Operations Management** - includes the activities of production control and the subset of the production scheduling, product inventory control, and material & energy control activities as operating Level 3 functions.
- **Quality Operations Management** - includes the activities of quality assurance that operate as Level 3 functions.
- **Inventory Operations Management** - includes the activities of management of inventory and material that operate as Level 3 functions.

For a more detailed explanation of the above models or the ISA S95 standards refer to **ANSI/ISA-95.00.03-2005 - Enterprise-Control System Integration Part 3: Activity Models of Manufacturing Approved 6 June 2005**

#### 3.2 Model for MES

A standards driven model achieves the goal of having MES fills the shop floor need utilizing readily available commercial off the shelf (COTS) product configured to the manufacturing domain specific needs. Ensuring the MES project provides the shop floor management with current production visibility and is fully integrated with other enterprise systems.

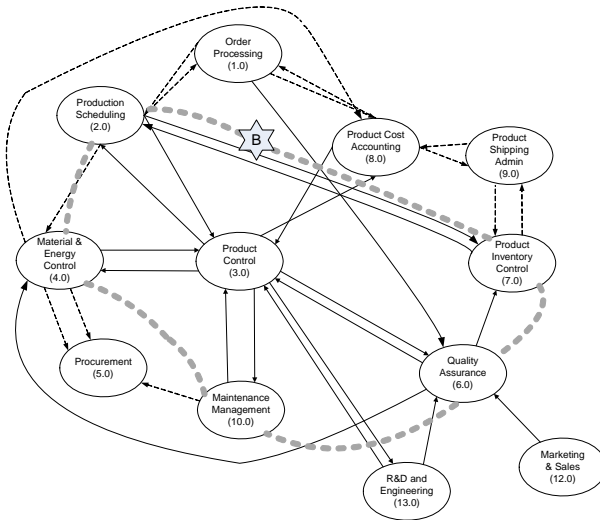
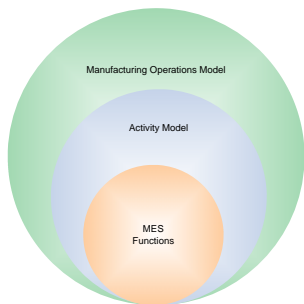


Figure 3-1 Manufacturing Operations Functions

Existing within the manufacturing domain are numerous Automated Information Systems (AIS) developed and licensed at both the enterprise and individual installation level to provide applications in areas such as planning, execution, management and analysis support production. These applications maintain the financial, asset management legal and regulatory information requirements pertinent to production. The initial usage of the ISA S95 model determines the current implementation of each manufacturing operation; making determination regarding the logical location of the function along the Manufacturing Operation Functions model. The activity identifies functions, which are solely level 4 or level 3 implementations along with functions that are currently satisfied without additional work.

With established boundaries agreed conduct shop floor requirements gathering sessions across the manufacturing domain to establish a baseline MES functional requirements matrix. The primary source for the structure and organization of these requirements in logical grouping follows established guidelines such as **ANSI/ISA-95.00.03-2005 - Enterprise-Control System Integration Part 3: Activity Models of Manufacturing** for defining the functional boundaries. Within each area, specific details emerge regarding current conditions and the desired operating conditions. Mapped against the standard guidelines an overall map emerges that determines the boundary of MES within each functional area. A production example is highlighted indicating deviations from the normalized functional boundary.

This model provides the framework for establishing the project boundary, the MES implementation boundary and the benchmark for evaluation of commercial software vendor products. The outcome is user driven functional requirements, conformed by industry guidelines that are specific and unambiguous.



With the overall functional needs identified the project proceeds:

- Complete a Business Case Analysis
- Prepare MES product requirements.
- Complete a market survey to establish the availability of suitable MES products.
- Develop an Acquisition strategy

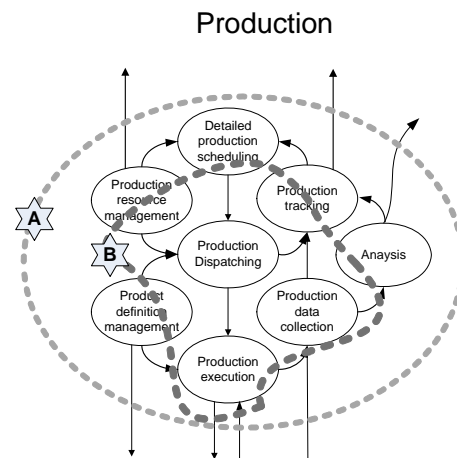


Figure 3-2 S95 Activity Model Example

## 4 Shop Floor Operational View

Throughout the manufacturing domain is a desire for enterprise software that will increase productivity through control and integration of engineering, management and the shop floor.

The enterprise model (right) shows the interaction between the engineering function that has responsibility for Product Lifecycle Management (PLM), the enterprise management function Enterprise Resource Planning (ERP), and the shop floor operations management function Manufacturing Execution (MES).

Each system maintains a significant database of role specific data, and procedures, with overlaps and intersections with the data in other systems. Providing for coordination and sharing of this overlap data, while preserving master data ownership is a critical component when integrating these systems.

By introducing, MES, actionable, real-time information into the traditionally paper-based shop floor environment creates the “paperless shop floor”. A “paperless shop floor” enables critical information to flow throughout the organization—including the forgotten areas of manufacturing.

Having information about events as they occur allows planners to identify and prevent potential problems or bottlenecks. Event management provides real-time notification of events and exceptions— often before, they occur—allowing proactive steps to manage the events. Ultimately, MES contributes to the enterprise’s ability to keep costs in check, production and shipments on schedule.

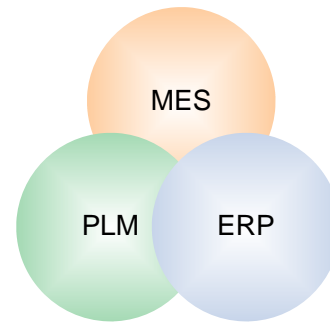
A seamless collection of data from the shop floor activities stored in a relational database enables compiling the product genealogy and produces manufacturing history report. The captured data allows for historic inquiries and work order to work order comparisons that is invaluable for quality investigations and process improvements.

Leveraging XML technology and industry standards like OAGIS or ISA-S95 in a Service Oriented Architecture (SOA) further reduces the cost to integrate MES to other applications. The SOA approach to application integration reduces the cost to less than half of the current typical point to point costs, and delivers in a fraction of the time.

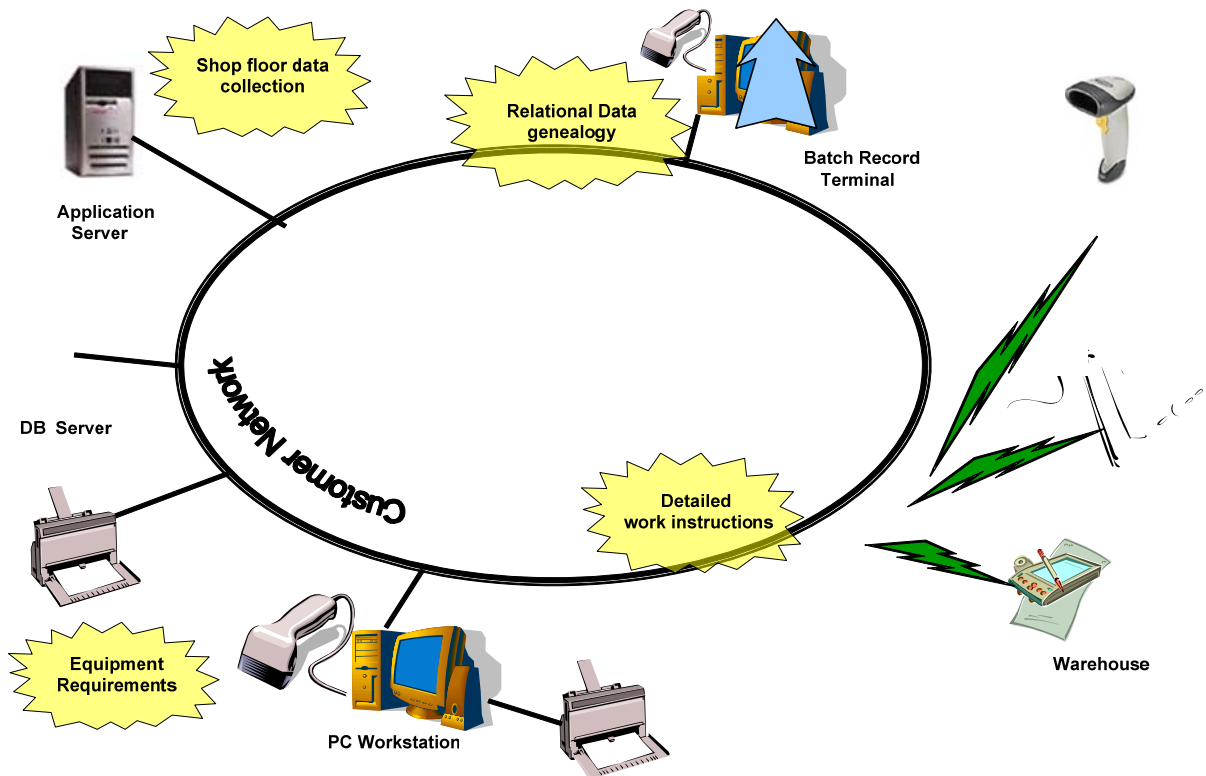
With a MES comes the capability to capture and report labor against work orders, track each employee’s certifications and skill sets, request material, close work orders, and create non-routine work — quite literally, MES saves significant steps associated with verification of work preformed, non-value add paper handling and rework in many work processes.

Implementing MES provides proactive visibility into disruptions in the manufacturing process communicating work instructions in real time using a variety of technologies, including radio frequency devices and Web-based touch screens. This approach replaces error-prone, paper-based communication with a streamlined, “paperless shop floor” environment. This real-time control empowers shop floor operations to streamline production and ensure production according to stringent customer demands.

The MES electronic work instructions provide the context for real time data collection embed data collection points to ensure completion of all work including quality inspection. The MES ensures that technicians and mechanics always have the direction required to build products and overhaul equipment, and that data is captured to meet the enterprise data needs.



**Figure 4-1 High Level Operational Concept**



**Figure 4-2 MES Shop Floor**

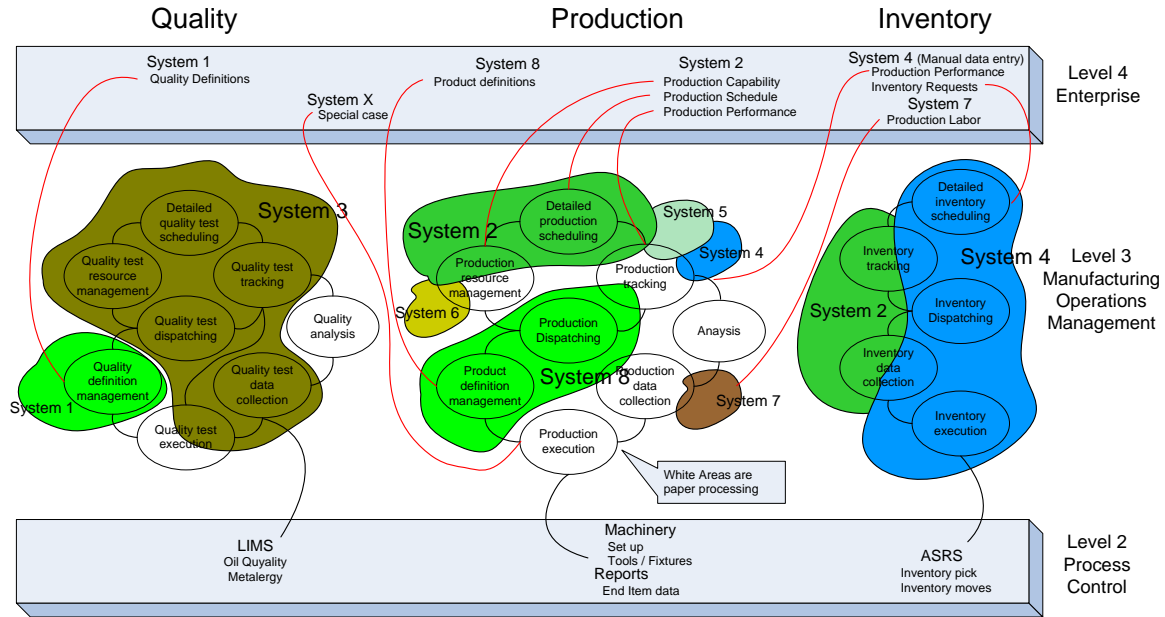
By streamlining data acquisition and execution for technicians and mechanics on the factory floor, the MES also creates efficient processes that consist only of value-added activities. The result is a leaner environment. From mobile data terminals for material handlers to strategically placed operator stations on the factory floor, directing operators to perform tasks and collect information in real time using intuitive and graphical user interfaces.

In addition, scripted work instructions and reference data presentation significantly reduce new employee training time is, while event-driven notification and workflow via electronic communication provides cross training opportunities for the existing workforce.

## 4.1 Shop Floor “As Is” Operational Activity Model

Implementation baseline for MES begins with a thorough analysis of the existing processes within the manufacturing domain.

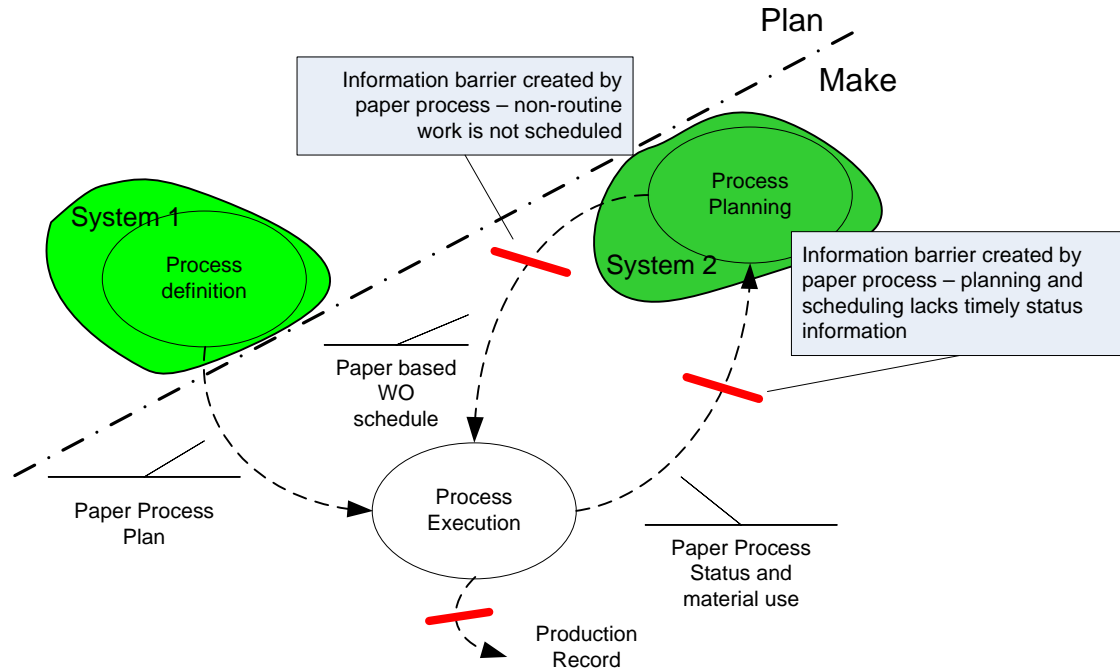
Within the manufacturing domain, through the years, deployment of commercial and home grown applications meet specific shop floor needs in an effort to increase productivity through better use of available information. Many rely totally on paper processes for control of the shop floor, most are unique installations. Below (Figure 4.3) is an example that depicts the systems deployed at a typical location.



**Figure 4-3 Typical Shop Floor Systems**

Deployment of Automated Information Systems (AIS), each system satisfies an immediate manufacturing need result, in a manufacturing domain of single function silo applications with overlapping data stores and manual paper processes filling the data sharing gaps. Add to the complexity, as new technologies became available to users outside of the IT group, home grown solutions proliferated that produced data stores which fell off the IT radar. Attempts to solve the data sharing shortcomings result in point to point data connections. The point to point connections while providing some relief proved expensive to implement and difficult to maintain as the number of connections grew or aging systems had to be replaced.

The As Is model (Figure 4.4) shows the production process dependence on paper to fill information gaps within manufacturing.



**Figure 4-4 Process Execution Detail As Is**

The information flow disconnect is especially problematic in the make activities where real time information is critical and Shop floor data for status of work in progress, exceptions and non-routine work to be scheduled is not received by the planning and scheduling group until a crisis arises. The production record becomes multitudes of scanned pages from varied sources.

Paper is easy to implement, easy to use, and requires little training. Yet paper is the great inhibitor of efficiency in process operations management. Paper documents travel through the course of manufacturing, ending in archive cabinets. The value of the information is lost to the enterprise as is visibility of the shop floor activities. Paper also defines the inputs and outputs of functional departments creating "walls" that hinder teamwork.

## 4.2 Shop Floor “To Be” Operational Activity Model

Starting with the end goal and work back is applicable to MES project. Identify the desired future state model before launching into the MES design.

MES, provides a modular solution designed to collect and provide visibility into shop floor data. It will provide the information needed by shop floor supervisors, plant managers, and upper management to measure current performance, analyze operations and identify opportunities for improvement.

The MES subsumes fragmented shop floor applications unifying the functions performed by legacy systems eliminating the need for cross application integration. Functional integration between MES platform enterprise systems provides bidirectional synchronization of master data and real time exchange of operational data

The To Be Shop Floor System diagram (Figure 4.5) shows the dramatic change from the As Is. The MES provides a unified shop floor environment that replaces the disconnected shop floor applications. Data now is in electronic format and readily transacted to the enterprise systems.

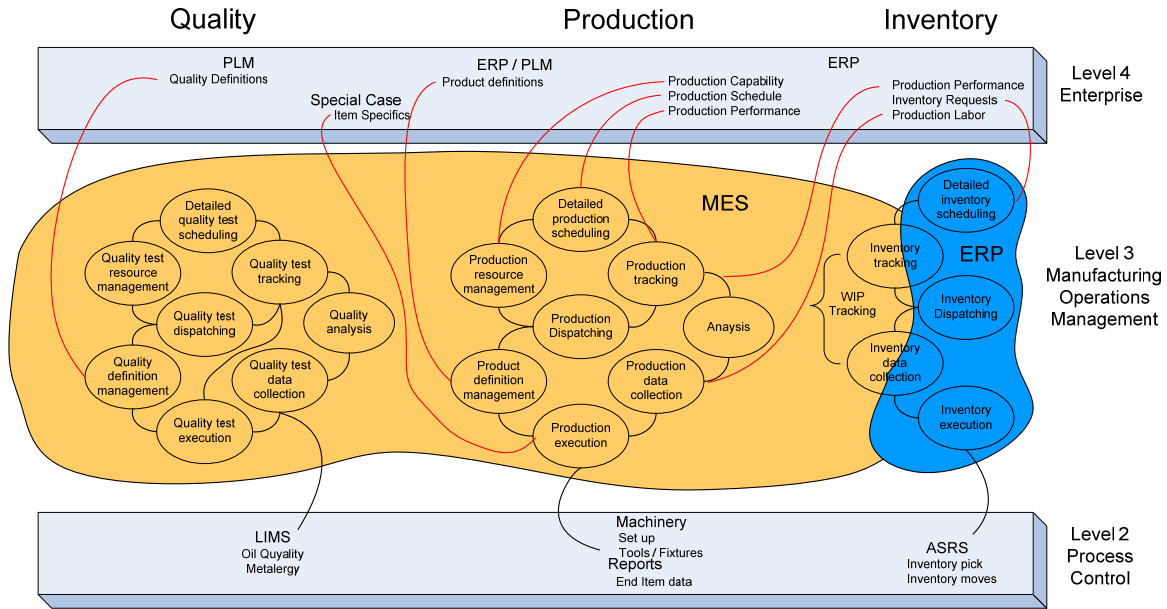


Figure 4-5 To Be Shop Floor Systems

Elimination of the information flow disconnects in the make activities where real time information is critical. Process execution is entirely electronic (Figure 8) with real time shop floor data for status of work in progress, exceptions and non-routine work to be scheduled updates to the planning and scheduling group. The production record package is now electronic.

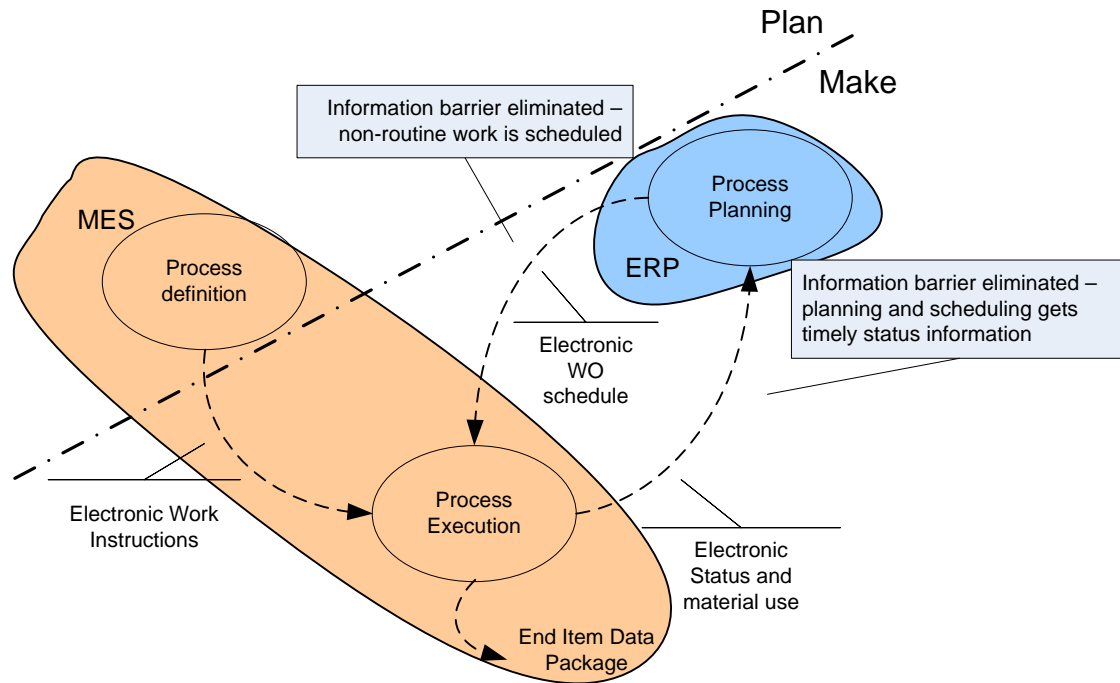


Figure 4-6 Process Execution Detail To Be

The MES stores all history for each item (See Figure 4.7), including work instructions, critical tolerance data, buyoff signatures, discrepancies, rework, operator certifications and the complete product genealogy. The data collected during process execution is stored in a relational database from which it is possible to create a multitude of reports and transactions that will satisfy the demands of the internal enterprise as well as external systems designated as the system of record.

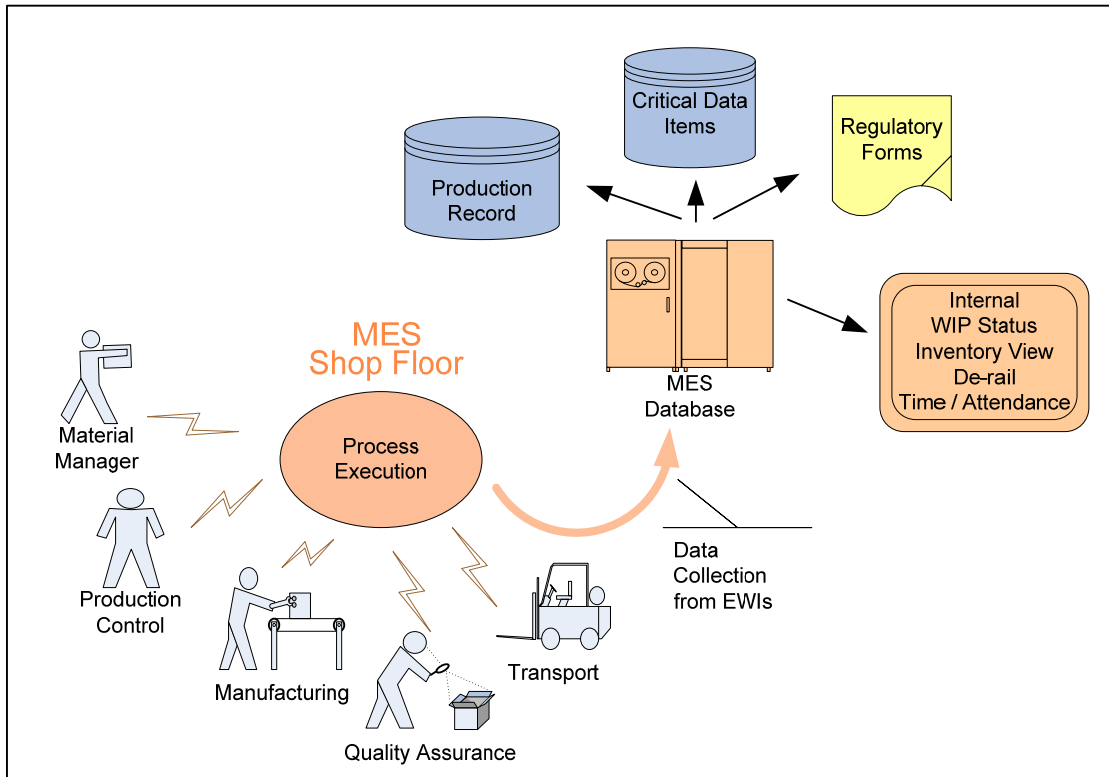


Figure 4-7 Data Collection and Reporting

### 4.3 Shop Floor Systems – Organizational View

No model is complete without consideration for people and their role changes with the transition from the current (AS IS) to the future (TO BE) operational paradigms. A depiction of environmental role change shown in Figure 4.8, concerns employees normally engaged in shop floor activities (level 3) that will migrate from legacy system operation to MES users. MES subsumes the legacy systems now used by these employees with the production activity now within the boundary of MES.

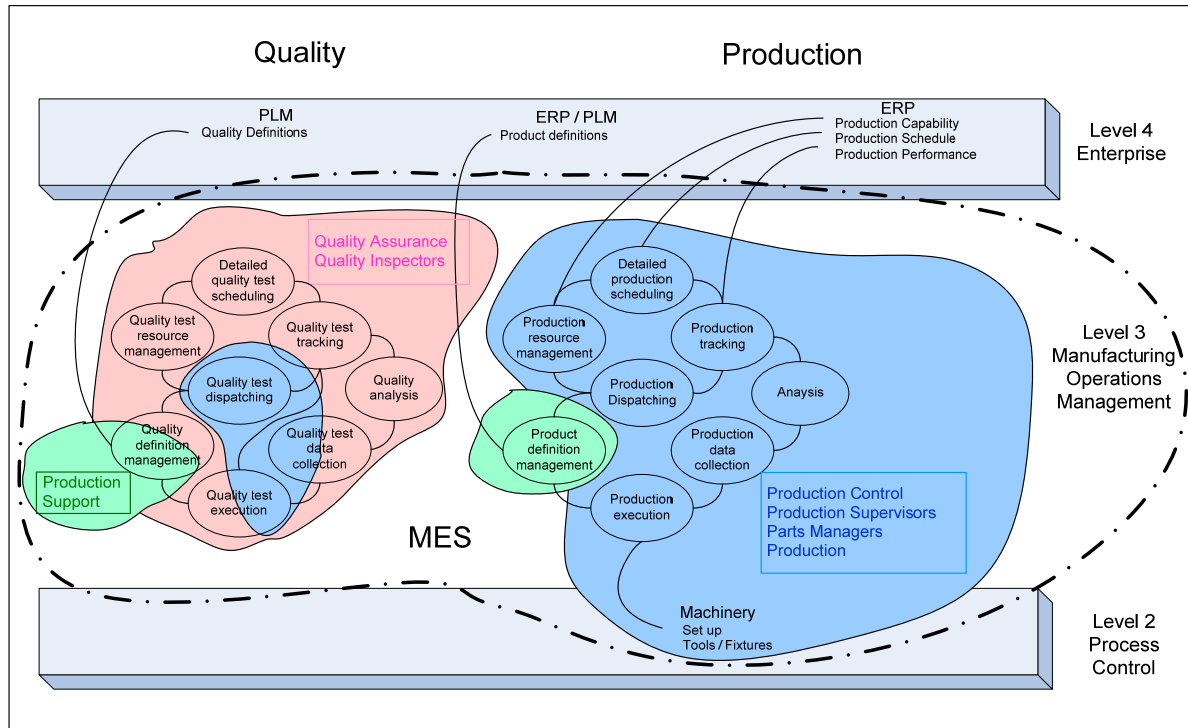


Figure 4-8 Organization View

## 5 Shop Floor Data Exchange

Data exchange and integration between systems must support the desired shop floor business processes in the future state (To be model) and not become a technical exercise. Data existence is not sufficient reason for its inclusion in the interface designs. Data management practices must align with the Data management. There are essentially two categories of data exchanged; master data is relatively static data that defines the product attributes and the plant resources used in the manufacturing activities, and operational data that is context sensitive dynamic data generated during normal plant activities consisting of measurements and actions taken during the work process.

With a bi-directional interface, the data may originate in either system updating the other system through an interface. Data origin does not necessarily predict the system of record. Many factors influence data origination such as the convenience of data availability varying with the type of production program.

The ERP handles job costing, financials, purchasing, inventory control, production planning, and scheduling. The MES creates the detailed work instructions for each work center within the work flow route. Both systems utilize the same Master data for different purposes and must be in harmony.

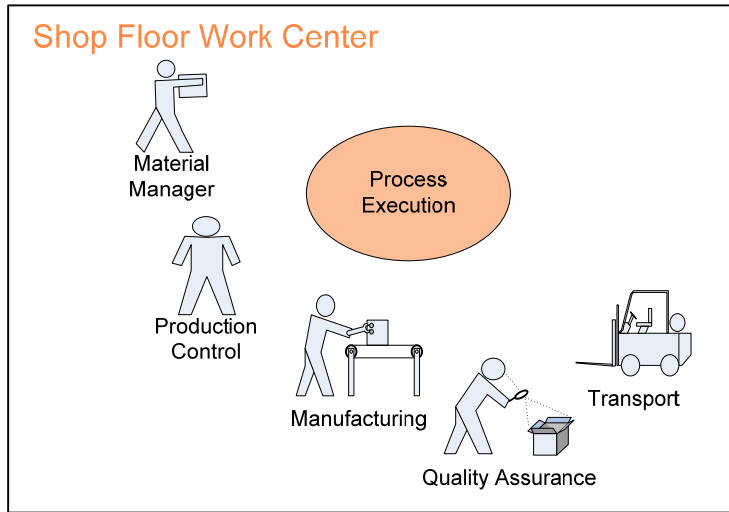


Figure 5-2 Shop Floor Work Center

provided by organizations such as Open Applications Group Integration Specification (OAGIS) and World Batch Form (WBF) to simplify the effort in data exchange between MES and ERP.

The PLM structure handles the process definition encompassing the intellectual property of the manufacturing domain and it is imperative that the “To Be” model leverage this intellectual property in current shop floor systems by mapping the contents to the MES.

Efficient interface between applications relies on the use of standards and tools

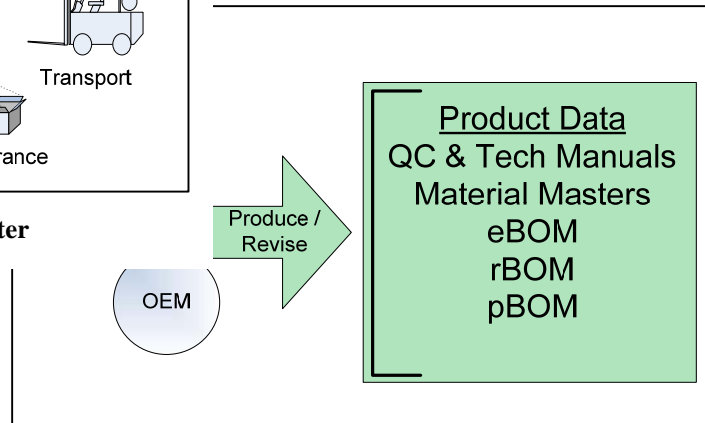


Figure 5-1 Product Data

## 5.1 Product Data

The product definition activity is outside of the MES scope; however, the shop floor activities and production planning activities require access to master data such as engineering drawings, parts lists, material specifications, and a plan for manufacture and overhaul.

PLM systems maintain product data as directed by Research, Development, and Engineering Centers. The data is available to the manufacturing domain as documents, CAD drawings and electronic BOMs, and procedures.

## 5.2 Plant Resources

Product data is just one part of the master data required for manufacture, repair and maintenance within the manufacturing domain installations. The locally defined and held organization and availability of plant resources is also master data.

The shop floor is composed of **Work Centers** (WC) organized to provide specific manufacturing capabilities. Within each work center are the skilled people, machinery and tools required to fulfill the specialized tasks assigned to the work center.

Routes organize the work flow through the work centers where parts pass from one specialized work center to another until the manufacturing or overhaul process is complete.

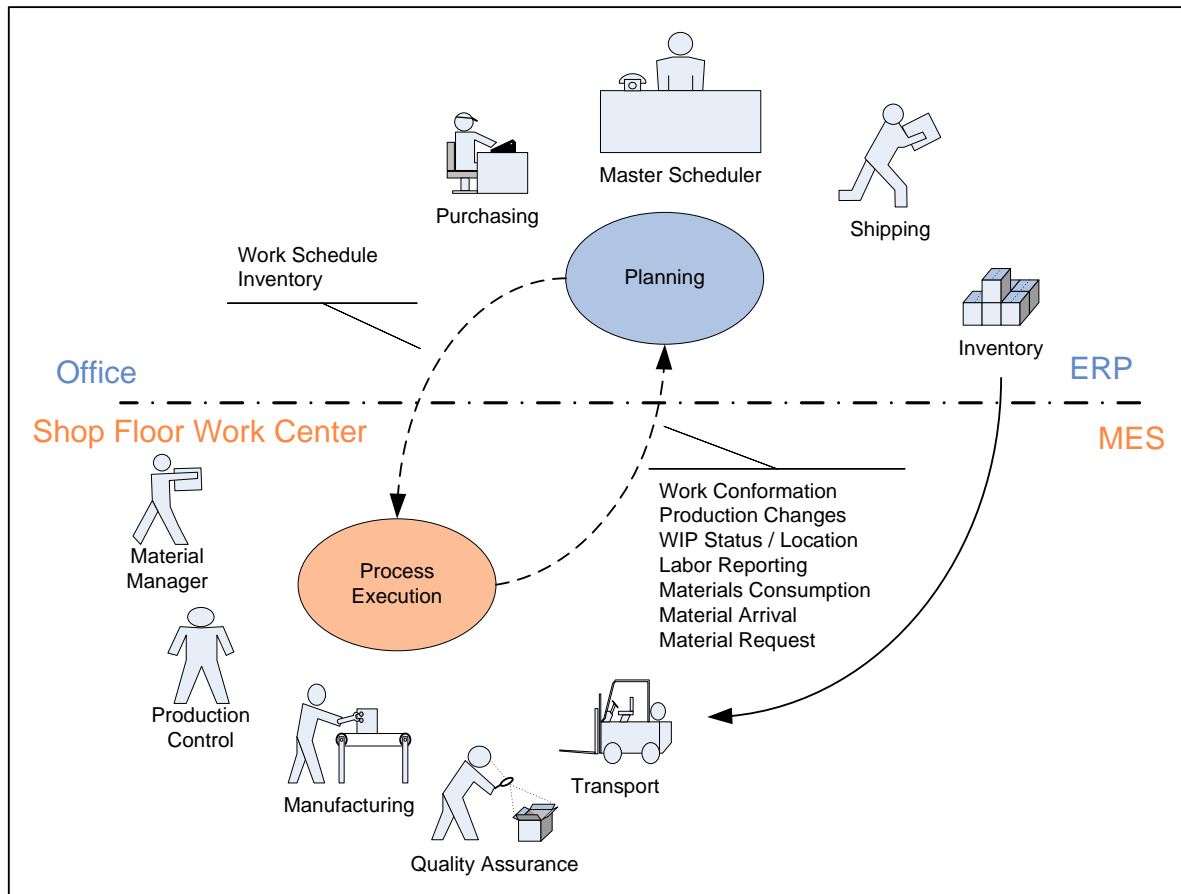
The work center and route concept is central to job costing, scheduling and the work flow through the plant.

### 5.3 Operational Data Exchange

The planning and scheduling of production activities is the role of the ERP system. Gathering the shop floor information efficiently and communicating that information is the role of the MES. Orchestrating the complex activities within the manufacturing demands sophisticated coordination with real time data from the shop floor

Production is composed of manageable work segments designed for a work center (WC), equipped with people, machinery and tools organized to carry out specific tasks.

The ERP system releases work to MES to inform a work center of a work segment. MES relates the work to shop orders that contain detailed work instructions describing how to carry out the assigned work. Figure 5.3 shows the people that use each system and the exchange of information between systems at a typical work center.



**Figure 5-3 Work Center Production Execution Activities**

A series of real time exchanges of information transactions between the MES and ERP coordinates the shop activity.

The MES matches shop orders to the released work and dispatches them for execution. Shop floor personnel interact with the MES through data terminals to access work instructions and confirm work accomplished. Through the interaction with shop floor personnel the MES issues transactions to the ERP updating progress, reporting labor hours, reporting materials consumed, reporting any changes to the production sequence, and requesting additional materials.

The MES transactions are event driven, automatic, and transparent to shop floor personnel.

## 5.4 Systems Interface Model

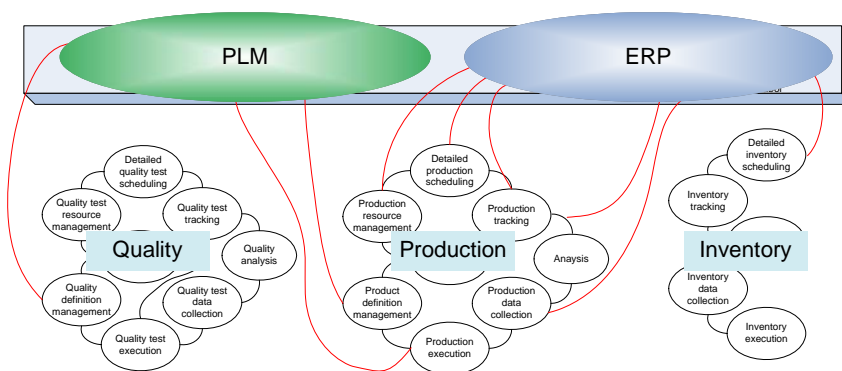
Communication between the MES applications and other enterprise applications is through an Enterprise Service Bus (ESB). An ESB acts essentially as a data traffic director in the system to transfer data from one application to another. When data is put on the service bus, the ESB decides which other application(s) is looking for this data and forwards it on.

The ESB addresses “How” of data transfer between systems. The next step in the process is to determine “What” data to transfer between each application and “What” the format of this data needs to be.

Industry standards identify the type of data needed, i.e. material consumption, material production, labor, and equipment usage. The specific transactions, the data content, and the volume / frequency of data transfers are to be determined during the MES project development.

Specifically the ANSI/ISA-95 consists of the following parts under the general title Enterprise-Control System Integration:

- Part 1: Models and terminology
- Part 2: Objects and attributes for Enterprise-Control System Integration
- Part 3: Models of manufacturing operations management
- Part 4: Object models and attributes of manufacturing operations management
- Part 5: Business to manufacturing transactions



**Figure 5-4 Required Data Flows**

Utilizing the various functional models developed the data necessary to support each area is clearly identified. With the information type and frequency required by each user role to support individual work processes and supporting information such as compliance with safety, regulations, and other imposed policies. Each data flow has characteristics regarding frequency, direction and expected system response that form patterns.

The **ANSI/ISA–S95.00.01–2000 Enterprise-Control System Integration - Part 1: Models and Terminology** and **ANSI/ISA–95.00.02–2001 Enterprise-Control System Integration Part 2: Object Model Attributes** define common definitions and attributes for each data flow identified through the functional modeling and facilitation of the technical implementation of the data integration through the use of published data schemas.

## 6 Summary

Within the complex world of discrete manufacturing, with original equipment production along with the unpredictable activities in repair and maintenance application of industry standards streamline the design effort and harmonize the discussions between the stakeholders. Starting with real world situation, multiple facilities and operations that evolved over many years into a current jumble of systems, formal and informal procedures and practices combine to build models to design a new operating environment.