On-line Real-time Data Sources

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About the Author

Michael McClellan has over 30 years of experience serving and managing manufacturing enterprises. He has held a number of positions in general management, marketing and engineering, including President and CEO for a multi-division equipment systems supplier. In 1984 he and a group of associates founded Integrated Production Systems, a company that pioneered the use of computer systems to manage and track production events on the plant floor. His first book, *Applying Manufacturing Execution Systems*, defines manufacturing execution systems and explains the reasoning and history behind them. He is a frequent speaker at companies and manufacturing conferences, has presented a number of papers on plant information systems, and holds one patent. He has recently completed a new book, *Collaborative Manufacturing: Using Real-time Information to Support the Supply Chain*.

He currently lives in Washington state and is President of Collaboration Synergies Inc., an advisory company providing consulting services in the area of collaborative manufacturing system development and implementation, plant floor information systems and manufacturing execution systems.
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On-line real-time information from production and logistics activities is used to confirm and track processes in compliance with collaborative agreements. This process is two-way communication. As demand information is provided to upstream partners, their commitment confirmation process comes back to the host. Information is generated and used by the processes to view two separate aspects of the collaborative process. The first is the general issuance of information to define the product, batch size, due date, batch recipe, shipment routing, warehouse location, bill-of-material information, etc. This is the information production management requires to get their job done. Along the way other information is generated as a result of production including quality assurance information, actual quantities produced versus planned amounts, laboratory batch test information, storage location, shipment information, lot numbers, etc. The second use of this data is to confirm that production processes and quantities have occurred in accordance with the expectations.

A fundamental business condition is revised through successful collaboration that changes the level of performance expectation from probably to absolutely. Historically companies have protected non-performance by their vendors through building safety factors into ordering and inventory calculations. The major impetus behind collaboration is the removal of these safety buffers, replacing them with time buffers or, better yet, event confirmation information. Much the same as a flight plan for aircraft is used to outline and later confirm the expected path of a flight as the flight progresses, so too is the production plan tracked to ensure actual events are occurring according to the plan. The real-time confirmation data is the trust-building element that confirms adherence to the plan.

It seems safe to accept the premise that real-time events are the internal cogs that run the business, and maintaining management control of those events has always been based on having sound and reliable information. As manufacturing facilities get larger and more geographically dispersed, reliable information needs are even more imperative. They must be more rigorous due to greater investment and expanded distances. When thinking in terms of the supply chain network, the need for reliable, accurate, and timely information is at its greatest. Adversarial management suggests everyone is on their own to find and make best use of whatever they can get. Collaborative management is precisely the opposite, based on the idea that the supply chain team is most effective when all partners have the latest applicable information that can support their value-adding contribution. This chapter will provide a roadmap of where real-time production related information is located and also tell you how to gain access to it.

To add perspective I outline the evolution of early concepts of production control techniques to computer integrated manufacturing (CIM), to the integrated packages and systems of today. A description of many of the system components within the production process will be identified and briefly described, including such sources as manufacturing execution systems (MES), Supervisory Control and Data Acquisition (SCADA), programmable logic controllers (PLC), human machine interface (HMI), data historian systems, and others. This overview of plant floor systems includes methods ranging from manual paper and pencil production control, manual data entry, programmable logic controllers used to control a process or machine, and computerized integrated manufacturing execution systems. The emphasis is to illustrate the availability of ALL real-time data within process control systems, equipment control systems, stand-alone or integrated production management systems, and manual data entry systems. The focus is on the real-time and pro-active aspects of plant floor management tools and the value of these systems as internal information generators.
What is real-time data? What is on-line data? These are ambiguous terms to some people and the use of them in this text could be even more so. These definitions were taken from the book, Design of On-line Computer Systems, by Edward Yourdan.

On-line: An on-line system is one which accepts input directly from the area where it is created. It is also a system that can return the output directly to the area where it is required.

Mr. Yourdan goes on to suggest other characteristics to support this definition.

- Remote access: The definition above implies that the input is delivered to the computer from a remote area.
- Files and data: The system works with a data-base that is on-line.
- A people orientation: Systems characterized as on-line are usually interacting with people or other immediate data input or requesting sources.

Some examples of on-line systems include the following:

- Airline reservation systems
- E-business systems such as Amazon.com
- Credit card approval and acceptance systems
- Medical information systems
- Manufacturing execution systems

Real-time systems as defined by James Martin in Design of Real-Time Computer Systems is as follows:

A real-time computer system may be defined as one that controls an environment by receiving data, processing them, and returning the results sufficiently quickly to affect the environment at that time.

Examples of real-time systems include:

- Machine or process control systems
- Missile guidance systems
- Airplane auto-pilot systems
Our definition of a collaborative manufacturing system is one made up of many integrated or linked computer system components and data sources that can receive and process data at random or programmed times. It is possible that a collaborative system would be required to process information at a real-time rate similar to a missile guidance system or a process control system, but would most often use these systems as data input sources. Collaborative manufacturing systems are on-line systems consisting of on-line and real-time components. Collaborative manufacturing systems are proactive, anticipatory, action and people oriented computerized management tools.

The need of the collaborative manufacturing system and production management to have access to the supply chain network information pool may be obvious, but presenting real integrated information, not just a lot of data, is a daunting task. The good news is that a vast amount of production information exists in every facility. The bad news is the information may be difficult to access, retrieve, and collate. This difficulty, more than any other factor, makes collaborative data exchange an evolutionary process rather than a giant leap forward.

The term plant-floor production infrastructure is used to describe and include all computer systems, electrical control systems, programmable logic controllers, and manual management tools used to manage and accomplish production. This collage has rarely been developed from an integrated vision, but instead is made up of individual methods, equipment, and software components implemented over the past thirty or so years of applying various stages of control equipment and data management technology. In many instances plant floor applications were developed or purchased, installed, and owned by a specific department or designed around and for a specific process. Examples include the installation of a quality assurance data system implemented by and for the quality assurance department, or a PLC control system to control an injection-molding machine. This has brought us to the same “islands of automation” or just, as bad, “silos of information” as was discussed in earlier chapters. The optimum production system has all of the data components within the production system linked. Unfortunately, that is not the case since many of the disparate legacy systems—legacy systems being any control system, data collecting, handling, collating, or information management system installed before today—may be based on obsolete technology, lack adequate documentation, and have limited functions.
For many years the three level pyramid was used to define and describe the hierarchical structure that illustrates how plant systems were applied. It is unlikely there ever was a time when this structure suggested some level of importance or emphasis. More likely it fits because of the response time for each level of the infrastructure.

In this paper the execution/productions system and the device control layer will be examined, both to suggest the availability of systems to assist in production and to illustrate the vast amount of data that exists within plant floor systems. As the capability of these applications have evolved, the hierarchy is being redefined to suggest there are only two types of data systems employed in the production management infrastructure: on-line transaction processing (OLTP) and decision support systems (DSS). The difference in this definition from the pyramid view is that nearly ALL device execution layer systems and control systems are included in the OLTP system definition. This definition suggests a broad view of the production management infrastructure complex to include all computerized or manual systems, methods, and tools used to accomplish production.

This outline of systems more closely matches how companies actually operate.

1. In most companies, large and small, planning systems ranging from a simple single plant MRP system to the most modern enterprise resource planning application are usually implemented and managed by the information technology group. The view of these systems is a broad corporate perspective concerned with corporate-wide macro issues such as financial planning, aggregate inventory data, human resource management, and customer relationship management. These systems are generally used to provide decision support information or respond to events on an exception basis. The emphasis is on enterprise system standards and data roll-up functions such as accounting and inventory. Consistent data presentation is a major thrust.
2. Plant floor applications are just the opposite, operating in an on-line transactional processing world of optimizing and accomplishing current operational requirements within minutes, seconds or milliseconds. The applications have been implemented on a system-by-system basis in response to requirements defined by department managers, manufacturing engineers or equipment vendors. These systems have highly varied applications that include turning on a machine tool to make a specific threaded hole from a stored part program, measuring and adjusting an oven temperature on a minute-by-minute basis, changing a machine load schedule because received material did not meet quality requirements, or turning on valves to deliver liquid material in response to the product recipe. Most of these real-time events do not require human intervention but are executed with software logic. Real-time plant systems usually have a very granular functionality focus not found in planning level applications.

The vendor/technology community is structured along these lines. Although planning system suppliers are moving closer to the plant floor and plant floor systems vendors are moving closer to planning system functions, the assumption of real-time event management by planning system vendors, or of plant system vendors assuming the corporate view is unlikely in the near future. The technology being applied is more than a little different. The issues viewed and the user needs are vastly different. Planning system implementations are frequently fully integrated to work with their own internal modules from a common database. On the other hand, the plant system infrastructure is made up of a wide assortment of legacy systems and manual methods that could not be discarded or quickly changed without extreme cost and disruption of production.

There are good business and system design reasons to support this dual approach.
1. This more clearly divides the systems into planning (decision support) and execution (transaction processing).
2. This allows a corporate-wide information systems strategy separate from the requirements of the localized production facility systems.
3. This provides a better environment for system improvement and upgrade at both corporate and local facility because of consistency and user perspective. Aside from the perfectly appropriate requirement of corporate IT standards, who really understands the requirements of an application better than the actual user?

In addition to the cultural and development history there have been technical and practical reasons that have brought plant systems to where we are. The most significant roadblock to a seamless system has been the cost and complexity of the integration of various data sources and/or software packages.

The systems used in the execution and control levels are usually referred to as on-line and real-time. In actual fact they may not always meet the definition of real-time but are nearly always on-line transaction processing as opposed to decision support systems that are usually batch operation oriented.

The development of managerial tools for the plant floor has also gone through continuous evolution. Early methods, from 1920 to 1970, were mostly manual record keeping. The tools used to manage production were very people-oriented, primarily based on written planning and control systems including forecasting, operations planning, inventory planning and control, operations scheduling, dispatching, and progress control. Computer systems had very limited use for the manufacturing facility but certain planning applications such as master scheduling and material requirements planning were implemented late in this period. This is the era when assembly line concepts were begun bringing with them new management opportunities such as assembly-line balancing, multiple plant inventory management, and scheduling of various products produced by a single facility. Later, new computer like devices called programmable logic controllers gained widespread use with their ability to maintain numerical control information for machine tools and processes. The general thinking behind production was based on mas-
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ter schedule forecasts, large lot sizes for economy of scale, building to a forecast warehouse inventory, and full production facility utilization. New ideas included Phil Crosby’s phrase “quality is free,” work cells, and work-in-process storage at the point of use. The great system equalizer was building up inventory throughout the process to allow for production contingencies.

Computer Integrated Manufacturing (CIM) arrived in the mid to late seventies and was a term in common use until the late eighties. CIM was an ambitious idea with many definitions and variations. It also was an idea of great promise that frequently fell short of expectations. Manufacturing facilities were large and complex. Management had extended and maximized the tools of the previous years and new ideas were being sought. At this time improved PLCs and smaller, easier to use mini-computers were in widespread use. The pejorative term “islands of automation” was frequently heard describing the many improved production devices with no ability to tie them together.

The focus in the plant was cost reduction with a strong bent toward technology-oriented solutions. Computer aided design (CAD) systems were bringing significant improvements in the ability to produce and manage product information including numerical control programs, improved bill-of material definitions, and material resource planning tools to determine purchasing and inventory management directions. One of the major ideas supporting CIM was the effort to define and develop very large monolithic software systems that could manage many more points of manufacturing process integration. Unfortunately this was the greatest weakness of the CIM concept. Large monolithic systems were very difficult to develop and debug. The other criticism or this era was the term “hard automation.” Because of the complexity of these systems, change was a very onerous task. Plant managers were generally and understandably skeptical of these projects for many reasons including possible computer failure and general lack of flexibility.

During the eighties plant floor production systems began to get serious attention from every level of management. The inexpensive personal computer became ubiquitous on the plant floor. Each department within the production infrastructure was able to develop and implement systems that fit their individual needs. The systems were relatively inexpensive and were applicable to specific functions within specific industries. A good example is a quality control measurement system developed to meet the requirements of a particular industry or even specific company. Screens, information input, and report formats could be developed to fit the requirements of a single person. Systems could be large custom developed implementations or “out of the box” applications where the user could simply load diskettes on their personal computer and get beneficial use within hours. Plant floor systems tracked and managed orders through production, following product routings or process plant data where recipe information could be automatically downloaded to device control systems. Stand-alone industrial computer installations were everywhere and programmable logic controllers came close to computer functionality with the ability to store and manipulate data. Manufacturing execution systems made up of modules to track and manage work-in-process plant production orders were developed and applied primarily in discrete item manufacturing. Process manufacturing systems became more extensive as integrated multifunction controllers. The concept of the linked supply chain arrived providing opportunities to improve management of inventory and logistics across the supply chain network. The application of the Internet and the idea of E-business grew explosively with a profound effect on manufacturing requiring immediate movement toward make-to-order production. Product design and manufacturing had become global with component manufacturing done in various countries and shipped to the point of final assembly. Outsourced manufacturing services turned into a major business strategy especially within the electronic equipment industries. Using the Internet and improved product data management tools, design information can now be easily transmitted and reviewed anywhere in the world among supply chain partners. Collaboration regarding design for manufacturability is accomplished simultaneously around the globe with multi-tiered suppliers.
Many pundits are describing this new idea of collaborative manufacturing as one of the most significant milestones in business and manufacturing management—if done effectively. Collaborative manufacturing is based on the central theme of sharing information both within and external to the supply chain network. It was originally begun in the electronics industry where manufacturing services are frequently supplied by offsite contractors. Normal business activity includes the need to provide timely direction and manufacturing information such as design drawings, engineering change order tracking, and supplier material delivery. It is also necessary to know and measure vendor performance. As this trend has grown it has become important that supply chain partners work closely together to meet the common objective of providing the most effective customer service. This requires systems that can easily couple or decouple between different enterprise and plant floor systems.

Collaborative manufacturing requires taking a whole new look at information availability and use. Plants are not just groups of people, machines and control panels. Each plant has a unique production system infrastructure made up of many linked subsystems each having its own set of conditions and rules. The result is to cause events to occur or to respond to events that have occurred on some managed basis. When a controller on a machine tool completes the read of a line of code, certain actions occur. When the production planning department completes its work, there is a plan of what to make and where. When we remove the roof from the plant and look from above we can see many seemingly disparate events taking place. In reality each event was begun based on a previous event, generally creating data during the process. Much of this data is available and necessary for subsequent events and other production system components. Some may be provided to the enterprise planning system either electronically or through manual input. Some of the data is used only internally within the facility or enterprise and some can be available for use by other legitimate interested partners.

For definition purposes the production management infrastructure includes all manual or computerized off-line or on-line transaction processing systems used to accomplish production. The following list is provided to indicate the broad range of system applications, devices, and data used to manage the production management infrastructure. The list is not a complete representation but is a good reference point. Many plants have similarly named applications with very different details.

**Manufacturing Execution Systems (MES)**

Manufacturing execution system describes a set of integrated functions within a packaged software system or it can also describe the accumulated functionality within the production management infrastructure. The term means many different things within different user companies and even within the companies that produce and implement these systems. They were originally designed to replace the difficult to manage paperwork system used to track work orders through production. The basic idea for manufacturing execution systems grew in large part from the concepts behind computer integrated manufacturing. The major improvement since the CIM era is the replacement of huge custom designed software systems with smaller reusable components. The original idea was to have modular systems that could be reapplied in various industries, but the factors of individual user company operation and continuous systems evolution have produced a wide variety of implemented functionality. Although these systems are in widespread use throughout many industries, they are not always described similarly nor are the functions identical. A manufacturing execution system in use at an electronics facility is similar only in concept to one used in the food processing industry. The ideas behind the systems may be similar but industries have their own set of differences and terminology that make them distinctive.
MESA International, the manufacturing enterprise systems vendor trade association, offers a list of functionalities that generally describe various areas of production management that might be included in a full manufacturing execution system implementation. They are as follows:

**Resource Allocation and Status**—Manages resources including machines, tools, labor skills, materials, and other equipment, and other entities such as documents that must be available for work to start at an operation.

**Operations/Detail Scheduling**—Provides sequencing based on priorities, attributes, characteristics, and/or recipes associated with specific production units at an operation.

**Dispatching Production Units**—Manages the flow of production units in the form of jobs, orders, batches, lots, and work orders.

**Document Control**—Controls records/forms that must be maintained with the production unit, including work instructions, recipes, drawings, standard operating procedures, part programs, batch records, engineering change notices, shift-to-shift communications; and edits as planned and as built information.

**Data Collection/Acquisition**—Provides a link to obtain the intra-operational production and parametric data.

**Labor Management**—Provides the status of personnel in an up-to-the-minute time frame.

**Quality Management**—Provides real time analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. Some systems can provide yield information and track rework requirements by serialized unit number.

**Process Management**—Monitors production and either automatically corrects or provides decision support to operators for correcting and improving in-process activities.

**Maintenance Management**—Tracks and directs the activities to maintain the equipment and tools, and to ensure their availability.

**Product Tracking and Genealogy**—Provides visibility of where work is at all times and of its disposition. Status information may include who is working on it; component material by supplier, lot, and serial number; current production conditions; and any alarms, rework, or other exceptions related to the product.

**Performance Analysis**—Provides up-to-the-minute reporting of actual manufacturing operations results along with comparisons to previous and expected business result.

Very few systems have been implemented as broad as the possibilities presented by MESA. Another approach to define these systems can be found in the book Applying Manufacturing Execution Systems published in 1997 by Michael McClellan, author of this book you’re reading. Although my list includes the same system functions as indicated by MESA International, it is based on specific software divisions within a system and is described using outlines from currently available software system products. They are divided into Core Functions that are directly associated with managing the production process and Support Functions that are peripheral to the value-adding production process.

**Core Functions**

**Planning System Interface**—This describes the connection with the planning system (ERP) and defines how and what information is exchanged.

**Order Management**—This function includes the accumulation and management of Work Orders in the system.

**Work Station Management**—This function is responsible for implementing the Work Order production plan, Work Station scheduling, and the logical configuration of each Work Station.

**Inventory Tracking and Management**—The inventory tracking function develops, stores and maintains the details of each lot or unit of inventory.

**Material Movement Management**—The movement of material, manual or automated, is managed and scheduled through this function.
Data Collection—This segment acts as the clearinghouse and translator for all data that is needed and/or generated on the plant floor.

Exception Management—This function provides the ability to respond to unanticipated events that affect the production plan.

Support Functions

These identified functions are only a representation of possibilities and are not an exhaustive list of what is available or what will be on the market in the future. The long-range idea behind most system design is to provide the ability to plug and play whatever support systems may exist in the facility currently or any new product that might be acquired in the future.

Maintenance Management—Maintenance management, sometimes called asset management systems are used to manage production-equipment-maintenance-related issues including predictive maintenance, work order and labor scheduling, procurement and storage of the repair parts inventory, and equipment record maintenance.

Time & Attendance—There are many software system products that produce time and attendance information that can be used on a wide scale. Systems usually include clock-in/clock-out information along with labor data collection and employee skills data.

Statistical Process Control—Statistical process control (SPC) is a quality control method that focuses on continuous monitoring of a process rather than the inspection of finished products. The intent is to achieve control of the process and eliminate defective production.

Quality Assurance—Quality assurance packages may or may not be tied together with SPC and/or ISO 9000 systems. Either as separate packages or combined they are frequent components of the production process.

Process Data/Performance Analysis—Process data collection and management can be a standard package developed for specific applications such as time/cost variance information or manufacturing process record.

Document/Product Data Management—This can be a very large component of the manufacturing system used to create product drawing and process information. A modern view of this area is Product Lifecycle Management, a system used to manage and record product data from design to disposal.

Genealogy/Product Traceability—Genealogy and traceability are similar functions designed to provide a complete history of a serialized item or a group of items. In addition to the in-house production data, most systems can include similar information on each bill-of-material item going into the finished product.
Supplier Management—This is usually a custom designed tool to communicate with suppliers. Data may include genealogy information, schedule information, quality assurance data, and logistics information.

Warehouse Management—Warehouse management systems are primarily used to monitor and manage outbound inventory activities with some systems capable of inbound, raw, or purchased material management. Product location information and order fulfillment instructions are two of many on-line functions. Sometimes called supply chain execution systems they can include logistics and other traffic management data.

In some companies elaborate efforts have been made to include these or more functions into an integrated system. The important thing to remember is that systems identified as manufacturing execution systems can have one or more of these components depending on the industry and the user company. Some companies have all of these systems and more but do not use the term MES or manufacturing execution system. Some companies might call a single module such as a statistical process control (SPC) package an MES system. Other companies have an assortment of packages collectively referred to as a manufacturing execution system but there is no tie between them. The MES descriptor does not have a broadly accepted meaning especially among batch and process industries, but these plant floor systems and their components do generate and maintain many data items that could be useful to supply chain partners.

The most interesting event in manufacturing execution systems design is the advent of systems made of modules that can be added or deleted as necessary using a single database, similar to modern planning systems. One company has brought this new dimension to plant floor systems. Propak Data GmbH of Germany (www.propak-data.com) has developed a broad reaching system that includes many or all of the plant management requirements using a set of modules tied together with a standard single database. The system is available as a complete integrated package or available by modules as required by the application. It is also capable of integrating with existing systems. The full system includes these integrated modules:

Product Data Management

Master Data Management covers the creation, control, release, and version management of process data such as production procedures, procedural descriptions, recipes, bills-of-material, routings, operations, and process related master data. The data is archived in the system database and made available for inquiries, evaluations, and conforming documentation.

Production Data and Batch Archive includes report components for the technical and operational evaluation of the production process. The system operates on the basis of a System Control and Data Acquisition (SCADA) system and uses a production monitoring board to integrate the data of all the facilities relevant to the production process. The module incorporates a range of fundamental applications from individual production reports and failure or stoppage protocols, to quantity balances and variance comparisons. The module can collect, collate and transfer operational information to other systems such as ERP.

Scheduling Systems

The On-line Monitoring System provides a representation of current production, giving production control the ability to see current schedule failures, predictable violations of dates, planned idle times as well as shortages of materials and resources.

Rough-cut Capacity Planning is provided to plan orders for a certain period of time such as a quarter or a month.

Personnel Placement and Training provides for administration of staff training plans, planning and execution of required training units, and documentation required by regulatory authorities. The module ensures compliance through qualification checks with every log-in to the system.
**Process Related Systems**

The **Warehouse Management System** provides complete material control and traceability. The module includes full inventory management including main and buffer warehouses for raw materials, auxiliary materials, work in process, and finished goods inventory. The batch and packaging units related inventory management is based on storage sites, storage locations, and on load carriers. Material is made available based on order related bill-of-material and business rules such as allocation, conditional release and processing up to a defined step.

**Paperless Dispensing** is used along with a step-by-step process for weighing materials in which the user is consistently guided. Information regarding order progress and the completion of weighing orders is directly transmitted back to the planning board. During weighing, labels are provided to identify material content at any time during processing.

**Surveillance and Control** of production is done through a line monitoring board that integrates all data from engineering, production and quality assurance that is relevant for the manufacturing, filling, and packaging processes. This module is the central information point for the production process. Using continuously collected data from work centers and quality assurance, this module provides complete documentation of the production processes. Information received with the scheduled orders including master data, calibration parameters and production procedures is downloaded to the relevant point of use such as scales and production equipment.

**Electronic Batch Recording** generates the order specific production and packaging instructions with all order related parameters for the respective processing facilities. The operator receives detailed processing instructions together with graphics or other visual data, planned defaults and order specific parameters. The batch record controls the user authorization and collects the actual data occurring in the course of the process. Through interfaces the processing data can be acquired from machines and facilities as well.

**Shop Floor Navigator** is an information system that visualizes production processes with updates every minute. Reports, graphics, and statistics can be generated providing effective operation reports. The information is also available via LAN and WWW for outside locations. Current order data such as actual quantity counters, efficiency, production, failure and stoppage times as well as order master data and planned quantities, and item numbers can be displayed on the production monitoring board. Zoom functions provide access to detail information.

**Monitoring** provides continuous recording, monitoring, and documentation of environmental conditions.

If recorded values exceed the value limits an alarm is triggered.

**Service Modules**

The **Web Gateway** module forms the link between remote locations and the plant modules. Using the abilities of the Internet, data of the processes currently running on the WEB gateway can be compiled and made available as an HTML document. The data can be retrieved and edited by authorized individuals from anywhere within the company or external partners worldwide. The on-line presentation is done with standard browsers and is constantly updated.

**Maintenance and Repair** comprises the management of machine specific data and machine maintenance with a running hour meter and a technical log. The module supports the spare part logistics, repair planning, and the scheduling of maintenance activities to fit in the operational process.

**Quality Management** supports the structure, maintenance, processing and evaluating of analyses, check plans, checklists, and sampling. The system-based documentation and evaluation of the quality data allows the detection of weak points, which can then be removed through both technical and organizational measures. Failures are not only discovered, but also avoided before they occur.
The system is designed with a uniform look and feel for all modules and is available with a multilingual and fully graphical user interface. This uniformity in the design will provide easier operator training across a broad range of functions within the plant and thus improve user acceptance.

The outline of this system has been presented to show how a fully integrated system can directly support the information needed for manufacturing collaboration. The information is first presented across the integrated business processes within the system itself, providing a full view of what is planned and occurring in production. Secondly this consolidated information is available for internal use or to outside sources on an authorized basis through a browser access.

Many plants have much of this functionality included in their production infrastructure even though the system components may not be fully or even partially integrated. Most MES systems currently available have not developed to the extent envisioned a few years ago. There are many reasons for this, not the least of which is the problem of integrating legacy components into a full plant-wide system. These systems do, however, have an extensive amount of real-time data that can be used across the supply chain. In many companies the information is still department owned and it is not unusual to find substantially different versions of these applications within a plant or company. The underlying thought here is that much data is available in these systems but a thorough review is required to identify where and what data exists and how it can be extracted.
The following list is representative of the systems in use in various industries with a brief outline of the usual function.

**Bill-of-Material Information and Delivery**—The Bill-of-Material (BOM) lists the items (by part number) of material included in an identified component. This information usually is provided from the Product Data Management system or it may be maintained in a product data library located in the ERP system. Information relating to the BOM can include as-built information that shows details of items included in the assembly.

**Boxing System**—This is used to identify contents within a specific handling or shipping container. It can include parts within boxes within boxes within boxes etc.

**Data Historian System**—This system organizes and maintains large amounts of data used to monitor and control process systems. These systems can collect data items from thousands of measuring points at a rate many times per second for each item. The data is often used in the control system to respond to variations in the production environment.

**Device Control System**—These systems are usually designed specifically to manage the functions of a device. One example is a PLC programmed to run an injection molding machine. DCSs can be extensive with the ability to collect data regarding such information as production quantities, downtime records, operator identification, and production orders processed.

**Electronic Signature Requirement System**—In regulated industries such as pharmaceutical manufacturing and medical device production, it is frequently necessary to have a formal confirmation and recording of an event that follows FDA rules. Recent industry changes have allowed certification to be validated by data processing devices.

**Engineering Change Order Tracking (ECO)**—The tracking and management of product engineering change orders can be part of other systems such as a product data management system, or a separate package designed for a specific application. Basic functions are to manage work-in-process to identify and process change order requirements.

**Genealogy Reporting**—Either as a stand-alone system or as an integral part of a manufacturing execution system, the purpose is to gather specific part source and process information for items on the bill-of-material. The information can be developed for a serialized part or lot and may include quality assurance test results, serial numbers of each component along with their genealogy data, and any other information that would help identify the source and breadth of a product defect.

**Graphical User Interface (GUI)**—The user interface is what operators use to view system information and to input data from their work-station. This is an excellent point to gather information regarding events as they occur and is far better than writing information that is later manually entered into the system.

**Human Machine Interface (HMI)**—See graphical user interface.

**In-process Material Tracking System**—In-process inventory management usually includes tracking work orders and material through the process of being released from the raw material inventory to begin manufacturing to being finished goods inventory stage. Systems that track work through production steps can provide substantial data such as where the production order is in its process, deviations from process or production plans, data accumulated at work stations, schedule status, quality assurance and statistical process information, cost and yield variance from standard, current priority or work sequence position, component material status, and current physical location.

**Interactive Process Instruction Information Delivered via Video or Audio**—Operator information is commonly delivered or made available to workstations. Frequently the production steps require interaction with instructions, recording events and supporting data or variances. Some systems are rigid, providing specific steps preventing the operator from taking alternative actions while other systems provide a range of choices for the operator.
Inventory Receiving—The receiving dock is a natural measuring point to begin or confirm source information, compare incoming material to the purchase order, begin or confirm product testing, recognize material shortage conditions, assign use priorities, collect source production data, and refresh inventory counts.

ISO 9000—Frequently part of quality assurance or certification, ISO systems usually focus on identifying and tracking the process steps necessary to be in compliance with predetermined standards.

Kanban Systems—Kanban describes the Toyota developed inventory pull methods where an inventory buffer is managed by signaling for or allowing replenishment only when material has been removed. The idea is to identify a replenishment need and then pull material to fill the need as opposed to building to an anticipated inventory requirement that frequently results in more inventory than is needed.

Labor Reporting—Labor reporting systems are used to identify the actual labor used on a shop order. With start and end times identified to the system for each work center or operation, the production times are accumulated throughout the in-process steps. From this data, variances from labor standards can be computed. In some systems this information can identify the last operation and look forward to project the workload at downstream workstations.

Labor Skills Management—Some industries require that specific and sometimes licensed skills be applied at some workstations. The identification of the employee begins a search of the database to ensure that an individual's current credentials match the requirements of the operation on this work order.

Laboratory Information Management Systems (LIMS)—In those industries where product testing and analysis is done during the manufacturing process, LIMS are used to identify the analysis requirements, collect results, and include the information as a part of the product or lot history. One example is testing a sample in a steel production facility and including test data as a part of the lot history.

Logistics Management—Logistics systems are used to manage material movement. Data can include shipper and shipping unit, dates, current location, estimated time of arrival, shipment cost, shipper performance, and inventory information.

Machine Controllers—Devices and systems used to control equipment are excellent sources of real-time information. Most systems installed within the past ten years are sophisticated enough to receive programs and other process information from manuals or automated external sources, store and manipulate data regarding the process performed, request and accept manual information from the human/machine interface, display variances, and maintain history.

Maintenance and Asset Management Systems—These systems are used to manage and record a range of maintenance information including parts inventory, maintenance work order information, asset maintenance requirements and history, and predictive maintenance schedules.

Manufacturing Execution Systems (MES)—See earlier in this chapter.

Material (inbound/offsite) Inventory Systems—Inventory management systems can include tracking and location information, warehouse data, logistics planning and execution, and process data.

Material Handling Systems—In-process material handling and storage systems such as automatic storage and retrieval equipment, power and free storage systems, and assembly line conveyors are usually managed with sophisticated computers or programmable controllers maintaining large amounts of data on location, progress, and status.

Offsite Production Monitoring—There are many systems operating in upstream supplier facilities that can provide on-line information to track progress.

PC Based Control—Much like programmable logic controllers, some programs are developed to run on a personal computer. The major difference lies in the increased ability of the computer over the PLC and the methods of programming.

Process Automation—Process automation systems can range from a simple small PLC or personal computer to a very extensive system used to manage a refinery. These systems can provide a wide range of data but may require extensive data management to get specific answers. It is important to remember a lot of data does not necessarily equal real information.
On-line Real-time Data Sources

Process Data Historian—These are large data-base systems used to poll and maintain data from points of information generation within the process. Information sources can include sensor based real-time data, non-sensor based data such as time, events, state transition changes, messages and logs, instructions, etc.

Processing Recipe Management and Reporting—Recipes are the equivalent to the bill-of-material and routing information found in discrete manufacturing. The management of a recipe from its source to implementation can include adjusting process steps and inventory quantities. ISA standards S88 and S95 establish some standards for recipe structure and management.

Product Data Collection—This is sometimes viewed as a simple data collection system or as a major component of the product lifecycle management process.

Product Lifecycle Management (PLM)—Sometimes a part of the enterprise resource planning system or frequently a separate component, Product Lifecycle Management is used to collect information throughout a product’s life from design to disposal. The system can begin at design with the original CAD document and record events through manufacturing, engineering change orders, quality assurance, genealogy, customer data, etc. PLM is used extensively in collaborative design applications.

Product Test Systems—Product test information may or may not be a part of the quality assurance system. In some industries where each individual item produced must be tested, a record of the results is or should be maintained. Actual test system criteria may reside here along with rules on how to respond to non-conformance test results.

Production Control—Production control includes methods to track work-on-process to ensure conformance with the production plan. This information may be included in most manufacturing execution systems or may be a manual hand written system using expediters to confirm performance on the plant floor. Systems may include work dispatch, order or batch priority assignment, workstation or process scheduling, and performance variance monitoring.

Programmable Logic Controllers (PLCs)—Programmable logic controllers are used to control equipment and processes. Nearing the capability of computers they can be an excellent source of real-time information.

Quality Assurance Systems and Rework Loops—Quality assurance systems are used to measure conformance to specified parameters for items being produced. These systems can have substantial information regarding yield or deviation from standard. Rework loops are used to track non-conforming items through rework processes.

Receiving Inspection—Whether a part of the ERP system or a stand-alone package, this process is used to monitor and manage inbound material through the receiving process. This can be designed to follow process routing information and production steps as outlined for the identified part number or vendor.

Regulatory Compliance Management—Certain industries, particularly food and life science industries, must meet regulatory requirements and gather data during the manufacturing process to confirm compliance. This can include manual confirmation and data entry, or confirmation by computerized systems with automatic data accumulation.

S88 or S95 Standards Automation Systems—These are system design standards developed and published through ISA to provide common automation and process control terminology and structure. A review of these standards will provide an excellent view of data availability methods. The systems installed in your plant may or may not follow these standards.

Safety and Environmental Systems—There can be severe issues associated with life threatening or regulatory compliance that can affect the entire supply chain.

Supervisory Control and Data Acquisition (SCADA)—This is a term applied in some industries to identify data collection and process control systems. These systems are usually application or company specific.

Schedule Exception Reporting—Scheduling exceptions are simply an easier way to monitor and react to events that will affect the manufacturing plan. Newer systems can expand this idea to include supply chain supplier partners and logistics enabling early warnings and presumably responses to missed events.
Scheduling Systems—Scheduling can be an extensive part of the planning system or it can be a simple set of sequencing rules for a workstation. Manual or automatic, enterprise or local level, these systems are the basis for how resources are assigned. As a source of real-time data it is necessary to close the loop between the scheduling system and the plant floor, to confirm the schedule has been met or to identify what alternative actions must occur as a result of the schedule not being met. Some systems can be as simple as applying a priority number to each order, following one of many sequencing ideas, or responding to an Advanced Planning and Scheduling (APS) system. Data availability and access to real-time information are necessary to any scheduling system.

Scrap Reporting—Either as a tare allowance or actual measurement of scrap this information reflects inventory or usage and can be used to identify production problems.

Sensors—Although many data items are collected through sensors located in the manufacturing process, information collected from an individual sensor is usually considered to be raw data and has little use by itself. Once the data item has been collected and applied within some broader application or production context, it has greater value and use in higher level systems.

Statistical Process Control (SPC)—Statistical process control is a quality control method that focuses on continuous monitoring of a process rather than the inspection of a finished product, with the intent to achieve control of the process and eliminate defective products.

Time and Attendance—Time and attendance information is a legal requirement in nearly every industry with the obvious primary purpose of providing payroll information. This can also be a good source of genealogy information (who worked on what and when) and is critical to on-line resource scheduling.

Transportation Management Systems—Logistics, traffic, and freight management for inbound and outbound material movement is obviously critical information, particularly in companies using just-in-time (JIT) techniques to support manufacturing. Information possibilities include product, supplier, physical source location, current location, estimated time to arrival, and cost.

Variance Calculation Systems—Most manufacturing facilities have established standards for their processes, and measuring actual variances against planned is very common. This has long been an accounting need but some data has other uses. Variance from standard could be important to quality assurance and may affect yield consideration in production planning.

Warehouse Management Systems—Frequently considered a part of supply chain execution or fulfillment systems, they are a significant step in storing and selecting finished products. Although generally used for outbound order fulfillment, finished-goods inventory management, and stock rotation management, some systems are used to manage and control inbound raw material. Either application can provide data such as physical location, date information, schedule, stock-outs, and quantities. Some systems can be global with the ability to define the best shipment point and some can provide processing rules and management for final point-of-shipment configuration.

A lot of space and time has been dedicated to explaining what is meant by the term real-time data. The primary use of real-time information is to control processes and to view and manage events occurring within the manufacturing facility such as equipment failure, production progress, yield production rework information, work-in-process status, production bottleneck loading, current and planned capacity usage, inbound/outbound inventory issues, etc.

Real-time information generated in the plant management infrastructure and the device control systems is extensive. The tools used to manage production are similarly applied in nearly every industry but there is unlikely to be much consistency in the details. It would be great if each system were made up of integrated modules but that is only now becoming available. The various standards programs being developed by industries will also provide progress. To gain an understanding of information availability it will be necessary to develop a map of information sources within the designated facilities. Determining where the information is and how to access it can be a part of the design and implementation plan.
There are some obvious rules behind designing a system that can provide precise and easily understood information rather than a lot of data.

1. The knowledge must be presented in a form that people can easily understand and work with.
2. The user should be able to view the rules and methods used to manipulate and present the data.
3. All results used for discussions between people need to be available to all participants.
4. Consistent and accurate information computed from actual events as they occur must be provided.

Information from the many sources within the production processes is the primary tool to ensure the events that have been planned are occurring. As John Kay of Daimler-Chrysler said, “If it is necessary to physically count inventory, the delivery date will already have been missed.” It must be possible to rely on information technology to provide information that tracks and confirms events as they occur. There is no substitute for the facts and the ability to confirm that most precious commodity in collaboration—trust.

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