The Eleventh International Conference on Machine Design and Production
13 - 15 October 2004, Antalya, Turkey

MANUFACTURING EXECUTION SYSTEMS FOR ADVANCED SHOP FLOOR CONTROL

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ABSTRACT

This paper overviews Manufacturing Execution Systems (MES) – the state of the art and the current trends. The analysis will be done in a bottom-up way, i.e. it will start with the current practice and demands. There are hundreds of MES systems in the market. They can be classified as standalone applications, components of Enterprise Resources Planning (ERP) systems and subsystems of Supervisory Control and Data Acquisition (SCADA).

MESA International's MES functional model identifies eleven functional areas. To improve the shop floor performance, three of them are of great importance: the process management, the operations and batches (re)scheduling and the quality management aspects. While today's manufacturing focuses on work in progress (WIP) and product attributes, a tighter integration with ERP systems and Supply Chain Management (SCM) systems is essential. MES systems provide more visibility and flexibility than traditional paper based systems. A MES system should present data concerning the current processes being under execution in the workshop, as well as on the status of the manufacturing orders in progress and on the manufacturing resources available.

In the second part of the paper a proposal is presented on the applicable IT solutions suitable for implementing a new WEB-based Manufacturing Execution System. The development framework and environment will also be discussed.

Keywords: Manufacturing Execution Systems (MES), Enterprise Resources Planning (ERP), Discrete Manufacturing, Application Servers.

INTRODUCTION AND MOTIVATION

Production Planning and Scheduling (PPS) and Manufacturing Execution Systems (MES) are the most important computerized applications of functional subsystems for modern digital enterprise.

Today's modern and competitive enterprise can not live without computer aided application systems integrated by means of computer networks which contributes the successful and efficient way of their running business.

In the field of make to order (MTO) type production, integrated planning and execution systems are more and more important because of the increasing requirements of cost, quality and time performances. MTO production is characterized by individual product (machine) usually designed from a set of firm level components, and small batch production on universal CNC machines at job-shop environment. In this environment there are a lot of uncertainties in incoming orders and availability of machines, equipment or human resources. For this reason, up-to-date engineering data and fast real time information management are most important tools to achieve production goals.

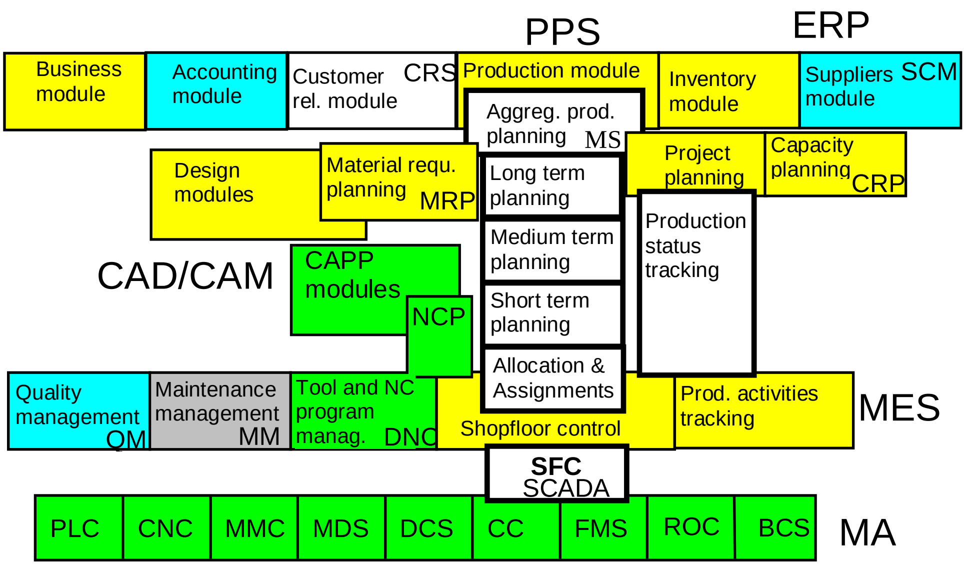

Figure 1. Hierarchy of production information system components

In the recent years a characteristic structure of production / management information systems has been developed in the manufacturing and engineering industries. The structure has multi-layered functionalities. In general, four horizontal layers can be identified, each of them having numerous components. They are as follows:

1. Enterprise Resources Planning, ERP;
2. Computer Aided Engineering, CAE, CAD/CAM;

3. Manufacturing Execution Systems, MES;
4. Manufacturing Automation Systems, MA.

Production Planning and Scheduling Systems form a representative “bridge” between management/decision making functions and the systems that control and execute production processes. Admittedly, PPS systems have multi-level hierarchical internal structure (Hierarchical Production Planning, HPP). This approach is coupled with the advantage of multi-layered modeling. Even using the latest IT infrastructure, multi-layered modeling is the only feasible method for large scheduling problems to accomplish an effective solving method and to assign a perspicuous Human Machine Interface (HMI).

One of the most elaborated and utilized functions of a MES system is the tracking of the status of production. This includes the monitoring and updating the status of jobs and the real time acquisition and archiving of manufacturing resources. (Machine/Production Data Acquisition, MDA/PDA).

The project-oriented production of enterprises producing individual machines requires high level project planning and scheduling application, which plans and schedules the time flow of project activities with special regards to the finite production resource capacities and hard time (due date) constraints.

In the course of this year a three years long research project has been successfully completed. One of the main goals of this project was to evaluate a new project oriented production planning and scheduling software application for factories, manufacturing individual machines to customer orders. The traditional production planning in the MTO field is based on MRP and lead time estimation, because of the separated handling of capacity planning and activities scheduling in aggregate planning level. A new, project based production planning and scheduling system (PROTERV [6]) has been developed using aggregate production activities, which represent a group of operations (e.g. mechanical design, electrical design, part manufacturing, assembly, etc). All activities may require certain number of resources and the execution of a planned amount of specific work.

Generally, these enterprises have high level decision meetings to compare the pre-planned and the actual progress of project activity works. In case of deviation between the plans and the actual status a decision should be make in order to eliminate the lateness. If there is a need for rescheduling due to the high level decision of project planning then the actual state of the project activities being in process is an important input for the scheduler.

Recently there are only few MES applications on the market which would support the project level following and aggregation of the status of production activities belonging to certain project.

The goal of the research work described in this paper is to develop an intelligent aggregated trace route component of production activities which is able to support the systems of project approach in project planning, scheduling and rescheduling.

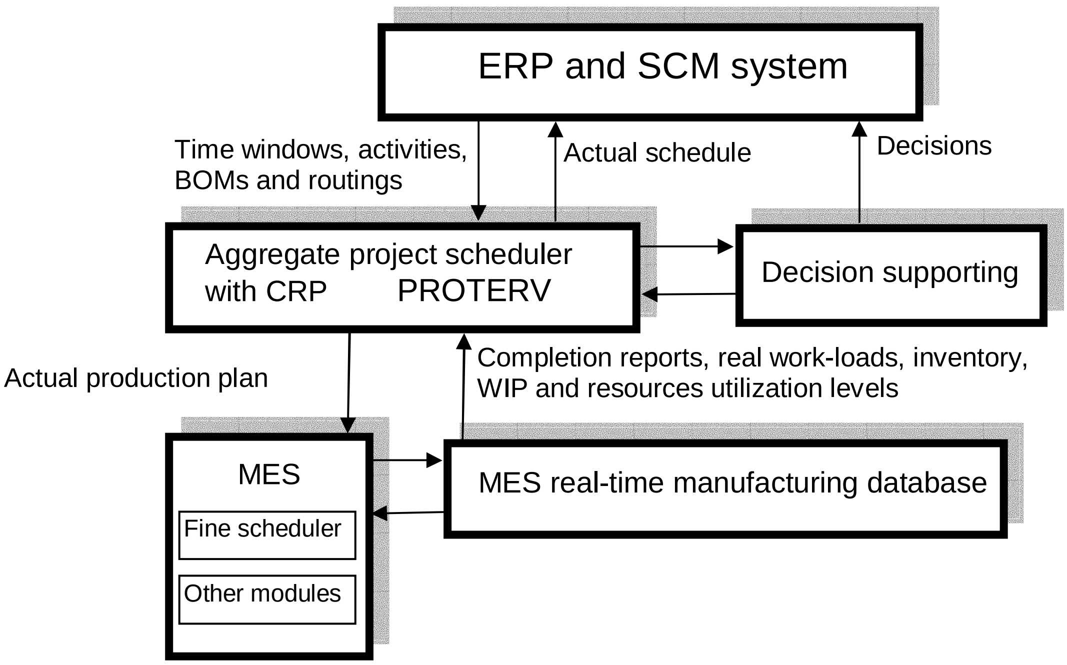

Figure 2. The environment of the intelligent, aggregated MES component

This component would form a bridge between ERP/project planning modules and MES systems – similar to the project scheduler discussed above.

STATE OF THE ART OF MES FUNCTIONAL COMPONENTS

A Manufacturing Execution System (MES) is a collection of hardware/software components that enables the management to control production activities from order launch to finished goods. While maintaining current and accurate data an MES guides, initiates responds to and reports on plant activities as they occur. MES provides mission-critical information about production activities to decision support processes across the shop floor level of manufacturing management [1].

MESs are intended to provide plant-wide insight into the production process, informing about the state of production, production performance, and emergence and allocation of production costs to products. MES may improve better resources planning and allocation, allows supervising the process execution, thus it is possible to promptly identify and react to abnormal events. Product tracking, as the core functionality of a MES system has the main objective to accompany and supervise the manufacturing process. Based on requests from the production manager or upper Enterprise Resources Planning (ERP) system, the feedback information from low level Supervisory Control and Data Acquisition (SCADA) systems, and inputs from the user/operator it has to be in the position not only to know the current state of production and state of all products, but also to recognize abnormal, deviant or critical states in the production process [2].

MESA International's identifies eleven functional areas which a MES should fulfill [3]:

1. Resource Allocation and Status

It manages resources including machines, tools labor skills, materials, other equipment, and other entities such as documents that must be available in order for work to start at the operation. It provides detailed history of resources and insures that equipment is properly set up for processing and provides status real time. The management of these resources includes reservation and dispatching to meet operation scheduling objectives.

2. Operations/Detail Scheduling

Scheduling provides sequencing operations based on priorities, attributes, characteristics, and/or recipes associated with specific production units at an operation such as shape of color sequencing or other characteristics which, when scheduled in sequence properly, minimize setup. It is finite and it recognizes alternative and overlapping/parallel operations in order to calculate in detail exact time or equipment loading and adjust to shift patterns.

3. Dispatching Production Units

It manages flow of production units in the form of jobs, orders, batches, lots, and work orders. Dispatch information is presented in sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It has the ability to alter prescribed schedule on the factory floor. Rework and salvage processes are available, as well as the ability to control the amount of work in process at any point with buffer management.

4. Document Control

Controls records/forms that must be maintained with the production unit, including work instructions, recipes, drawings, standard operation procedures, part programs, batch records, engineering change notices, shift-to-shift communication, as well as the ability to edit "as planned" and "as built" information. It sends instructions down to the operations, including providing data to operators or recipes to device controls. It would also include the control and integrity of environmental, health and safety regulations, and ISO information such as Corrective Action procedures.

5. Data Collection/Acquisition

This function provides an interface link to obtain the intra-operational production and parametric data which populate the forms and records which were attached to the production unit. The data may be collected from the factory floor either manually or automatically from equipment in an up-to-the-minute time frame.

6. Labor Management

Labor Management provides status of personnel in and up-to-the-minute time frame. It includes time and attendance reporting, certification tracking, as well as the ability to track indirect activities such as material preparation or tool room work as a basis for activity based costing. It may interact with resource allocation to determine optimal assignments.

7. Quality Management

Quality Management provides real time analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. It may recommend action to correct the problem, including correlating the symptom, actions and results to determine the cause. May include SPC/SQC tracking and management of off-line inspection operations and analysis in laboratory information management system could also be included.

8. Process Management

It monitors production and either automatically corrects or provides decision support to operators for correcting and improving in-process activities. These activities may be intra-operational and focus specifically on machines or equipment being monitored and controlled as well as inter-operational, which is tracking the process from one operation to the next. It may include alarm management to make sure factory person(s) are aware of process changes which are outside acceptable tolerances. It provides interfaces between intelligent equipment and MES possible through Data Collection/Acquisition.

9. Maintenance Management

It tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance as well as the response (alarms) to immediate problems. It maintains a history of past events or problems to aide in diagnosing problems.

10. Product Tracking and Genealogy

Product Tracking provides the visibility to where work is at all times and its disposition. Status information may include who is working on it; components materials by supplier, lot, serial number, current production conditions, and any alarms, rework, or other exceptions related to the product. The on-line tracking function creates a historical record, as well. This record allows traceability of components and usage of each end product.

11. Performance Analysis

Performance Analysis provides up-to-date reporting of manufacturing operation results along with the comparison to past history and expected business result. Performance results include such measurements as resource utilization, resource availability, product unit cycle time, conformance to schedule and performance to standards. It may include SPC/SQC. Draws on information gathered from different functions that measure operating parameters. These results may be prepared as a report or presented online as current evaluation of performance.

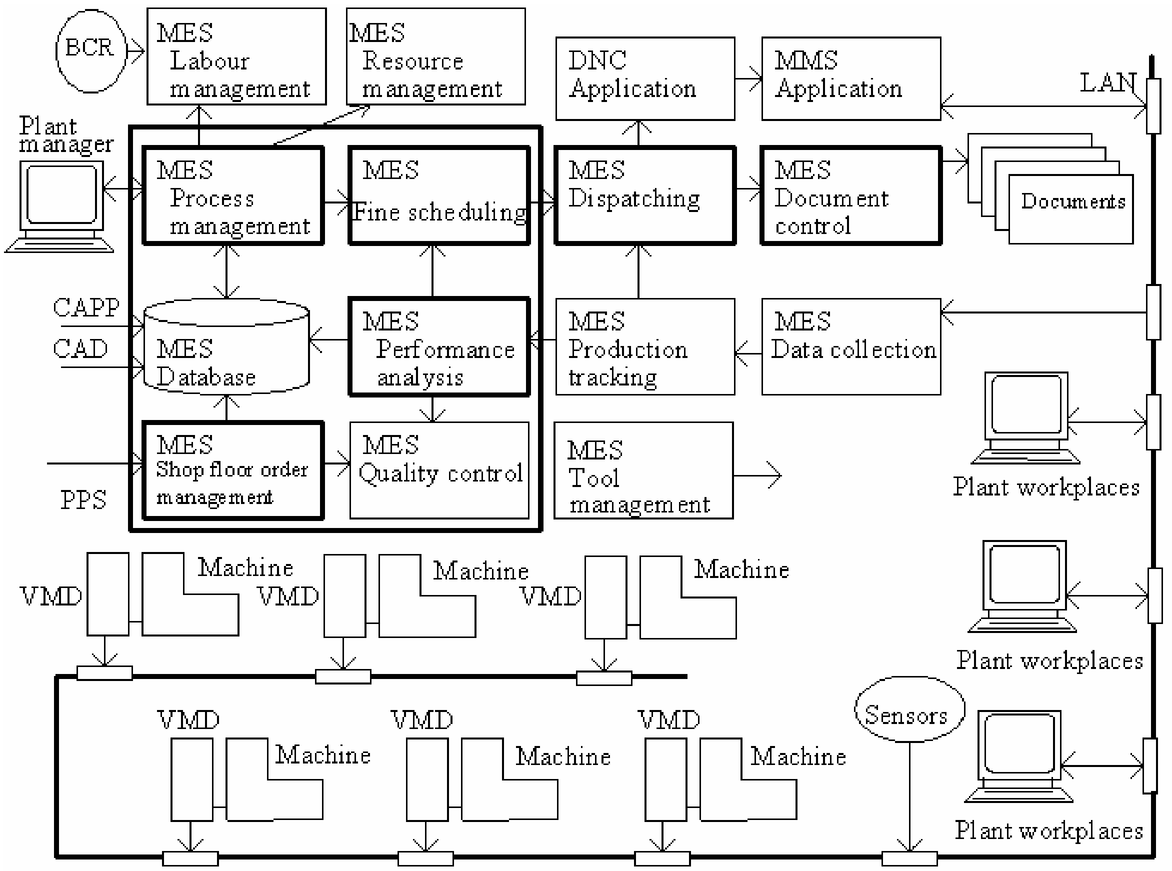

Figure 3. Typical MES components

PRODUCTION ACTIVITIES TRACKING

Product tracking dealing with the tracking the state of products and production equipment is in the centre of any MES system. From product tracking other important MES functionality can be derived, e.g. storing trace histories or computing performance indices. To accomplish product tracking, MES software has to represent:

- the state of production equipment and state changes of equipment based on feedback information on work in progress (WIP);
- the workflows of products, i.e., the work steps required to produce a particular product, together with the alternatives and applying requirements and constraints;
- the work steps which can actually be carried out on equipment, i.e., what it means when an operation is carried out by an equipment, in particular, what indicates that a operation is started and finished and what the consequences in terms of states of products are.

AGGREGATION OF DATA ON PRODUCTION ACTIVITIES

One of the most important tasks of an integrated production planning (PPS) and execution (MES) system is the monitoring of the planned and the realized activities. In the preplanning phase the production plans, BOM designs and routing plans are created by means of models and in general they includes some reserves. In the make to order type manufacturing the delivery date is generally a hard constraint. Similarly, the highest available load of manufacturing resources is also hard limited. The objective function of finding the optimal scheduling may consist of various criterions including lowest achievable level of average WIP, highest utilization rate of manufacturing resources, minimum of the sum of supplying work order etc. This requires the rational consideration of "*make or buy*" type decisions.

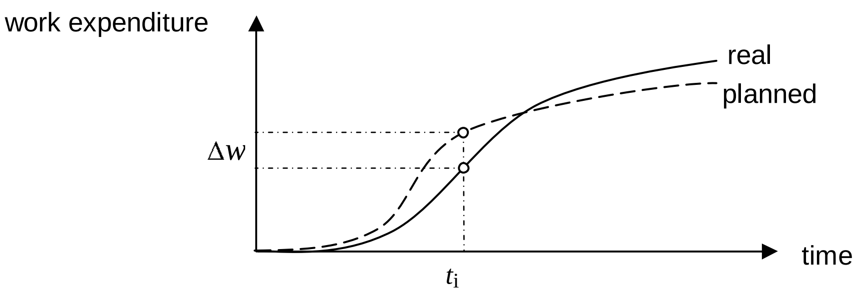

Figure 4. Real and planned expenditures on a production activity

SOFTWARE ENGINEERING APPROACH

By definition, MES consists of a set of functions. These functions have to be performed on distributed computerized clients. The clients may collect/report data automatically or by user input thus human activities can be also brought under the umbrella of MES. Recently *thin* clients are also used which are low-cost, centrally-managed computers devoid of disk drives, and expansion slots. They also have the advantage of reduced risk of virus infections, configuration error, and misusage. Another important factor is the handling of permissions to data. The approach to use database level permission handling or to modify the user interface as hiding buttons which would execute ungranted actions is not satisfactory. These should be included to business logic.

In a real manufacturing environment the high variety of legacy Enterprise Information System (EIS) has also be taken into account, the enterprises may have mixture of operating systems and database management systems.

From IT point of view it is expedient to use the latest software engineering methodology which has been widely accepted. The end users (manufacturing companies this case) do not upgrade their system to the latest available version unless it is proven to be usable. For object oriented software engineering UML provides support to visualize the models. By means of UML high level software analysis and design can be accomplished. The implementation can be any of the modern object oriented computer languages such as C++ or Java. The project described in this paper prefers the latter one.

Regarding to the complex requirements against the intelligent MES component to develop it is advisable to use a framework which supports distributed applications over the network, security and connections to legacy system and conventional or thin client. *Sun's J2EE* (Java 2 Platform, Enterprise Edition) is a Java platform for multi-tier server-oriented enterprise applications which meets these requirements. J2EE model generally includes the following three tiers: client- , middle -, and Enterprise Information System tier (see Figure 5). The client tier is a set of applications or browsers on a thin client or on a desktop computer. The J2EE platform takes place in the middle tier and consists of a Web server and an Enterprise JavaBeans (EJB) server. These servers are also called "containers." The middle tier can be divided into additional sub-tiers. The Enterprise Information System tier has the existing applications, files, and databases.

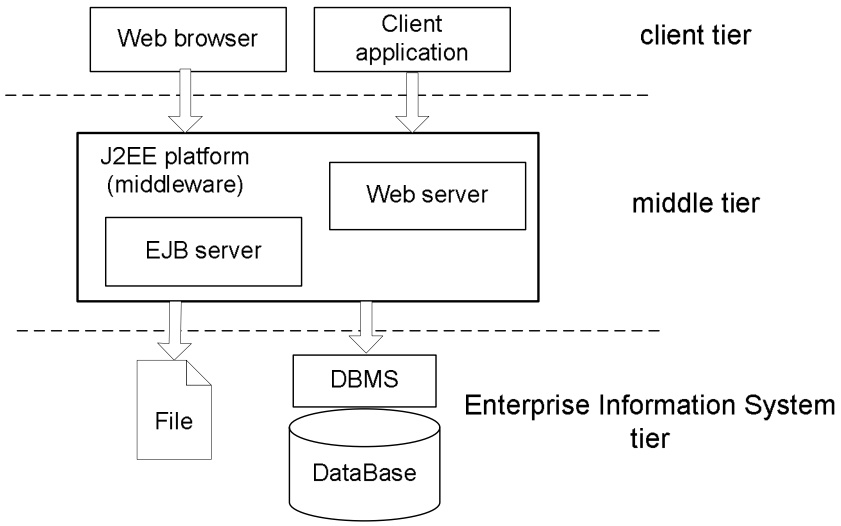

Figure 5. Three-tier software architecture

Application Servers

An *application server* (middleware system) is an implementation of the J2EE platform specification that resides in the middle-tier of a three-tier architecture. It provides middleware services for security and state maintenance, along with data access and persistence. We can declare a middleware as software layer between client and server processes. *An application server* includes a number of components and services, such as:

- Support for Enterprise JavaBeans. EJB is a server-based technology for the delivery of software components in an enterprise environment. It supports the Extensible Markup Language (XML) and has enhanced deployment and security features.
- Support for Java servlet API (Application Programming Interface) enhances consistency for developers without requiring a Graphical User Interface (GUI).
- Support for Java Server Pages (JSP) which is used for dynamic Web-enabled data access and manipulation.

EJB-s plays the most important role in the MES component development. J2EE specification defines three different types of enterprise beans: Session, Entity and Message-driven beans.

1. Session bean: as its name suggests, a session bean is similar to a (not shared) interactive session. It drives user interactions.
2. An Entity bean represents a persistent business object. In MES systems, examples of these business objects are: product, machine, task, batch.
3. A Message-driven bean is an enterprise bean that allows J2EE applications to process messages asynchronously. It acts as a message listener. The messages may be sent by any J2EE component - a client application, another

enterprise bean, or a Web component. This method enables to notify the MES management system of the status about sensors or other low-level devices.

There are some implementations of application server available on the market. In the framework of this project an open source implementation has been decided to use called JBoss [7]. This supports the object oriented Java language thus enabling high level UML models and offers the services required for such a complex development. Further details of proposed software engineering tools are discussed in [5].

DISCUSSION

Fast and effective decision support is the main performance and benefit of modern MES systems. Recently the MES applications being on the market have component-oriented structure to comply with the different manufacturing requirements. The state variables of the products, the operations, the resources and the released orders are the most important data for decision making of real time production control on shop-floor and higher level, too. At higher level it is necessary to compute aggregate data comparing the planned and accomplished workload of production activities. Advanced information technology makes it possible to solve this issue with a distributed application system.

ACKNOWLEDGEMENTS

The research and development summarized in this paper has been carried out by the Production Information Engineering and Research Team (PIERT) established at the Department of Information Engineering and supported by the Hungarian Academy of Sciences. The financial support of the research by the aforementioned source is gratefully acknowledged.

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APPENDIX

List of Acronyms

API – Application Programming Interface

BCS – Business Communication System

BOM – Bill of Materials

CAD/CAM – Computer Aided Design / Manufacturing

CAPP – Computer Aided Process Planning

CC – Cell Controller

CNC – Computer Numerical Control

CRP – Capacity Requirements Planning

DCS – Data Collection System

DBMS – Database Management System

DNC – Distributed Numerical Control

ERP – Enterprise Resources Planning

EJB – Enterprise Java Beans

FMS – Flexible Manufacturing System

GUI – Graphical User Interface

HMI – Human Machine Interface

HPP – Hierarchical Production Planning

J2EE – Java 2 Enterprise Edition

JSP – Java Server Pages

LAN – Local Area Network

MA – Manufacturing Automation

MES – Manufacturing Execution System

MDA/PDA – Machine / Production Data Acquisition

MDS – Master Demand Scheduling

MMS – Manufacturing Message Specification

MS – Master Schedule

MRP – Material Requirements Planning

MMC – Measuring Machine Controller

MTO – Make to Order

NCP – Numerical Control Programming

PLC – Programmable Logic Controller

PPS – Production Planning and Scheduling

QM – Quality Management

ROC – Robot Control

SCADA – Supervisory Control and Data Acquisition

SCM – Supply Chain Management

SFC – Shopfloor Control

SPC/SQC – Statistical Process / Quality Control

SQL – Structured Query Language

UML – Unified Modeling Language

XML – Extensible Markup Language

VMD – Virtual Manufacturing Device

WIP – Work in Progress