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The evolution of manufacturing planning and control systems: From reorder point to enterprise resource planning.

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EVOLUTION OF MANUFACTURING PLANNING AND CONTROL SYSTEMS: FROM REORDER POINT TO ENTERPRISE RESOURCE PLANNING

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Manufacturing planning and control (MPC) systems have existed since the earliest days of the industrial revolution [30]. To gain a historical perspective, it is useful to look at the evolution of these systems. Five major stages were involved: (1) reorder point (ROP) systems, (2) materials requirement planning (MRP) systems, (3) manufacturing resource planning (MRP-II) systems, (4) MRP-II with manufacturing execution systems (MES), and (5) enterprise resource planning systems (ERP) with MES [19, 22, 23, 27, 33]. When examined in detail, each stage represents the next logical step in manufacturing philosophy and technological innovation over the preceding stage.

Perhaps more than any other single factor, information technology has changed the basis of production economics by automating many clerical tasks and greatly improving manufacturing accuracy, reliability, and predictability [15]. As manufacturing planning and control systems have evolved, their designers adopted many of the latest information technologies. These technologies have been embedded in new MPC system versions or sold as "add on" functions and features intended to enhance their basic capabilities.

In this article we seek to explore in more detail the most recent stages of MPC evolution, MRP-II with MES, and ERP with MES. In today's global manufacturing environment, it is necessary to continue integrating advanced information technologies with existing MPC capabilities to maintain and improve MPC system effectiveness. The need for such technologies has grown beyond simply processing information faster, to inferring greater meaning and value from it. MPC systems such as MES and ERP have emerged to support the greater integration of internal firm operations as well as the greater integration of customers and suppliers into these operations.

We propose a stage model as a useful way of organizing and defining our thoughts concerning the nature and content of manufacturing planning and control systems. The MPC stage model presented within this article dis-cusses the evolution of computerized manufacturing planning and control systems from ROP to MRP, MRP to MRP-II, MRP-II to MRP-II/MES, and finally MRP-II/MES to ERP/MES systems (see fig. 1). For each stage, the major attributes of that stage as well as the forces driving the evolutionary process between stages will be discussed. These driving forces and attributes will be framed in terms of a review of the appropriate manufacturing and information systems literature.

BRIEF HISTORY OF MPC SYSTEM EVOLUTION

In their earliest form manufacturing planning and control systems consisted of groups of plant foremen, each responsible for the scheduling of production, ordering of materials, and shipment of products within their assigned plant area. Although often their skill varied widely, the relatively simple design and operation of these plants allowed even the most poorly trained foreman to operate them successfully. As these early industrial era firms evolved, highly specialized reorder point systems of production and inventory control gradually replaced the simple and often inefficient plant foreman system [30].

Reorder point systems have been described as being positional in nature. That is, they use a historical approach to forecasting future inventory demand, which assumes that past data are representative of future demand. If, at any time, an item's inventory level falls below some predetermined level, either additional inventory is ordered or new production orders are released in fixed order quantities (FOQ). Although most early ROP systems were manual, automated ROP systems soon followed when commercial mainframe computers were introduced in the late 1950s and early 1960s [27].

During the mid-1960s computerized materials requirement planning systems slowly began to replace ROP systems as the manufacturing control system of choice. MRP systems presented a clear advantage in that they offered a forward-looking, demand-based
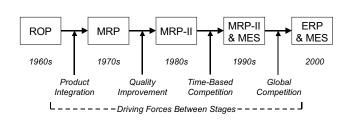
| ROP | MRP | MRP-II | MRP-II & MES | ERP & MES |
| 1960s | 1970s | 1980s | 1990s | 2000 |

Product Integration   Quality Improvement   Time-Based Competition   Global Competition

— — — — Driving Forces Between Stages — — — — — —

FIGURE 1:   Manufacturing planning and control stage model

approach for planning the manufacture of products and the ordering of inventory. This approach allowed the peaks and valleys of inventory levels experienced under ROP's FOQ capabilities to be smoothed and managed more effectively under MRP's more precise lot-for-lot order-generation capabilities. In addition, MRP systems introduced basic computerized production reporting tools that could be used to evaluate the viability of the master schedule against projected materials demand [5, 9, 33]. By the mid-1970s it was estimated that there were approximately 700 users of computerized MRP systems [27].

In the mid-1970s manufacturing resource planning gradually began to replace MRP as the primary manufacturing control system of choice. MRP-II systems built on the demand-based material management capabilities of MRP systems, adding capacity requirements planning (CRP) capabilities to create an integrated, or *closed-loop* MPC system. For the first time ever MRP-II systems made it possible to integrate both materials and production capacity requirements and constraints in the calculation of overall production capabilities. Supported by new shop floor control (SFC) reporting capabilities, firms were able to more efficiently schedule and monitor the execution of production plans [1, 9, 33]. By the late 1980s it was estimated that tens of thousands of firms were using MRP-II systems [17].

The information technology (IT) that characterized manufacturing environments of the 1960s, 1970s, and 1980s focused primarily on the automating power of technology that could be used to make large manufacturing operations more efficient [34]. The ROP, MRP, and MRP-II systems that eventually evolved were characterized by large mainframe computers, hierarchical databases, and complex transactions processing systems geared primarily toward managing a production environment of few products, produced in high volumes, under conditions of constant demand. Although highly efficient, these systems were often inflexible when it came to producing variable quantities of more custom products on short

order [2, 8, 10]. Table 1 summarizes the major MPC and IT characteristics of interest in this article.

The driving forces behind the evolution of each MPC stage correlate highly to the changing business climate of the time [10]. In the 1960s the primary competitive thrust was cost, which resulted in a product-focused manufacturing strategy based on high-volume production, cost minimization, and stable economic conditions. The newly computerized ROP system satisfied the basic MPC needs of these firms. In the 1970s the primary competitive thrust shifted to marketing, which resulted in the adoption of target-market strategies with an emphasis on greater production integration and planning. MRP systems fit that requirement nicely. In the 1980s the primary competitive thrust changed to quality. Manufacturing strategy emphasized greater process control, world class manufacturing, and reduced overhead costs. The closed-loop scheduling, enhanced shop floor reporting, and detailed cost reporting features of MRP-II systems were designed to support many of these activities. Much of the background information documenting this change may be found in the literature on the rise of the information age, postindustrial manufacturing, and global competition [4, 8, 13].

MANUFACTURING EXECUTION SYSTEMS

By the late 1980s the growing manufacturing instability faced by U.S. firms could be directly linked to the changing nature of information technology and the rise of time-based competition [2, 31]. Technology both creates and transforms choice, which in turn transforms the marketplace via revolutionary changes to customer and supplier capabilities. Rapid advances in information technology rendered the "old rules" of competition and long-standing understandings of customer-supplier relationships obsolete. Customers no longer cared how suppliers did business last year or even yesterday for that matter. What matters is a supplier's ability to create or adapt new products and services on a timely basis to meet a customer's specific needs today [24].

This "new reality" translated into the need for a dynamic production environment in which products and processes may change weekly and production schedules may change on a daily or even hourly basis. MRP-II systems require a high degree of human intervention in making the proper adjustments to schedules and in determining the optimal sequence of manufacturing orders that best accommodates the dynamic and often volatile environment of the shop floor. Although the CRP and SFC capabilities of MRP-II do provide valuable additional feedback in report-

TABLE 1: Manufacturing Planning and Control System Stage Characteristics

MPC Stages ⟶	ROP	MRP	MRP-II	MRP-II / MES	ERP / MES
MPC characteristics:					
1. Overall production planning orientation	Positional (based on historical demand)	Predictive (based on future demand)			
2. Material planning	Min/max reorder point logic	Lot-for-lot & min/max reorder point logic			
3. Capacity planning	Manual capacity planning		Capacity requirements planning (CRP)		
4. Manufacturing execution & control	Manual production execution & control		Shop floor control (SFC)	Real-time machine feedback & control	
5. Master planning	Manual master scheduling		Limited decision support (DSS) features		Full DSS features
6. Cross-functional data linkages	Degree of cross-functional information access and sharing varies by firm				Real-time information access and sharing
IT characteristics:					
1. Information technology focus	***Automating*** power of technology (i.e., IT enables manufacturing firms to realize greater cost efficiencies.)			***Informating*** power of technology (i.e., IT enables more effective decision making.)	
2. Computer hardware environment	Mainframe Systems ⟶	Mini-Computer Systems ⟶		Client-server systems ⟶	Web server systems ⟶
3. Information processing	Batch-processing	Online transaction processing		Real-time transaction processing	
4. User interface	Command-based		Menu-based	Graphical user interface (GUI)	
5. Database technology	Sequential files	Hierarchical database ⟶		Relational database ⟶	Object-oriented Database ⟶
6. External MPC interfaces to customers and suppliers	Manual forms & correspondence ⟶	Magnetic tape ⟶	Electronic data interchange (EDI) ⟶		Internet & Extranets ⟶

ing the status of shop floor activities, they provide little information about how to better manage the execution of these activities. Thus, by the mid-1990s many firms and professional organizations like APICS reached the conclusion that a more advanced MPC system, capable of real-time manufacturing planning and execution control, was needed.

The solution to this problem came during the early 1990s in the form of manufacturing execution systems. The emergence of MES represents the development of a critical interface between a firm's MRP-II systems and its shop floor and device control systems. MES's most important contribution is that it unites core manufacturing processes into a value delivery system focused on meeting customer requirements and demand [21]. It provides for the flexible, real-time execution, feedback, and control of a wide range of manufacturing related processes to better meet future market requirements. The implementation of MES has significantly extended many firm's current MPC capabilities supporting greater vertical and horizontal integration within their manufacturing function. Thus, while MRP-II has often been described as a

closed loop MPC system, MRP-II with MES can best be described as a *continuous loop* MPC system [11].

Early MES implementations were first achieved in industries such as semiconductors, aerospace, defense, and pharmaceuticals. These industries are characterized by high-value products, complex or unstable processing, or heavy governmental regulations [20]. An MES is an online integrated computerized system that is the accumulation of the methods and tools used to accomplish production [22]. A typical MES software package may consist of 25 modules and cost up to a couple of hundred thousand dollars. The six general functions that most MES systems seek to serve include (1) the management of machine resource availability, (2) prioritization of production schedules, (3) control of the flow of production units between machines, (4) management of available labor, (5) automated document control, and (6) provision of quality, process, and maintenance management support [14].

At a more detailed level the core MES modules as defined by the Manufacturing Execution Systems Association (MESA) include a planning system interface, work

order management, workstation management, inventory tracking and management, material movement management, factory data collection, and exception management. The key MES support functions include maintenance management, time and attendance, statistical process control, quality assurance/ISO 9000, process data/assurance analysis, documentation/product data management, genealogy/product traceability, and supplier management [22]. A survey conducted by MESA and reported by *Modern Materials Handling* identifies the major benefits of MES: (1) 45% average reduction in manufacturing cycle times, (2) 17% average reduction in work-in-process levels, (3) 75% average reduction in data entry time, (4) 32% average reduction in production lead time, (5) 56% average reduction in shop floor paper work, and 6) 15% average reduction in finished goods defects [25].

The information technology drivers behind the increasing adoption and acceptance of MRP-II/MES include the development of automatic identification and data-collection systems. Greatly improved technologies such as bar code readers, radio frequency transponders, vision systems, device controls systems, and touch systems gradually replaced people or reduced the opportunity for them to make errors in manufacturing data collection. The emergence of low-cost, fault-tolerant computer systems, maturation of relational database technologies, and improvements in high-capacity local area networks have all allowed for the faster, more reliable collection, processing, and transmission of a greater range of data types on a real-time basis. Finally, the migration toward open system standards has allowed many different computers and software systems to communicate more effectively via common interface designs and/or data manipulation and exchange tools [22].

ERP: CURRENT STAGE OF MPC SYSTEM EVOLUTION

By the late 1990s increasing levels of global competition combined with changing markets and technology caused many firms to rethink and reinvent their products and services, including their organizational structure and operational controls. Firms operating globally soon found that more flexible resource deployment and a better approach to extracting value from their information-rich environment were needed to align themselves with customers' needs. It was not that these firms had a choice, the dynamics of the new customer–supplier relationships demanded it [28].

Customer-centered supply chain management has become the standard mode of operation for most global competitors today. This view recognizes the growing importance of supply chain processes extending across the firm, allowing individual customer relationships to be managed from a total customer perspective [12]. This view also recognizes that the changing role of the information systems (IS) function from support staff to business partner makes the flexible management of customer information possible. As the firm seeks to manage the development and delivery of products and services to a geographically diverse set of customers, it is required to restructure customer, supplier, and product line data frequently to reflect changing business structures and emerging global opportunities [16].

IS infrastructure decisions made before the rise of customer-centered supply chain management were often segmented and discontinuous in nature because of conflicting organizational objectives and preferences. Often, within global firms the uses and consequences of information technology emerge unpredictably to form complex social interactions. History has shown that as firms seek to better integrate organizational processes, more highly interactive collaborative work tools are required to better support these processes. IS infrastructure decisions related to the selection of these tools are important because end users are either inhibited or empowered by them to simultaneously create, share, and manage large amounts of information for improved decision making [3].

This has compelled firms to adopt cross-functional, customer-driven MPC systems designed to improve organizational speed and flexibility. In such systems, the informating power of the technology systems is unleashed as workers "act with" co-workers to process information, make decisions, and solve problems in unison [34]. Along the way the organization's capacity to learn and innovate is significantly enhanced through greater levels of cross-functional involvement enabling it to more fully realize the potential of intelligent technologies [7].

Although the introduction of MES systems greatly improved the degree of vertical integration within the production function of the 1990s, enterprise resource planning systems deliver a greater degree of horizontal integration in firms today. ERP systems mark a significant turning point in the development of MPC systems because they enable firms to meet the global directive of continuous improvement of supply-chain processes through flexible, customer-driven information management. The successful implementation of an ERP system allows for the identification and implementation of the set of best practices, procedures, and tools designed to achieve organizational excellence through functional integration [19, 29]. At the same time it allows for many important functional business processes to remain intact if so desired.

ERP systems promise to deliver increased salability over their MRP-II predecessors in the form of a suite of integrated products running under a common information technology architecture that can be tightly coupled or entirely decoupled and integrated with any other application or legacy system [32]. ERP applications are designed to optimize an organization's underlying business processes in an effort to create a seamless, integrated information flow from suppliers, through manufacturing and distribution [23].

Relevant Business Systems defines a fully functioned ERP system as performing eight major types of business functions [26]: (1) engineering part and bill of material control, (2) engineering change and documentation control, (3) purchasing, (4) materials management, (5) manufacturing planning and control, (6) cost management and control, (7) finance (accounting), and (8) marketing and sales systems.

ERP systems may operate on a single mainframe computer or a network of distributed computers engaged in real-time transaction processing. However, their objective is to allow for the simultaneous aggregation, de-aggregation, and manipulation of data to support the creation of multiple business scenarios on a cross-functional basis as well as for the examination of business decisions from both centralized and decentralized points of view. This supports the need to better understand the constantly changing global business environment in which the firm operates so that new opportunities can be identified as they emerge.

As the nature of the decision in question changes, so too can the data views examined within the ERP system. This approach allows individual functional areas to examine detailed cross-sectional slices of a firm's manufacturing data according to specific information needs. Multiplant or global views as well as customer and supplier views may also be examined. Thus, the improved visibility of ERP systems allows for much greater organization-wide and external stakeholder involvement in the planning and execution of production in the future.

Like MRP-II systems, ERP systems are often integrated with MES systems [23]. Some ERP systems may be purchased with MES modules. However, most MES systems are still purchased to meet the firm's specific manufacturing requirements. This allows the firm to identify and adopt a more effective solution that best meets its manufacturing execution requirements. Because of the development of better data management tools, the issue of interfacing MES to ERP systems is not as great a concern as was the interfacing of MES to MRP-II in the past.

ERP systems must also interface with and capitalize on the Internet as a major conduit of new business growth. E-business capabilities are an important part of today's ERP systems that encompass business-to-business applications such as dealer networks and online sourcing and procurement. Direct business-to-consumer applications such as electronic storefronts, customized product configuration, warranty registration, and online catalogs also offer opportunities to generate large profits [23]. Today, the best ERP systems recognize and accommodate the changing nature of the firm's customer base because of the Internet and other advanced information technologies.

Examples of those technologies include data mining software, decision support systems, expert systems, and statistical analysis software. Although various forms of these technologies have existed for many years, often they have been difficult to learn and cumbersome to use. New versions are more user friendly and often are designed to interface with modern ERP systems that integrate corporate data into a single data warehouse. This creates new and exciting opportunities to evaluate firm and supplier performance in the satisfaction of customer product and service needs.

CLOSING REMARKS

The purpose of this article has been fourfold. First, stage models present an excellent opportunity for academics to convey their findings to industry practitioners and conduct a dialog about them in a meaningful way. We have attempted to create a historical context in the form of a stage model by which to better understand and reflect on the evolution of MPC systems and the forces driving their development. In doing so, we have sought to identify the manufacturing and information systems characteristics of primary importance at each stage in MPC development. This is useful in that it also forms a basis on which to discuss the context of future MPC system development.

Second, throughout this article we have examined the impact of the evolution of information technology on MPC systems. Information technology is a change agent, both creating and transforming opportunities within firms. Although information technology does not represent the driving force behind each stage of MPC development, it does represent a critical enabler of change. Each new MPC stage has required manufacturing firms to revise and restructure their standard business processes. Thus, the transition from stage to stage can be marked by conflict between functions when one or more are slow in changing their way of doing business.

Third, although there are currently many software vendors selling ERP systems, it should be noted that no industry-wide standards or common functional specifications exist for ERP systems as they do for MES

systems. ERP does not as of yet have a dominant industry association such as MESA governing its development. That is a problem because competing views presented by the different ERP vendors and industry associations currently exist, creating further confusion as to what exactly ERP really is and does. This presents a great challenge and an opportunity for organizations such as the American Production and Inventory Control Society (APICS) to step forward to provide both leadership and a forum for unifying these competing views, as MESA has done for MES.

Fourth, it is important to establish an interdisciplinary basis on which researchers may conduct critical theoretical discussions about existing and emerging phenomena in MPC system development and adoption. Such interdisciplinary discussions often yield valuable results in defining the common variables of interest across related fields of study. More ERP-related research is definitely needed in several areas: (1) software evaluation and selection; (2) implementation leadership and change management; (3) training, education, and technology diffusion; (4) cost and budget management; and (5) ongoing operational and technical support issues [6, 16, 18, 26]. This is not intended to be an all-inclusive list of opportunities, but is presented to illustrate the many ERP research possibilities.

One final conclusion that may be drawn from this article is that manufacturing planning and control systems are alive and well. Although some researchers and practitioners have predicted their demise, the architects of these systems have continually responded to threats and opportunities with new and more creative solutions such as MES and ERP. At each stage in MPC development, this has resulted in the wide-ranging set of highly effective MPC tools and techniques we have today. If the past can be used as a predictor of the future, the next generation of MPC systems will be even more exciting than those that preceded them.

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