CHAPTER 999

An Overview of Enterprise Resource Planning Systems in Manufacturing Enterprises

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1 INTRODUCTION

Enterprise resource planning (ERP) is a class of commercially developed software applications that integrate a vast array of activities and information to support tactical level operations and operations planning for an industrial enterprise. The term “ERP” refers to the software and not to the related business processes. However, as software, it enables better execution of certain processes. Although often presented as a single package, an ERP system is an envelope around numerous applications and related information. For manufacturers, those applications typically support the operations processes of materials sourcing, manufacturing planning, and product distribution. To its end-users, an individual application of an ERP system may appear seamless; however, to those who procure, implement, and/or maintain ERP systems, they are complex software systems that require varying levels of customization and support both centrally and across applications. While ERP systems are commercial applications developed by individual vendors, they can hardly be considered "off-the-shelf." They are part of a continuing trend of outsourcing IT solutions in which part of the solution is bought, part is configured, and part is built from scratch. In general, as the scope and complexity of integrated applications have increased from systems supporting a single business unit to systems supporting an entire enterprise and its relationships with business partners, the portions of an IT solution that are bought and configured have increased while the percentage of custom-built software has decreased. Given their broad organizational and functional scope, ERP systems are unlike any other contemporary commercial manufacturing applications. They provide "transaction management," both from the business perspective and from a database perspective. Additionally, they provide a basic level of decision support. Optionally, they enable development of software for higher levels of decision support, which may be offered by ERP vendors or third-party vendors. It is clear that ERP, as a subject, is very complex. Its use marries technology, business practices, and organizational structures. The purpose of this chapter is to present a high-level view of ERP in order to frame a discussion of technological challenges and research opportunities for improving ERP interoperability. Although ERP is relevant to many types of industries (i.e., goods and services) and organizations (i.e., for-profit and not-for-profit), the discussion in this chapter is limited to ERP in manufacturing enterprises. More specifically, the focus of this chapter is ERP that supports the principal operations of a manufacturing enterprise: planning, procuring, making, and delivering products. An ERP system may support other enterprise functions such as finance management, human resource management, and possibly sales and marketing activities. Detailed analysis of those functions is beyond the scope of this chapter; however, the linkages of those functions with manufacturing-specific functions are not.

This overview looks at ERP by itself and as part of a larger entity (Figure 1). Section 2, *An Internal View of ERP Systems*, is a discussion of ERP internals such as core functions, implementation elements, and technology issues. Additionally, Section 2 identifies critical integration points for ERP and other applications within manufacturing enterprises. Section 3, *An External View of ERP Systems*, is a discussion of ERP and its relationship to three larger entities, namely the U.S. economy, supply chains, and individual manufacturers. Section 4, *ERP Challenges and Opportunities*, presents issues and possible resolutions for improving ERP performance and interoperability.

Figure 1 External and Internal Views of ERP

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The concepts presented in this chapter were gathered from a variety of sources including literature reviews, manufacturing industry contacts, ERP vendor contacts, consultants specializing in the applications of IT to manufacturing, relevant professional and trade associations, and standards organizations.

1.1 Major Business Functions in Manufacturing Enterprises

Manufacturers typically differentiate themselves from competitors along the three major business functions through which they add value for their customers. *Customer relationship management* (CRM), the first dimension of competitive advantage, seeks to add value for customers through those processes that involve direct contact with customers before, during, and after sales. The idea is to understand the prevalent needs and concerns of individual customers and groups of customers. *Product development*, the second dimension of competitive advantage, focuses on product—i.e., what and how to produce an object to satisfy the customer's *want*. *Operations*, the third dimension of competitive advantage, focuses on satisfying *demand*—i.e., how much to make, when to make, and where to make—by producing and delivering products in an effective and efficient manner.

The notions of *needs*, *wants*, and *demands* are basic concepts underlying modern, market-based economies [Kotler, P., and Armstrong, G. (1999)]. *Needs* beget *wants* which beget *demand*. Needs are states of felt deprivation. They are a basic part of our human condition and are physical, social, and individual in nature. The customer's needs include product capabilities, product servicing, user instruction, and business relationships. Wants are the forms taken by human needs as shaped by culture and individual personality. They are described in terms of objects that will satisfy needs. Demands are human wants that are backed by buying power. Identifying needs and translating them into wants in terms of product and process definitions are the objectives of *product development*. Satisfying demand, given supply conditions as well as product and process definitions, is the objective of *operations*. This high-level partitioning of manufacturing business functions into CRM, product development, and operations has growing acceptance in manufacturing and related industries [Hagel III, J., and Singer, M. (1999)]. This acceptance has been fostered by the realization that the underlying activities of these high level functions are those that add value for the customer.

The complex activities of product development seek to satisfy customer want by translating the abstract to the physical through the *product development process*. As such, in commercial manufacturing enterprises, product development typically starts with an analysis of market opportunity and strategic fit and, assuming successful reviews through intermediate phases, ends with product release. Among other things, product release serves as a signal to operations to begin production and distribution as the necessary design and manufacturing engineering specifications are ready for execution in a production environment.

Operations, on the other hand, consists of processes for satisfying customer demand by transforming products—in raw, intermediate, or final state—in terms of form, location, and time. To accomplish this objective both effectively and efficiently—and thus meet specific, customer-focused, operational objectives—a manufacturing enterprise must have timely and accurate information about expected and real demand, as well as expected and real supply. A manufacturer then considers this information on supply and demand with the current and expected states of its enterprise. It is ERP that allows a manufacturer to monitor the state of its enterprise—particularly the current and near-term expected states. In fact, ERP systems often serve as the cornerstone in the emerging information architectures that support balancing external and internal supply and demand forces. ERP systems play both direct and indirect roles in this trend among manufacturing enterprises towards a synchronized, multi-level, multi-facility supply chain planning hierarchy.

1.2 Manufacturing Operations Planning

Figure 2 illustrates the emerging synchronized, multi-level, multi-facility supply chain planning hierarchy with ERP as its foundation. The goal of this architecture is to enable more efficient and effective execution across plants, distribution systems, and transportation systems. Independently, these planning activities focus on the strategic, the tactical, and the operational (i.e., execution) levels. Collectively, they support the translation of strategic objectives into actions on the plant floor, in warehouses, and at shipping points throughout the extended enterprise. In addition, they provide top management with up-to-date, synchronized information regarding the state of the entire enterprise.

Figure 2 Intra-Enterprise View of Supply Chain Planning Hierarchy

This synchronization is accomplished by transforming information in a meaningful way from one level within the supply chain planning hierarchy to the next. At the strategic level, top management evaluates numerous factors to determine the design or re-design of the supply chain network as well as time-independent sourcing, production, deployment, and distribution plans. These factors typically include the enterprise's business philosophy as well as company, market, technological, economic, social, and political conditions. Supply chain planning at the strategic level involves "what-if" analysis particularly with respect to the first three factors: business philosophy, company conditions, and market conditions. A business philosophy might specify maximizing net revenues or return on assets. Assessment of company conditions considers existing and potential aggregates of fixed (i.e., plant), financial, and human resources. When evaluating market conditions, top management analyzes aggregate product/part demand as well as the anticipated capacity of suppliers and transportation channels—also in aggregate terms. Optimization at this level, which usually employs mathematical programming methods, typically yields the location, size, and number of plants, distribution centers, and suppliers as well as product and supply volumes.

Supply chain operations planning at the tactical level determines the flow of goods over a specific time horizon. Mathematical programming methods yield time-dependent integrated sourcing, production, deployment, and distribution plans typically designed to satisfy a financial management objective such as minimizing total supply chain costs or maximizing net revenues by varying product mix. Often, once these plans are established, a more detailed level of tactical planning occurs to optimize supply, production, and distribution independently. Frequently, the objective at this lower level of tactical planning is to minimize costs related to inventories and/or major equipment changeovers.

Supply chain planning at the operational level is, in essence, supply scheduling that occurs on a facility-by-facility basis. As such, separate but coordinated schedules are generated for plants, warehouses, distribution centers, and vehicle systems. Planning at this level differs from tactical and strategic levels in that demand actually exists. That is, orders have been placed. These orders need to be scheduled based on the immediate state of resources (i.e., materials, equipment, and labor). The diverse nature of facilities means that the specifics of optimization vary widely at this level, but the objective typically is to maximize throughput in a given facility.

Individually, these layers serve to separate concerns and enable the definition of tractable planning problems for which mathematical and managerial solutions can be obtained. Collectively, these layers of supply chain planning enable manufacturing enterprises to more effectively and efficiently balance supply, resources, and demand. The upper layers buffer the lower layers from sudden shifts in the market, thus allow for smoother changes in the enterprise's plants, distribution channels, and transportation systems.

1.3 Partitioning the Domain of Manufacturing

The domain of manufacturing is, in fact, an aggregate of many sub-domains of many types. There is no single correct method for decomposing that complex and dynamic aggregate. The method of decomposition depends on the particular objective at hand. Generally speaking, there are four common approaches to partitioning the manufacturing domain. Each looks at a different aspect of the manufacturing enterprise:

- Nature of the Product—This approach categorizes manufacturing industries by the general nature of the product itself – fertilizers, pharmaceuticals, metals, automotive parts, aircraft, etc. This is the approach used by industry classification systems such as the North American Industry Classification System (NAIC) [Office of Management and Budget (1997)] and its predecessor the Standard Industrial Classification (SIC) [Office of Management and Budget (1988)]. In general, this approach is a good mechanism for characterizing market communities, and thus economic estimators, but it is not a particularly good mechanism for characterizing ERP requirements or planning approaches.
- Nature of the Customer—Since most manufacturing output is consumed by other industries, many manufacturers are part of the supply chains ending in "original equipment manufacturers" (OEMs) in a single major industry: automotive, aerospace, shipbuilding, household appliances, computers, etc. The members of the chain produce different kinds of products, using different processes, with different business behaviors, but the behavior of the supply chain itself often is dominated by the demands of the OEMs.
- Nature of the Process—This approach characterizes a domain by the organization of the manufacturing facility and the general nature of the manufacturing processes it employs: continuous process, assembly line, discrete batch, job shop, and construction. There is some correlation between the process type and the product type, in that most manufacturers of a given product type tend to use a particular process organization. In general, process type strongly influences the manufacturing-specific aspects of ERP, including both information capture and planning approaches. On the other hand, large manufacturers often use several different process styles for different products and different components of larger products.

- Nature of the Business in Terms of Customer Orders—This characterization includes make-to-stock, make-to-order, assemble-to-order, engineer-to-order. It has a great deal to do with what the detailed business operations are, and how operational and tactical planning is done. Clearly this categorization has a tremendous influence on the ERP requirements and on the behavior of the enterprise in its supply chain. More than any other, this characterization determines the nature of the delivery activities and the dependence on supplier relationships.

Since it is these last two categories that are differentiators for ERP, they warrant more detailed discussion.

1.3.1 Nature of Process

Continuous process refers to a facility in which products are made by an essentially continuous flow of material through some set of mixing, state transformation, and shaping processes into one or more final products. The final form may itself be intrinsically discrete, or it may be discretized only for packaging and shipment. Examples are wet and dry chemicals, foods, pharmaceuticals, paper, fibers, metals (e.g., plate, bar, tubing, wire, sheet), and pseudo-continuous processes such as weaving, casting, injection molding, screw machines, and high-volume stamping.

Assembly line refers to a facility in which products are made from component parts, by a process in which discrete units of product move along an essentially continuous line through a sequence of installation, joining, and finishing processes. Examples are automobiles, industrial equipment, small and large appliances, computers, consumer electronics, toys, and some furniture and clothing.

Discrete batch, also called *intermittent*, refers to a facility in which processes are organized into separate work-centers and products are moved in lots through a sequence of work-centers, in which each work-center is set up for a specific set of operations on that product, and the setup and sequence is specific to a product family. This describes a facility which can make a large but relatively fixed set of products, but only a few types of product at one time, so the same product is made at intervals. This also describes a facility in which the "technology" is common – the set of processes and the ordering is relatively fixed, but the details of the process in each work-center may vary considerably from product to product in the mix. Examples include semiconductors and circuit boards, composite parts, firearms, and machined metal parts made in quantity.

Job shop refers to a facility in which processes are organized into separate work-centers and products are moved in "order lots" through a sequence of work-centers in which each work-center performs some set of operations, and the sequence of work-centers and the details of the operations are specific to the product. In general, the work-centers have general-purpose setups which can perform some class of operations on a large variety of similar products, and the set of centers used, the sequence, the operations details, and the timing vary considerably over the product mix. Examples include metal shops, wood shops, and other piece-part contract manufacturers supporting the automotive, aircraft, shipbuilding, industrial equipment, and ordnance industries.

Construction refers to a manufacturing facility in which the end-product instances rarely move; equipment is moved into the product area, and processes and component installations are performed on the product in place. The principal examples are shipbuilding and spacecraft, but aircraft manufacture is a hybrid of construction and assembly-line approaches.

1.3.2 Nature of the Business in Terms of Customer Orders

Make-to-stock describes an approach in which production is planned and executed on the basis of expected market rather than specific customer orders. Because there is no explicit customer order at the time of manufacture, this approach is often referred to as a "push" system. In most cases, product reaches retail outlets or end-customers through distribution centers, and manufacturing volumes are driven by a strategy for maintaining target stock levels in the distribution centers.

Make-to-order has two interpretations. Technically, anything that is not made-to-stock is made-to- order. In all cases there is an explicit customer order, and thus all make-to-order systems are described as "pull" systems. However, it is important to distinguish *make-to-demand* systems, in which products are made in "batches," from *option-to-order* systems, in which order-specific features are installed on a product-by-product basis. The distinction between make-to-demand batch planning and on-the-fly option selection using single set-up and prepositioning is very important to the ERP system.

A *make-to-demand* manufacturer makes fixed products with fixed processes, but only sets up and initiates those processes when there are sufficient orders (i.e., known demand) in the system.

This scenario may occur when there is a large catalog of fixed products with variable demand, or when the catalog offers a few products with several options. The distinguishing factor is that orders are batched, and the facility is set up for a "run" of a specific product or option suite. The planning problem for make-to-demand involves complex trade-offs among customer satisfaction, product volumes, materials inventories, and facility set-up times.

Option-to-order, also called *assemble-to-order*, describes an approach in which production is planned and executed on the basis of actual (and sometimes expected) customer orders, in which the product has some pre-defined optional characteristics which the customer selects on the order. The important aspects of this approach are that the process of making the product with options is predefined for all allowed option combinations and that the manufacturing facility is set up so the operator can perform the option installation on a per-product basis during manufacture. This category also applies to a business whose catalog contains a family of "fixed products," but whose manufacturing facility can make any member of the family as a variant (i.e., option) of a single base product. The option-to-order approach effects the configuration of production lines in very complex ways. The simplest configurations involve "prepositioning" in which option combinations occur "on the fly." More complex configurations involve combinations of batching and prepositioning.

Engineer-to-order describes an approach in which the details of the manufacturing process for the product, and often the product itself, must be defined specifically for a particular customer order, and only after receipt of that order. It is important for other business reasons to distinguish *contract engineering*, in which the customer defines the requirements but the manufacturer defines both the product and the process, from *contract manufacturing*, in which the customer defines the product details and the manufacturer defines the process details. But the distinction between contract engineering and contract manufacturing is not particularly important for ERP, as long as it is understood that both are engineer-to-order approaches. In these scenarios, some set of engineering activities must take place after receipt of customer order and before manufacturing execution, and certain aspects of manufacturing planning can begin.

1.3.3 Combining Nature of Process and Nature of Business in Terms of Customer Orders

Many attempts to characterize manufacturing roll up some combination of the four major categorization approaches (product, customer, process, business) into a single categorization scheme, in order to make certain useful generalizations. But because resource planning and ERP systems must deal with important details of the organization's business process, these generalizations do not provide good guidelines for studying the variations in planning and execution information. In particular, no generalization about industries applies to all manufacturing organizations in that industry, and there is no way to roll up the nature of the process with the nature of the business in terms of customer orders. For example, all four business patterns can be observed in the continuous (and pseudo-continuous) processing industries. Even though engineer-to-order (customer-specific recipe) is fairly rare in the chemical and raw metal industries, it is the norm (customer-specific mold) in the injection-molding and casting industries. It does make sense, however, to cross the nature of the process with the nature of the business in terms of customer orders to identify those combined characteristics which have the most significant influence on ERP system requirements. Table 1 identifies 14 distinct categories, out of a possible 20, for which there are known manufacturers in specific industries.

Table 1 **Examples per Process and Customer Order Characteristics**

	Make-to-Stock	Make-to-Demand	Option-to-Order	Engineer- to-Order
Continuous	refineries	solvents, plastics, alloys	fuels	casting, injection molding
Assembly Line	appliances	electric motors, valves	autos, computers	aircraft
Discrete Batch	electronic components	windows, auto parts	*no known*	semi-conductors, circuit boards
Job Shop	*none*	*none*	*none*	metal parts, composites
Construction	*none*	*no known*	aircraft	ships

2 AN INTERNAL VIEW OF ERP SYSTEMS

The objective of this section is to describe what ERP systems do and how they do it. Sections 2.1 through 2.3 describe the core functional elements of ERP systems: human resource management, finance management and accounting, contracts management, materials acquisition, materials inventory, maintenance management, order entry and tracking, manufacturing management, process specification management, warehousing, and transportation. Sections 2.4 through 2.6 describe implementation aspects, particularly ERP systems architecture, configuration management tools, and Internet interfaces.

2.1 Scope of ERP Systems in Manufacturing Enterprises

As illustrated in the portion of Figure 2 bounded by the gray box, the functionality of ERP systems encompasses certain interactions among the following elements:

- four categories of resources (inventories, facilities/equipment, labor, and money)
- two generic activities (planning/decision support and execution/transaction management)
- three types of manufacturing operations activities (supply, production, and delivery)
- five major types of physical facilities (stockroom, plant floor, warehouse, vehicle/depot, and distribution center) through which material flows in manufacturing enterprises.

The gray box does not envelop all physical facilities because there is considerable variation among manufacturers as to which functions in which facilities fall within the scope of an ERP implementation. Typically, in some way or another, all transactions—all changes of state and many decisions—are captured in an ERP system. Each of these facilities may use additional systems for planning and analysis, execution level scheduling, control, and automated data capture. Some of the planning, analysis, scheduling, and management systems are part of, or tightly connected to, the ERP systems; others are more loosely connected. This variation results from two major factors: systems which are closely coupled to equipment, most of which are highly specialized, and systems which manage information and business processes that are specific to a particular industry which the ERP vendor may not offer. Because of the historic emphasis on reducing inventory costs, the management of stockroom is, in almost all cases, an intrinsic part of an ERP system. To the contrary, plant floor activity control is almost never a part of ERP. Management of execution activities within warehouses, vehicles/depots, and distribution centers may be handled in a centralized fashion by an ERP system or in a decentralized fashion by an applications specific to those facilities.

2.2 Transaction Management and Basic Decision Support: The Core of ERP

Transactions are records of resource changes that occur within and among enterprises. Through the use of a logically (but not necessarily physically) centralized database, it is the management of these transactions that constitutes the core of an ERP system. More specifically, this transaction database captures all changes of state in the principal resources of the manufacturing enterprise. It also makes elements of the current state available to personnel and software performing and supporting the operations of the enterprise. This scope encompasses all of the numerous "resources" (i.e., materials inventories, facilities/equipment, labor, and money) and product inventories of all kinds. It also includes the states and results of many business processes, which may not be visible in physical instances (e.g., orders, specifications). The detailed breakdown of this broad scope into common "separable components" is a very difficult technical task, given the many interrelationships among the objects, significant variations in the business processes, and the technical origins of ERP systems. Nonetheless, it is possible to identify general elements from that complexity and diversity. The functions of a manufacturing enterprise that are supported by transaction management correspond to the major types of resources as follows:

- for inventories, *materials inventory* and *materials acquisition*
- for facilities/equipment, *manufacturing management*, *process specification management*, *maintenance management, warehousing* and *transportation*
- for labor, *human resource management*
- for money, *financial management and accounting*
- for product, *order entry and tracking*

These functions—in whole or in part—make up the core of ERP. The following sections describe each function and its relationship to "core" ERP. These functions are then discussed in terms of finer grain execution and planning activities.

2.2.1 Materials Inventory

This function comprises all information on stores of materials and allocations of materials to manufacturing and engineering activities. That includes information on materials on-hand, quantities, locations, lots and ages, materials on-order and in-transit, with expected delivery dates, materials in inspection and acceptance testing, materials in preparation, and materials allocated to particular manufacturing jobs or product lots (independent of whether they are in stock).

ERP systems routinely capture all of this information and all transactions on it. It is sometimes combined with materials acquisition information in their "component architecture."

Execution activities supported by materials inventory include receipt of shipment, inspection and acceptance, automatic ("low-water") order placement, stocking, stores management, internal relocation, issuance and preparation, and all other transactions on the materials inventory. Except for some stores management functions, all of these are revenue-producing.

Planning activities supported by materials inventory include supply planning, manufacturing planning, and manufacturing scheduling.

2.2.2 Materials Acquisition

The function deals primarily with information about suppliers and materials orders. It includes all information about orders for materials, including recurring, pending, outstanding, and recently fulfilled orders, and long-term order history. Orders identify internal source and cost-center, supplier, reference contract, material identification, quantity, options and specifications, pricing (fixed or variable), delivery schedule, contacts, change orders, deliveries, acceptances, rejects, delays, and other notifications. It may also include invoices and payments. This also includes special arrangements, such as consignment and shared supply schedules.

ERP systems support part of an enterprise's materials acquisition function by handling all of this information for *active* suppliers and orders and by journalizing all transactions. But they regularly purge closed orders and relationships, using the journal or some other export mechanism to move this information to an archival or data warehouse system. ERP systems generally maintain simple materials specifications directly, but typically carry only references to more complex specification documents in some other product data management (PDM) or document management system.

Execution activities supported by materials acquisition include internal requests, placement of external orders and changes, receipt and acceptance of materials, and all other transactions against materials orders. All of these are revenue-producing activities.

Planning activities supported by materials acquisition include supply chain development, supplier identification and qualification, supply planning, manufacturing planning, and cash-flow projections.

2.2.3 Order Entry and Tracking

These functions focus on the customer order through its lifecycle. Order entry is the mechanism by which the decision to make product enters the ERP system. It begins with the capture of customer order, including all specifications and options, quantities, packaging requirements, and delivery requirements. It ends with the creation of one or more corresponding "manufacturing orders" and "delivery orders." At that point it becomes "order tracking," which follows the customer order through the fulfillment processes (for the surrogate orders) and finally through the payment processes. It is important to note that although manufacturing may be "driven directly by customer order," there is a decision point between the entry of the customer order and the release of the associated manufacturing orders, and in most ERP systems they are maintained as separate objects. While this release is often automated, it is a critical business control point, and the automation reflects the business rules for the release.

The execution activities supported by order entry and tracking include the revenue-producing activities of customer order capture, production start, and delivery start.

The planning activities supported by order entry and tracking include tactical planning for all of engineering, manufacturing, and delivery, according to the "nature of the business" as described in Section 1.3.2.

2.2.4 Manufacturing Management

This function deals primarily with the tracking of work through the manufacturing facilities and the management of manufacturing resources that are used in performing that work.

The manufacturing resources include personnel, equipment, and materials. Since each of these is also the subject of another ERP domain (human resources, maintenance, inventory), there is *always* overlap among the concerns. And since many ERP systems developed from

Manufacturing Resource Planning (MRP II) systems, which dealt with various aspects of those resources listed above, there is no agreement about where the boundaries are. The one concern that is clearly unique to manufacturing management is the assignment of resources to specific work items. But at some level of planning that depends on resource availability and resource capabilities, which are the boundary areas.

The tracking of work begins with tentative and actual placement of “manufacturing orders” through the order entry component described above. In general, the “manufacturing order” information is a part of the manufacturing management component. Planning processes determine which resources (materials, equipment, labor) will be assigned to fulfilling these orders in which time frames, and these assignments are captured. Execution processes draw materials (usually tracked as “lots”) and use equipment and personnel to perform the work. These usages and the flow of work through the facility are captured. Finished goods leave the “manufacturing domain” for some set of distribution activities, and at this point the completion of the manufacturing orders is tracked.

The execution processes supported by manufacturing management are the revenue-producing processes that convert materials into finished goods, but that support is limited to tracking those processes.

The planning processes supported by manufacturing management are all levels of manufacturing resource planning and scheduling, except for detailed scheduling as noted above.

2.2.5 Process Specification Management

This function deals with the information associated with the design of the physical manufacturing processes for making specific products. As such it is an engineering activity, and like product engineering, should be almost entirely out of the scope of “core” ERP systems. But because several information items produced by that engineering activity are vital to resource planning, ERP systems maintain variable amounts of process specification data. In all cases, the materials requirements for a product lot – the “manufacturing bill of materials” – is captured in the ERP system. And in all cases, detailed product and materials specifications, detailed equipment configurations, detailed operations procedures, handling procedures, and equipment programs are outside the core ERP information bases. These information sets may be maintained by ERP add-ons or third-party systems, but the core contains only identifiers that refer to these objects.

For continuous process and assembly-line facilities, the major process engineering task is the design of the line, and that is completely out of scope for ERP systems. What ERP systems maintain for a product mix is the line configurations (identifiers) and equipment resources involved, staffing and maintenance requirements, the set of products output, the production rates and yields, and the materials requirements in terms of identification and classification, start-up quantities, pre-positioning requirements, and feed rates.

For batch facilities, the major process engineering tasks are the materials selection, the routing (i.e., the sequence of work-centers with particular setups), and the detailed specifications for operations within the work centers. The materials requirements, the yields, and the routings for products and product mixes are critical elements of the ERP planning information. The detailed work center operations are unimportant for planning, and all that is captured in the ERP core is the "external references" to them, the net staffing and time requirements, and the assigned costs of the work-center usages.

For job shop facilities, the major process engineering tasks are materials selection, the routing, and the detailed specifications for operations within the work centers. The materials requirements and yields for specific products are critical elements of the ERP planning information. The routing is often captured as a sequence of work center operations – "unit processes," each with its own equipment, staffing and time requirements, associated detail specification identifiers, and assigned cost. The detailed unit process specifications – operator instructions, setup instructions, equipment control programs – are kept in external systems.

No execution processes are directly supported by process specification management. All levels of resource planning are directly and indirectly supported by this information.

2.2.6 Maintenance Management

This function includes all information about the operational status and maintenance of equipment, vehicles, and facilities. "Operational status" refers to an availability state (in active service, ready, standby, in/awaiting maintenance, etc.), along with total time in service, time since last regular maintenance, etc. The ERP system tracks maintenance schedules for the equipment and actual maintenance incidents, both preventive and remedial, and typically an “attention list” of things that may need inspection and refit. With any of these there is both technical data (nature of fault, repair or change, parts installed, named services performed, etc.) and administrative data (authorization, execution team, date and time, etc.). In addition, this component tracks the schedules, labor, and work assignments of maintenance teams, external maintenance contracts and calls, and actual or assigned costs of maintenance activities.

In those organizations in which “machine setup” or “line setup” is performed by a general maintenance engineering group rather than some “setup team” attached to manufacturing operations directly, it is common to have such setups seen as part of the “maintenance component,” rather than the “manufacturing component.” Similarly, operational aspects of major upgrades and rebuilds may be supported in the “maintenance component” of the ERP system. These are areas in which the behavior of ERP systems differs considerably.

This component supports sourcing, manufacturing, and delivery activities indirectly. Maintenance, per se, is purely a support activity.

Planning activities supported by maintenance management include all forms of capacity planning, from manufacturing order release and shipment dispatching (where immediate and expected availability of equipment are important) up to long-term capacity planning (where facility age and statistical availability are important).

2.2.7 Warehousing

This function deals with the information associated with the management of finished goods and spare parts after manufacture and before final delivery to the customer.

For products made-to-stock, this domain includes the management of multiple levels of distribution centers, including manufacturer-owned/leased centers, the manufacturer's share of concerns in customer-owned/leased centers, and contracted distribution services. The primary concerns are the management of space in the distribution centers and the management of the flow of product through the distribution centers. Thus there are two major elements that are sometimes mixed together: the management of the distribution center resources – warehouse space, personnel, and shipping and receiving facilities – and the management of finished product over many locations, including manufacturing shipping areas, distribution centers per se, and cargo in-transport. By distribution center and product (family), this includes tracking actual demand experience, projected demand and safety stocks, units on-hand, in-flow and back-ordered, and units in-manufacture that are earmarked for particular distribution centers. The primary object in product distribution tracking is the shipment, because that is the unit of product management at the factory, in transportation, and through all distribution centers, except possibly the one nearest the final customers. For shipments, what is tracked is the product content, the ultimate recipient, the current location, and the associated delivery/shipping orders.

For certain products made-to-order (both made-on-demand and option-to-order), the distribution center approach is used because it facilitates planning and use of delivery resources, and usually because a sizeable part of the manufacturer's product line (such as spare parts) is made to stock. In these cases, the information managed is similar to the made-to-stock case, but actual demand

and safety stock concerns are replaced by tracking specific customer orders. Customers orders are part of shipments up to the final distribution center, and final delivery to customer is tracked from there.

For most products made-to-order, the warehousing component manages information only for finished goods in factory holding areas awaiting shipment and shipments that are in transportation to the customer. In this case, each shipment is associated with a particular customer at creation, and it may be associated with one or more manufacturing orders even before manufacturing starts. For shipments, what is tracked is the product content, the customer order, the current location, and the associated delivery/shipping orders. In many make-to-order cases, the manufacturing holding areas are managed as *manufacturing* resources instead of *warehousing* resources, and the shipments are managed as part of order tracking, thus eliminating the warehousing component.

Execution activities supported by warehousing are the revenue-producing delivery of finished goods via distribution centers and the support activities of distribution center management. The primary planning activities supported by warehousing are distribution planning and distribution requirements planning.

2.2.8 Transportation

This function includes all aspects of movement of parts and finished goods among manufacturing facilities and distribution centers as well as final delivery to customers. It can be subdivided into the management of vehicle fleets, transportation service contracts, and shipping orders.

All manufacturers manage shipping orders—the decision to move shipments of parts and finished goods from one facility to another in the process of fulfilling customer orders. What is captured for the order is the associated shipments, the starting and ending locations, the means of transfer, the nominal pickup and delivery times, and the associated authorizations. The means of transfer can be by owned vehicles or transportation service contracts, or a combination.

For transportation service contracts, what is tracked is the contractual information, the shipping and housing orders placed under those contracts, the states of those orders, and corresponding states of the internal shipping orders, and the shipments themselves. In addition, the system tracks other actions under the contract, including payment authorizations, change orders, delays, misdeliveries, damaged and misplaced goods, shipments not accepted, etc.

The management of vehicle fleets, for enterprises that have their own, entails the capture of maintenance and spare parts information and the capture of vehicle staffing, routes and schedules, and current orders, states, and locations. In general, the activities are the same as those of contract shipping organizations, but the manufacturer’s transportation fleet has only one customer and usually a small and largely pre-defined set of destinations.

Execution activities supported by transportation include movement of parts between manufacturing centers and movement of spare parts and finished products to customers and distribution centers, all of which are revenue-producing. The supporting activities of managing transportation fleets and services are also supported.

Planning activities supported by transportation include delivery planning, transportation resource planning, and transportation route planning.

2.2.9 Human Resource Management

The human resource management (HRM) component includes the management of all information about the personnel of the manufacturing enterprise – current and former employees, retirees and other pensioners, employment candidates, and possibly on-site contractors and customer representatives. For employees, the information may include personal information, employment history, organizational placement and assignments, evaluations, achievements and awards, external representation roles, education, training and skills certification, security classifications and authorizations, wage/salary and compensation packages, pension and stock plan contributions, taxes, payroll deductions, work schedule, time and attendance, leave status and history, company insurance plans, bonding, and often medical and legal data. For contract personnel, some subset of this information is maintained (according to need), along with references to the contract arrangement and actions thereunder.

The HRM system is often also the repository of descriptive information about the organizational structure, because it is closely related to employee titles, assignments, and supervisory relationships.

The execution activities supported by the HRM system are entirely support activities. They include the regular capture of leave, time, and attendance information and the regular preparation of data sets for payroll and other compensation actions and for certain government-required reports. They also include many diverse as-needed transactions, such as hiring and separation actions of various kinds, and all changes in any of the above information for individual personnel. But the HRM system supports *no* revenue-producing function directly, and it often plays only a peripheral role in strategic planning.

2.2.10 Finance Management and Accounting

This function includes the management of all information about the monies of the enterprise. The primary accounting elements are grouped under accounts payable – all financial obligations of the organization to its suppliers, contractors, and customers; accounts receivable – all financial obligations of customers, suppliers, and other debtors to this organization; and general ledger – the log of all real and apparent cash flows, including actual receipts and disbursements, internal funds transfers, and accrued changes in value. In reality, each of these is divided into multiple categories and accounts. While smaller organizations often do *finance management* under the heading *general ledger*, larger ones, and therefore ERP systems, usually separate the *finance management* concerns from *general ledger* transactions. They include: fixed asset management –

acquisition, improvement, amortization, depreciation of plants, facilities, and major equipment; financial asset management – cash accounts, negotiable instruments, interest-bearing instruments, investments, and “beneficial interests” (e.g., partnerships, etc.); and debt management – capitalization, loans and other financing, and “assignments of interest” (e.g., licenses, royalties, etc.).

The major enterprise execution activities supported by the finance management component are contracting, payroll, payment (of contractual obligations), invoicing, and receipt of payment. Payroll is a supporting activity, but payment and receipt are revenue-producing.

The primary financial planning activities supported are investment planning, debt planning, and budget and cash flow planning and analysis.

2.3 Interaction Points

It is the intent of many ERP vendors to provide the information systems support for all the business operations of the manufacturing enterprise, and ERP systems have gone a long way in that direction. But there are still several areas in which the manufacturing organization is likely to have specialized software with which the ERP system must interface. The primary mission of the ERP system is to provide direct support to the primary operations activities – materials acquisition, manufacturing, product delivery – and to the planning and management functions for those operations. The software environment of a large manufacturing enterprise includes many other systems that support non-operations business functions. This includes product planning and design, market planning and customer relations, and supply-chain planning and development. Additionally, software that supports the detailed manufacturing processes and the control of equipment is so specialized and therefore so diverse that no ERP provider could possibly address all customer needs in this area.

On the other hand, the wealth of data managed within the ERP core, as well as its logical and physical infrastructure, and the demand for that data in many of these related processes, opens the door for integrating these other functions with the ERP system. This is the situation that leads to demands for “open ERP interfaces.”

Moreover, as the ERP market expands to medium-sized enterprises, the cost of the monolithic ERP system has proved too high for that market, leading ERP vendors to adopt a strategy using incremental “ERP components” for market penetration. This strategy in turn requires that each component system exhibit some “pluggable interface” by which it can interact with other component systems as they are acquired. While ERP vendors have found it necessary to document and maintain these interfaces, thus rendering them “open” in a limited sense, none of the vendors currently has an interest in interchangeable components or *standard* (i.e., “public open”) interfaces for them. But even among components, there are “forced” ERP boundaries where the medium-sized enterprise has longer standing enterprise support software (e.g., in human resources and finance). These also offer opportunities for standardization.

At the current time, the most significant ERP “boundaries” at which standard interfaces might be developed are depicted in Figure 3.

Figure 3 Opportunities for Standard ERP Interfaces

2.3.1 Contracts Management

Contractual relationships management deals with the information associated with managing the formal and legal relationships with suppliers and customers. It consists of tracking the contract development actions; maintaining points of contact for actions under the agreements; and tracking all formal transactions against the agreements – orders and changes, deliveries and completions, signoffs, invoices and payments, disputes and resolutions, etc. ERP systems rarely support the document management function, tracking the contract document text through solicitation, offer, counter-offer, negotiation, agreement, amendments, replacement, and termination. They leave that to a legal or business document management system, and carry only references into that system where needed. They do routinely capture all transactions against agreements, but they often capture them in different places. Only a few centralize all these transactions under "contracts management."

2.3.2 Supplier Relationship Management

This activity includes information on contractual arrangements with suppliers and points of contact, relationship history (orders, fulfillments, disputes, resolutions), business evaluations, and technical evaluations of products and capabilities, including certifications for specific materials. For specific materials (or product families), there are approved supplier lists that identify suppliers from whom the organization may order that material, often with preference ranking or ranking criteria.

2.3.3 Customer Relationship Management

As mentioned previously, the objective of CRM is to add value for customers through those processes that involve direct contact with customers before, during, and after sales. This function encompasses marketing and sales activities related to the identification and characterization of markets, the characterization of product opportunities within those markets that are consistent with the strategies and expertise of the enterprise, and the development of those markets into a customer base that generates recurring demand for the products of the enterprise. ERP systems may support demand planning activities which make projections for existing products with target volumes and time requirements as well as projections for new products or product modifications. ERP systems may also support customer inquiries as to product lines and company capabilities as well as inquiries and negotiations for alternative supply arrangements. As discussed in Section 2.2.3, ERP systems always support customer orders for existing products, customer order changes and cancellations, and inquiries about customer order status.

2.3.4 Product Configuration Management

A “product configurator” tracks the design of product options from desired features to manufacturing specifications. It captures product planning, pricing, and engineering decisions about option implementations and inter-option relationships. The “sales configurator” component tells the sales staff what option combinations a customer can order and how to price them. The “manufacturing configurator” converts the option set on a customer order to a specification for bill of materials, station set-up, prepositioning requirements, batching requirements, and process selections.

In “to-order” environments, an ERP system may include a product configuration function. A product configurator captures customer-specified product options in make-to-demand, option-to-order, and engineer-to-order environments. In those environments, product configurators connect the front office with the back office. In make-to-demand and option-to-order environments, product configurators link sales with manufacturing operations. In engineer-to-order environments, product configurators are a conduit between sales and engineering.

2.3.5 Product Data Management

While ERP systems are the principal repository for all operations data, they contain only fragments of product and process engineering data. One of the reasons for this is that the ERP core is short transactions with concise data units, while engineering data management requires support for long transactions with large data files. As ERP systems have grown over the last 10 years, PDM systems have grown rapidly as the product engineering information management system, especially in mechanical and electrical parts/product industries. The rise of collaborative product and process engineering in the automotive and aircraft industries has led to increasing capture of process engineering information in the PDM. Product engineering software tools, particularly CAD systems, are used to design tooling and other process-specific appliances, and these tools often have modules for generating detailed process specifications from the product definitions (e.g., exploded bills of materials, numerical control programs, photomasks, etc.). These tools expect to use the PDM as the repository for such data. Moreover, increased use of parts catalogs and contract engineering services has led to incorporation of a significant amount of part sourcing information in the PDM. Many ERP vendors are now entering the PDM product market, and the interface between PDM and ERP systems is becoming critical to major manufacturers and their software providers.

2.3.6 Supply Chain Execution

Although ERP systems may offer a one-system solution to supporting the operations of a given enterprise, one cannot expect that solution to extend beyond the walls. The information transactions supporting the materials flows from suppliers to the manufacturing enterprise and the flows of its products to its customers are becoming increasingly automated. Although basic Electronic Data Interchange (EDI) transaction standards have been in existence for 20 years, they are not up to the task. They were made intentionally very flexible, which means the basic structure is standard, but most of the content requires specific agreements between trading partners. Moreover, they were made to support only open-order procurement and basic ordering agreements, while increased automation has changed much of the behavior of “open-order procurement” into automated catalogs and automated ordering, and made several other supplier-customer operation techniques viable in the last several years. Thus, there is a need for ERP systems to operate, via upgraded “e-commerce” interfaces, with the ERP systems of the partners in the supply chain.

2.3.7 Supply Chain Planning

Until recently, ERP-supported planning algorithms have focused on the internal behavior of the enterprise in managing its production and distribution, treating both customers and suppliers largely as black boxes with documented behaviors. The new concept is resource and market planning that focuses on the participation of the enterprise in various supply chains; thus, it can only be effective if it is part of a joint planning effort of multiple partners in those chains – the enterprise, its peers in the chain, its customers in the chain, and its suppliers. The joint planning activity must be supported by information interchanges between the decision-support software in (or linked to) the separate ERP systems of the partners. Algorithms for performing such joint planning are emerging, and first-generation software to support those algorithms is now available under the title Advanced Planning and Scheduling (APS). Further development of these algorithms and interfaces is a necessary element of the future of ERP systems.

2.3.8 Manufacturing Execution

At some point, the gathering of manufacturing resource status information and work-in-process information becomes specific to the resource and the particular manufacturing task. It requires specialized systems to implement the specialized data-capturing technology and convert that data into resource planning, job planning, and tracking information. Further, particularly in discrete batch and job shop environments, the resource scheduling process itself becomes deeply involved with the details of the manufacturing tasks and the resource setups. Finally, a great deal of information gathered on the manufacturing floor is used to improve the process and product engineering as well as to improve the characterization of machine capabilities, process yields, product quality, etc. This domain is now loosely called Manufacturing Execution Systems. Such systems deal with the details of data gathering, conversion, and assessment for specific purposes and industries. Future ERP systems must expect to interface with such “companion” factory management systems in a significant number of customer facilities. The need is to share resource planning information, resource status information, and order/job/lot release and status information.

2.3.9 Human Resource Management

Although it is considered a part of ERP, human resource management (HRM) systems have already penetrated the medium-sized enterprise market in many industries, of which manufacturing is only a subset. As ERP systems grow out of the manufacturing industry to other business areas, the need for interfacing with established HRM systems becomes apparent. And this makes standard interfaces to the “HRM Component” more attractive to ERP and HRM vendors and customers.

2.3.10 Finance

In a similar way, most businesses, large and small, have long since built or acquired financial management software to support their business practices. Moreover, those practices and the related legal requirements vary significantly from country to country and, to a lesser extent, from state to state. For ERP systems, this means no “one size fits all” customers or even all business units of a single customer. Thus, interfaces to specialized and in-place financial software packages will continue to be a requirement.

2.4 Elements of ERP Implementations

The previous section addressed the functional aspects—or the “what”—of ERP systems. This section deals with the “how” of ERP, specifically the generic software elements of current commercial ERP systems. It does not address the rationale used by a specific manufacturing enterprise to manage its own ERP selection, deployment, and upkeep. However, it covers briefly some of the tools for managing an ERP system. Additionally, it describes the generic architectures used by ERP vendors.

The basic elements of an ERP implementation include the core transaction system, packaged decision support applications provided by the ERP vendor, in-house or third-party extended applications, and a collection of tools for managing various aspects of the system (Figure 4). Each of these software elements reside in a computing environment that is typically distributed and possibly multi-platform.

Figure 4 Basic Implementation Elements of ERP Systems

2.4.1 Core ERP—Transactions

The ERP core consists of one or more transaction databases as well as transaction services. As described earlier in Section 2.2, these services include capturing, executing, logging, retrieving, and monitoring transactions related to materials inventories, facilities/equipment, labor, and money.

2.4.2 Packaged Decision Support Applications

In addition to transaction management, ERP vendors provide decision support applications that offer varying degrees of function-specific data analysis. The terms “decision support application” and “decision support systems” (DSS) refer to software that performs function-specific data analysis irrespective of enterprise level. That is, decision support includes applications for supply, manufacturing, and distribution planning at the execution, tactical, and strategic levels of an enterprise. There is considerable variability among ERP vendors regarding the types of decision support applications that they include as part of their standard package or as “add-on.” At one end of the spectrum, some vendors provide very specific solutions to niche industries based on characteristics of the operations environment (i.e., process and business nature) as well as enterprise size in terms of revenue. For example, an ERP vendor at one end of the spectrum might focus on assembly line/engineer-to-order environment with decision support functionality limited to manufacturing and distribution planning integrated with financials. At the other end of the spectrum, an ERP vendor could offer decision support functionality for supply, manufacturing, and distribution planning at all enterprise levels for a host of operations environments for enterprises with varying revenues. While such a vendor offers an array of decision support tools, one or more tactical level, function-specific applications (i.e., supply, manufacturing, distribution) are typically part of a standard ERP implementation (Figure 2). The others tend to be considered “add-ons.” While a vendor may offer these add-ons, a manufacturer may opt to forego the functionality they offer altogether or implement them as extended applications, either developed in-house or procured from third-party software vendors.

2.4.3 Extended Applications.

The wealth of data in ERP systems allows many manufacturing enterprises to use ERP as an information backbone and attach extended applications to them. The motivation for such applications is that manufacturers typically see them as necessary to achieve differentiation from competitors. These applications may be developed in-house or by a third-party. A third party may be a systems integrator who develops custom software or it may be a vendor who develops specialized commercial software. As discussed in Section 2.3, these add-ons may provide additional functionality for customer and supplier relationship management, product data management, supply chain planning and execution, and human resource management. Regardless of the source, these applications must integrate with the ERP. Application programmer interfaces (APIs) are the common mechanism for integrating extended applications with the ERP backbone, and specifically the ERP core. Even among their partners and strategic allies (i.e., certain systems integrators and third-party software vendors), ERP vendors discourage the practice of integrating their standard applications with extended applications because of potential problems with upward compatibility. Because APIs to the ERP core have a longer expected lifetime, it is presently the most common approach to accessing information in the ERP system.

2.4.4 Tools

Given the enormous scope of the system, ERP can be a challenge to set up and manage. As such, ERP and third-party vendors provide software tools for handling various aspects of these complex systems. These tools generally fall into two categories: application configuration tools, which support the setup and operation of the ERP system itself, and enterprise application integration (EAI) tools, which support integration of the ERP system into the enterprise software environment.

2.4.4.1 ERP Configurators. In an effort to decrease the amount of time and effort required to install, operate, and maintain an ERP system, vendors may provide a variety of *application configuration tools*. These tools vary in complexity and sophistication, but they all perform essentially the following tasks:

- Define the computing topology. Query the manufacturing administrator about the enterprise computing environment, the operating platforms, and the number, locations, and kinds of user workstations. Direct the set-up program to install the appropriate versions of the ERP core and packaged modules on the server and workstation platforms.
- Define the information base. Query the manufacturing administrator about the specifics of their business information environment, and assist in developing specialized information models (based on the vendor's generic ERP models) to support those business specifics. Automatically configure the ERP databases and transaction formats accordingly.
- Define tasks and workflows. Query the manufacturing administrator about the specifics of their business processes, map individual tasks to users across organizations, applications, and systems, and assist in developing specialized workflow models and decision support models. Then automatically configure the ERP workflow/task models, decision support invocations, and report formats.

- Define security and control requirements. Query the manufacturing administrator for user classifications by task responsibilities and authorizations. Define the user privileges, activity logging requirements, and security controls.

2.4.4.2 Enterprise Application Integration. Unlike application configuration tools, which are part of an ERP vendor's suite and centered on the ERP system as the integrator of business processes, *enterprise application integration* (EAI) tools are actually a non-ERP-specific category of software tools whose primary function is to support business processes by linking up distinct software systems in the overall enterprise computing environment. As such, they view ERP as one part of a manufacturer's entire IT solution. But many of these tools come with pre-defined interfaces to specific ERP systems (some are provided by ERP vendors) and are designed primarily to link other software systems and applications with the ERP system.

This is a relatively new and fragmented class of software, employing a number of techniques of varying sophistication and providing quite variable capabilities. One view of EAI is as "a selection of technologies to address a number of applications integration problems" [Gold-Bernstein, B. (1999)]. In this perspective, EAI technologies include platform integration solutions (messaging, message queueing, publish-and-subscribe, and object request brokers), message brokers (translations and transformation, intelligent routing, and application adapters), some graphical user interface (GUI) tools to define routing and mapping rules, and process automation and workflow.

A simplified view of a typical EAI architecture is provided in Figure 5. The EAI package consists of a number of application-specific “adapters,” each of which is capable of extracting data from and providing data to a particular application software package in some form convenient to that application. The adapter may also communicate directly with a central EAI engine that moves data sets between the adapters in some “message form.” In many cases the “message” is just a file while, in some cases, the sole function of the adapter is to command the application to input or output a particular file. In some architectures, the adapter is responsible for converting the application information to/from a common interchange model and format used by the EAI package. In others each adapter produces information in a convenient form, and the engine is responsible for the conversion of the messages or files between the adapters, using a common reference model or an application-to-application-specific translation, or both.

Most EAI packages are designed primarily to solve intra-enterprise communication problems. Many provide some mechanisms for Web-based access as a means of interaction with customers and suppliers.

Figure 5 EAI Systems Architectures

2.5 ERP Architectures

For purposes of illustration, the ERP community refers to tiers when describing the general logical architectures of ERP systems. While the notion of tiers generally infers a hierarchy, such is not the case with tiers in present-day ERP architectures. Advances in distributed computing technologies enable more open communication among components. Instead these tiers are the basic types of logical elements within an ERP implementation and thus provide a means for describing various ERP execution scenarios.

Figure 6 illustrates the five tiers of ERP architectures: core/internal (often called “data”), application, user interface, remote application, and remote user interface. A common intra-enterprise scenario involves the data, application, and user interface tiers. This scenario does not preclude application-to-application interaction. Similarly, common inter-enterprise scenarios include an internal user or application requesting information from an external application or an external user or application requesting information from an internal application. The Internet is the conduit through which these internal/external exchanges occur. Additionally, in many ERP systems, web browsers have emerged as the platform for both local and remote user interfaces.

Figure 6 Tiers in ERP Architectures

2.6 ERP and the Internet

The emergence of the Internet as the primary conduit for exchange of ERP-managed information among trading partners has spawned the term “Internet-based ERP.” This term does not convey a single concept but may refer to any of the following:

- Internal user-to-ERP-system interfaces based on Web browsers
- External user-to-orders interfaces based on Web browsers

- Interfaces between decision support software agents of different companies that support supply chain operations
- Interfaces between decision support software agents of different companies that support joint supply chain planning

The increasingly commercial nature of the Internet and the development of communication exchange standards have had significant impact on ERP systems. In describing this impact, the term “tier” is used in the context of ERP architecture (Section 2.5).

2.6.1 Internal User-to-ERP Interfaces

Also called “application hosting,” this approach employs user interfaces (Tier 3) based on Internet/Web technologies, notably Java, the Hypertext Markup Language (HTML), and the Extensible Markup Language (XML). In this scenario, ERP vendors as well as systems integrators take on a new role as application service providers (ASPs). It is an important change in the “product architecture” of ERP, in that the ERP vendor no longer has to maintain the dedicated workstations or the workstation software for users so connected. It also means that the ERP vendor cannot price that part of its services by “station” but instead uses transaction volume metrics. This differs from other impacts by being pure “Intranet-based” (i.e., all such connections are from within the enterprise and thus subject to alternative controls and security mechanisms).

2.6.2 External User-to-ERP Interfaces

In this scenario a remote user (Tier 5), via an interface based on Web technologies, accesses application service modules (Tier 2). This is a widely-used approach among ERP vendors and CRM vendors. It differs from the first by having many electronic business technical concerns — access authorization and data filtering, secure sockets, contract and payment references, etc. The critical question here is whether the functions supported include "order entry" or just "order tracking" and how the Web services are related to internal orders management. The CRM system may act as a staging system with no direct connect between the Web interface and the ERP system itself.

2.6.3 B2B Supply Chain Operations Interfaces

This scenario involves communication between a remote application and a local application (i.e., Tier 4 and Tier 2). The actual exchange is usually based on EDI or some XML message suites (e.g., RosettaNet [RosettaNet (2000)], CommerceNet [CommerceNet (2000)], Electronic Business XML [Electronic Business XML (2000)], Open Applications Group Interface Specification (OAGIS) [Open Applications Group (2000)], etc.) using file transfers, electronic mail or some proprietary messaging technology to convey the messages. This scenario is significantly different from the above in that neither of the communicating agents is a user with a browser. Rather this is communication between software agents (decision support modules) logging shipment packaging, release, transportation, receipt, inspection, acceptance, and possibly payment on their respective ERP systems (with some separate Tier 3 user oversight at both ends). Special cases of this include vendor-managed inventory and consignment management which are illustrate the use of the Internet in direct support of an operations process.

2.6.4 Joint Supply Planning (Advanced Planning and Scheduling) Interfaces

This scenario also involves communication between a remote application and a local application (i.e.,Tier 4 and Tier 2) with the exchange based on a common proprietary product or perhaps a XML message suite. Again the communicating agents are software systems, not users with browsers, but their domain of concern is advanced planning (materials resource planning, distribution resource planning, etc.) and not shipment tracking. In this area, there are very few vendors or standards activities yet, because this represents a major change in business process. This scenario illustrates use of the Internet in direct support of a tactical planning process.

3 AN EXTERNAL VIEW OF ERP SYSTEMS

The objective of this section is to illustrate ERP systems in a larger context. Section 3.1 provides some current thinking on the apparent macroeconomic impacts of IT, with a yet-to-be-proven hypothesis specific to ERP systems. Section 3.2 describes the relationship of ERP specifically with respect to electronic commerce, supply chains, and individual manufacturing enterprises.

3.1 ERP and the Economy

Much has been written and said about the emerging digital economy, the information economy, and the new economy. It is the authors' view that the information economy must support and coexist with the industrial economy, because certain fundamental needs of mankind are physical. However, while these economies coexist, it is clear that the sources of wealth-generation have changed and will continue to change in fundamental ways. In the last fifty years, the U.S. gross domestic product (GDP), when adjusted for inflation, has grown more than 500 percent (Figure 7). While each major industry has grown considerably during that period, they have not grown identically. Confirming that the economy is a dynamic system, the *gross product by industry as a percentage of GDP* (GPSHR) saw significant changes in the last half of the twentieth century (Figure 8). GPSHR is an indication of an industry's contribution (or its value added) to the nation's overall wealth. While most goods-based industries appear to move towards a kind of economic equilibrium, non-goods industries have seen tremendous growth. The interesting aspect of ERP systems is that they contribute to both goods- and non-goods-based industries in significant ways. In fact, for manufacturers ERP plays a critical role in extending the existing industrial economy to the emerging information economy. In the information economy, ERP accounts for a significant portion of "business applications" sales, not to mention the wealth generated by third parties for procurement, implementation, integration, and consulting. While these are important, in this chapter we focus on the use of ERP in manufacturing. Therefore, the following sections describes how ERP and related information technologies appear to impact the goods-producing sectors of the current U.S. economy.

Figure 7 GDP Growth, 1950 - 1999

Figure 8 Gross Product Originating by Industry Share of GDP, 1950 - 1997

Macroeconomics, the study of the overall performance of an economy, is a continually evolving discipline. Still, while economists debate both basic and detailed macroeconomic theory, there is consensus on three major variables [Samuelson, P. A., and Nordhaus, W. D. (1998)]: output, employment, and prices. The primary metric of aggregate output is the gross domestic product (GDP), which is a composite of personal consumption expenditures, gross private domestic investment, net exports of goods and services, and government consumption expenditures and gross investment. The metric for employment is the unemployment rate. The metric for prices is inflation. While these variables are distinct, most macroeconomic theories recognize interactions among them. It appears that the use of information technology may be changing economic theorists' understanding of the interactions among economic variables, particularly for predicting gross domestic product, unemployment, and inflation. It is important to gain a deeper understanding of these changes because their impact would affect government policy decisions—particularly those involving monetary policy and fiscal policy.

In the current record domestic economic expansion, real output continues to increase at a brisk pace, unemployment remains near lows not seen since 1970, and underlying inflation trends are subdued. During this period, inflation has been routinely over-predicted while real output has been under-predicted. Conventional economic theory asserts that as real output increases and unemployment decreases, significant pressures mount and force price increases. Yet, in this economic expansion, inflation remains in check, *apparently* due in part to IT-enabled growth in labor productivity [Greenspan, A. (1999)]. In the early 1990s, the labor productivity growth rate averaged less than one percent annually. In 1998, that rate had grown to approximately three percent. So what has happened in this decade? In the last ten years, information technology enabled—and continues to enable—companies, most notably manufacturers, to change the way they do business with access to better information (often in real-time) and better decision-support technologies. These changes have improved the way manufacturers respond to market wants (i.e., for products) and market demands (wants for products backed by buying power). ERP systems play a significant part in satisfying the latter by enabling better planning and execution of an integrated order fulfillment process. In short, ERP software enables these improvements by providing decision-makers in an enterprise with very accurate information about the current state of the enterprise. Moreover, an increasing number of manufacturers have direct access to demand information from their customers and to resource information from their suppliers. In many cases, the customer's demand information and the supplier's resource information originate in their respective ERP systems. Just as that data is more accurate for the customer/manufacturer/supplier enterprise, so too is the resulting information flowing up and down the supply chain. For the manufacturer between them, this information enables decision-makers to base decisions on accurate external information, as well as accurate internal information. The following remarks by Federal Reserve Chairman Alan Greenspan perhaps best capture the essence of this phenomenon:

> As this century comes to an end, the defining characteristic of the current wave of technology is the role of information. Prior to the advent of what has become a veritable avalanche of IT innovations, most of twentieth century business decision-making had been hampered by limited information. Owing to the paucity of timely knowledge of customers' needs and of the location of inventories and materials flows throughout complex production systems, businesses required substantial programmed redundancies to function effectively.

Doubling up on materials and people was essential as backup to the inevitable misjudgments of the real-time state of play in a company. Judgments were made from information that was hours, days, or even weeks old. Accordingly, production planning required adequate, but costly, inventory safety stocks, and backup teams of people to maintain quality control and for emergency response to the unanticipated and the misjudged.

Large remnants of information void, of course, still persist and forecasts of future events on which all business decisions ultimately depend are still inevitably uncertain. But the recent years' remarkable surge in the availability of real-time information has enabled business management to remove large swaths of inventory safety stocks and work redundancies....

Moreover, information access in real-time resulting from processes such as, for example, checkout counter bar code scanning and satellite location of trucks, fostered mark reductions in delivery lead times on all sorts of goods, from books to capital equipment. This, in turn, has reduced the overall capital structure required to turn out our goods and services, and, as a consequence, has apparently added to growth of multi-factor productivity, and thus to labor productivity acceleration.

Intermediate production and distribution processes, so essential when information and quality control were poor, are being bypassed and eventually eliminated....[Greenspan, A. (1999)]

ERP systems, in part, enable those activities described by Chairman Greenspan by providing two core functions: transaction management and near-term decision support. The objective of transaction management is to track the effect of execution activities on inventories, resources, and orders while the objective of intermediate-term decision support is to use that and other information to generate accurate plans for sourcing, production, and delivery.

3.2 ERP, Supply Chains, and Electronic Commerce

ERP systems do not provide a complete solution for supply chain management (SCM) or electronic commerce. However, especially for manufacturers, the functionality provided by ERP is a necessary (although by no means sufficient) element of both SCM and, therefore, electronic commerce. This section provides definitions of electronic commerce and SCM, and it explains the relationships among these concepts and ERP.

3.2.1 Electronic Commerce

Ask ten people to define electronic commerce and you'll likely get ten different definitions that reflect the particular biases of those asked. Recognizing the existence of these broad interpretations, this chapter uses an inclusive definition developed by the Gartner Group:

> Electronic commerce is a dynamic set of technologies, integrated applications, and multi-enterprise business processes that link enterprises together. [Terhune, A. (1999)]

The concept of electronic commerce centers on the use of technology, and those technologies tend to be infrastructural in nature. Some obvious, current technological issues include network-related subjects (the Internet, the Web, and extranets), security, interoperability of applications software, and the exchange of application-based information within and across enterprises. These integrated applications, which collectively comprise an enterprise's "electronic business" or "e-business" environment, include EDI software, supply chain management, ERP, customer relationship management, and enterprise application integration software. Issues in multi-enterprise business processes revolve around the different interactions that occur across enterprises. Electronic commerce changes—in part or in whole—the mode of these interactions from paper and voice to networked, digital information flows. The nature of these interactions, and the relationships among trading partners in general, range from coercive to collaborative depending on the general structure and practices of a given industry, the goods and/or services produced, and the impact of information technology on the distribution channels through which those goods and services flow. Recognizing and understanding these distinctions are critical for evaluating the existing and potential impact of electronic commerce across industries.

Manufacturing industries face particular challenges in realizing the benefits of electronic commerce because of the coupling of goods and information, and the coordination required across those domains. Information-intensive industries (e.g., banking, traveling, advertising, entertainment) experience the effects of electronic commerce before materials-intensive industries such as manufacturing, construction, and agriculture. In information-intensive industries, products and services lend themselves to the technology. In many of these cases, electronic commerce technology simply becomes a new distribution channel for the information product or service. The manufacturing situation is significantly more complex as it requires reconciliation of goods *and* information. The objective is not to develop new distribution channels per se (the information network does not move goods); the objective is to improve the flow of goods by using the information technology to improve the business practices. Optimizing the flow of goods through distribution channels is one particular type of electronic commerce improvement. By so doing, trading partners can root out the inefficiencies within channels and make them more adaptive to changes in the market. It is precisely those inefficiencies and adaptability that are the foci of SCM.

3.2.2 Supply Chain Management

Supply chain management is one of several electronic commerce activities. Like electronic commerce, SCM has acquired buzz-word status. Nonetheless, a common understanding of SCM has emerged through the work of industry groups such as the Supply Chain Council (SCC), the Council on Logistics Management (CLM), the APICS organization, as well as academia.

> SCM is the overall process of managing the flow of goods, services, and information among trading partners with the common goal of satisfying the end customer. Furthermore, it is a set of integrated business processes for planning, organizing, executing, and measuring procurement, production, and delivery activities both independently and collectively among trading partners.

It is important to note a critical distinction here, especially since that distinction is not explicit in the terminology. While SCM is often used synonymously with *supply chain integration* (SCI), the two terms have connotations of differing scopes. As stated previously, SCM focuses on planning and executing trading partner interactions of an *operations* nature—that is, the flow of goods in raw, intermediate, or finished form. SCI is broader and includes planning and executing interactions of any kind among trading partners, and in particular refers to the development of cooperating technologies, business processes, and organizational structures.

The operations-specific objectives of SCM can only be achieved with timely and accurate information about expected and real demand as well as expected and real supply. A manufacturer must analyze information on supply and demand along with information about the state of the manufacturing enterprise. With the transaction management and basic decision support capabilities described earlier, ERP provides the manufacturer with the mechanisms to monitor the current and near-term states of its enterprise. As depicted in the synchronized, multi-level, multi-facility supply chain planning hierarchy of Figure 2, ERP provides the foundation for supply chain management activities. Section 1 described the various levels of the hierarchy, and Section 2 described the details of transaction management and decision support.

4 ERP CHALLENGES AND OPPORTUNITIES

While evidence suggests that ERP systems have had profound positive economic effects by eliminating inefficiencies, there is still room for substantial improvement. The technical challenges and opportunities for ERP systems arise from how well these systems satisfy the changing business requirements of the enterprises that use them. Case studies in the literature highlight the unresolved inflexibility of ERP systems [Davenport, T. H. (1998)], [Kumar, K., and Van Hillegersberg, J. (2000)]. The monolithic nature of these systems often hampers, or even prevents, manufacturers from responding to changes in their markets. Those market changes relate to ERP systems in important two ways: the suitability of decision support applications to an enterprise's business environment, and the degree of interoperability among applications both within and among enterprises.

These two issues lead to three specific types of activities to improving ERP interoperability: technology development, standards development, and business/technology coordination.

4.1 Research and Technology Development

4.1.1 Decision Support Algorithm Development

Manufacturing decision support systems (DSS), especially those that aid in planning and scheduling resources and assets, owe their advancement to progress in a number of information technologies, particularly computational ones. The early versions of these applications—namely materials requirements planning (MRP) and manufacturing resource planning (MRP II)—assumed no limitations on materials, capacity, and the other variables that typically constrain manufacturing operations (e.g., on-time delivery, work-in-process, customer priority, etc.). The emergence of constraint-based computational models that represent real-world conditions, has enabled manufacturers to better balance supply and demand. In spite of the improvement in DSSs, significant opportunities still exist. Different models apply to different business environments. With the rapid pace of change, the commercial viability of the Internet, and push to “go global” there are new variables to examine and new models to develop. Instead of converging to any single optimization function, there will likely be specialization to classes of functions. That specialization has begun as illustrated in Figure 2 and described in Section 3.2 Continued specialization (not simply customization) is likely and necessary. Those classes will account for the variety of ways that manufacturing enterprises choose to differentiate their operations from those of their competitors. While cost reduction has been the focus of the current generation of DSSs, models that also address revenue enhancement and response time are expected to be the focus of future generations.

4.1.2 Component Decomposition Analysis

As decision support technology evolves, so too does ERP system functionality. While advances in software functionality effect an enterprise’s continuous IT improvement strategy, they do not comprise all of that strategy. Migration is another critical aspect of continuous IT improvement. That is, it must be possible to replace and upgrade an existing system—in whole or in part—for an enterprise to move from one functional state to another. In general, ERP vendors have focused on providing functionality at the expense of replaceability and upgradability [Sprott, D., and Wilke, L. (1998)]. Consequently, lock-in effects are major concerns for manufacturing and non-manufacturing enterprises alike.

Possessing the concepts of services and encapsulation, components are touted as the solution to this problem. A component delivers functionality to a user or another software entity through one or more well-defined interfaces. Encapsulation means that a component is a separate entity, thus making it easier with which to manage, upgrade, and communicate. Yet components alone do not guarantee interoperability, especially in complex e-business and electronic commerce environments. For ERP systems to be interoperable, there must be wide-spread agreement on the services that ERP applications provide and on the boundaries of encapsulation. There are numerous approaches to defining services and interfaces including vendor-specific conventions, intra-enterprise conventions, industry-specific standards, and technology-specific standards.

None of these approaches meet the challenges of enabling ERP interoperability in e-business and electronic commerce environments because they lack broad perspective. To achieve interoperability with the vendor-specific conventions, a single ERP vendor must dominate not just the ERP system market but the markets of all the other systems which (need to) interoperate with ERP. Intra-enterprise conventions work up to the bounds of the enterprise, as long as there are no major internal changes (such as mergers or acquisitions). The approach based on industry-specific standards fails to realize that the focal point of operations is business process and that information varies according to the characteristics of those processes. Industries obviously are defined by product not business process, and commonality of product does not translate into commonality of business process. Operations-wise, what makes sense for one supply chain member (e.g., an original equipment manufacturer (OEM)) does not necessarily make sense for another (e.g., a lower-tier supplier). The fourth approach—technology-specific standards—tends to yield limited solutions as it focuses on syntax and not semantics. Without agreement on the meaning of the information to be exchanged and the function that the information supports, the challenges of reconciliation persist. Many technology-focused efforts fail to perform sufficient domain-specific information requirements analysis.

Component decomposition analysis must address the three emerging models of business-to-business (B2B) markets because electronic commerce dramatically changes the nature of power and control in supply chains. The first approach is an OEM-controlled model such as those recently announced by US automakers and defense contractors [Stoughton, S. (2000)].The second is supplier-controlled model such as those in metals, chemical and paper industries. The third is an open model that allows control to be shared among all supply chain players. Many think that the open model will prevail in the long-run. However, industries will not collectively reach that point at the same rate or at the same time. To realize this model, it is necessary to look beyond industry-specific exchange of operations data. It is necessary to analyze business processes and characterize them at appropriate levels of detail. These characterizations would highlight the different kinds of components, and thus the information that needs to be exchanged in different scenarios.

4.2 Standards Development

Standards play an important role in achieving interoperability. With respect to ERP systems, there are opportunities for establishing standard interface specifications with other manufacturing applications.

4.2.1 ERP-PDM Interfaces

As discussed in Section 2.3.5, there is an obvious interaction point between ERP and PDM systems. Thus, there is a need for interfaces between the two systems to share separately captured engineering and sourcing specifications. In the longer run, the goal should be to have PDM systems capture all the product and process engineering specifications, and to extract resource requirements information for use in ERP-supported planning activities. Conversely, sourcing information, including contract engineering services, should be captured in the ERP system. To do this, one needs “seamless interactions” as seen by the engineering and operations users.

4.2.2 ERP-MES Interfaces

As presented in Section 2.3.8, future ERP systems must expect to interface with such “companion” factory management systems in a significant number of customer facilities. There is the need to share resource planning information, resource status information, order/job/lot release, and status information. However, developing such interfaces is not a straightforward exercise. The separation of responsibilities and the information to be exchanged varies according to many factors both at the enterprise level and the plant level. Pre-standardization work is necessary to identify and understand those factors.

4.2.3 Supply Chain Operations Interfaces

Supply chain information flows between the ERP systems of two trading partners has been the subject of standardization activities for 20 years, with a spate of new ones created by Internet commerce opportunities. Most of these changes concentrate on basic ordering agreement and open procurement mechanisms. Requirements analysis of this information is necessary before actual standards activities commence. As the business practices for new trading partner relationships become more stable, standards for interchanges supporting those practices will also be needed. Changes in business operations practices as well as in decision support systems have changed the information that trading partners need to exchange. This includes shared auctions, supply schedule, vendor-managed inventory, and other operational arrangements, but the most significant new area is in joint supply chain planning activities (i.e., advanced planning and scheduling).

4.3 Establishing Context, Coordination, and Coherence for Achieving Interoperability

Several developments of the past decade have combined to extend the locus of information technology from research labs to boardrooms. The commercialization of information technology, the pervasiveness of the Internet, and the relatively low barriers to market entry for new IT companies and their technologies, all serve to create an environment of rapid growth and change. The ERP arena, and electronic commerce in general, suffers from a proliferation of non-cooperative standards activities, each aimed at creating "interoperability" among a handful of manufacturers with specific software tools and business practices. There is an imperative to reduce competition among standards efforts and increase cooperation.

Understanding the complex environment that surrounds ERP and other e-business/electronic commerce applications is a critical challenge to achieving interoperability. *Topsight* is a requirement for meeting this challenge. The objective of topsight is to establish context, coordination, and coherence among those many activities which seek standards-based interoperability among manufacturing applications. While the hurdles that exist in the current environment are considerable, there is significant need — as well as potential benefit — for an industry-led, multi-disciplinary, and perhaps government-facilitated effort to provide direction for the development and promulgation of ERP and related standards.

The notion of topsight for improving interoperability among specific applications is not new. The Black Forest Group, a diverse assembly of industry leaders, launched the Workflow Management Coalition (WfMC), which has produced a suite of specifications for improving interoperability among workflow management systems. A similar ERP-focused standards strategy effort would strive to better understand the diversity of operations and operations planning in order to improve interoperability among ERP and related systems.

For a topsight effort to succeed in an arena as broad as ERP, particularly one that is standards-based, there must be a cross-representation of *consumers*, *complementors*, *incumbents*, and *innovators* [Shapiro, C., and Varian, H. R.,(1999)].

As *consumers* of ERP systems, manufacturers and their trading partners face the risk of being stranded when their systems do not interoperate. The lack of interoperability in manufacturing supply chains can have significant costs [Brunnermeier, S., and Martin, S., (1999)], and those costs tend to be hidden. More accurate cost structures must be developed for information goods, particularly for buy-configure-build software applications. Unlike off-the-shelf software applications, ERP systems are more like traditional assets, in the business sense, with capital costs and ongoing operational costs.

Complementors are those who sell products or services that complement ERP systems. Given the role that ERP plays in electronic commerce, this group is very large. It includes both software vendors as well as systems integrators and management consultants. Some of the software that complements ERP was discussed previously in Section 2.3. Others include additional categories of software necessary for achieving e-business: "EDI/e-commerce," business intelligence, knowledge management, and collaboration technologies [Taylor, D. (1999)].

Incumbents are the established ERP vendors, and they make up a market that is very dynamic and diverse (Table 2). Achieving consensus of any kind with such a diverse market is a considerable challenge. To achieve ERP interoperability requires, among others, deeper understanding of common elements. That understanding can be acquired by detailed functional and information analysis of the ERP systems.

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Table 2: **The Current State of ERP Market**

ERP Vendor Categories	Total Annual Revenue	Cross- Functional Scope	Manufacturing Environment Scope	Targeted Industry Scope
Tier 1 ERP Vendors	more $2 billion	Broad Manufacturing, materials, human resource, financial	broad continuous, assembly line, discrete batch, job	broad larger and mid market manufacturers

		SCM and CRM	shop, construction	across numerous industries
Tier 2 ERP Vendors	between $250 million and $2 billion	moderate, but expanding beyond one or two functional areas some adding SCM and/or CRM	variable some support one or two manufacturing environments while others support more	moderate larger and mid market manufacturers across several industries
Tier 3 ERP Vendors	less then $250 million	Narrow fill void of Tier 1 and Tier 2	narrow typically supports one type of manufacturing environment	narrow smaller manufacturers in niche industries

The notion of *innovators* in the standards process focuses on those who *collectively* develop new technology. While many individual technology development activities associated with ERP and electronic commerce might be considered innovative, there have been few explicit collective development efforts. Most ERP vendor partnerships tend to be confined to making existing products work together through application programmer interfaces. They generally do not involve the joint creation of new (and often complementary) technologies. The dynamics that compel banks and credit card companies to pursue smart card development do not exist the ERP environment. However, there are others who meet this definition of innovator. Academia is one group of innovators whose relationship with ERP vendors tends not to make headlines. Still, many of the technologies in today's ERP systems have academic roots. The perspective of university researchers across numerous disciplines would add significant value to a topsight effort.

5 CONCLUSIONS

ERP, as a subject, is very complex. It marries technology, business practices, and organizational structures. ERP systems are commercially developed software applications that integrate a vast array of activities and information necessary to support business operations and operations planning at the tactical level. ERP is software and not a business process or a set of business processes. However, as software, it enables better execution of certain processes. Although often presented as a single package, an ERP system is an envelope around numerous applications and related information. For manufacturers, those applications typically support the operations processes of materials sourcing, manufacturing planning, and product distribution. To its end-users, an individual application of an ERP system may appear seamless; however, to those who procure, implement, and/or maintain ERP systems, they are complex software systems that require varying levels of customization and support both centrally and across each application. While ERP systems are commercial applications developed by individual vendors, they can hardly be considered "off-the-shelf." They are part of a continuing trend of outsourcing IT solutions in which part of the solution is bought, part is configured, and part is built from scratch. Given their broad organizational and functional scope, ERP systems are unlike any other contemporary commercial manufacturing applications. They provide transaction management from both the business perspective and a database perspective. Additionally, they provide a basic level of decision support. Optionally, they enable higher levels of decision support that may be offered by ERP vendors or a third-party vendor.

This chapter presented an overview of ERP “from the outside” and “from the inside.” The outside view clarified the connection between ERP, electronic commerce, and supply chain management. The inside view describe the functional and implementation elements of ERP systems, particularly in the context of manufacturing enterprises, and identified the points at which ERP interacts with other software applications in manufacturing enterprises. Finally, we looked at open research problems surrounding ERP and identified those that are important to fitting ERP systems into current and future business processes.

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