The Changing Role of Information Technology in Manufacturing

Although its role in manufacturing has been more to support processes, IT is evolving to become a catalyst for process and product change. In this case study, an apparel manufacturer used a modeling framework developed by Georgia Tech to implement multiple IT solutions. It was then able to rapidly shift production resources between two separate product lines.

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Today's manufacturing enterprise, whether it produces consumer goods or weapons systems, must often juggle a range of conflicting demands. Smaller lot sizes, increased product flexibility, higher product quality, decreased delivery time, and smaller profit margins are typical of the ambitious goals in many such organizations. Through it all, the enterprise must consistently aim for the five R's—produce the right product, with the right quality, in the right quantity, at the right price, and at the right time—and it must do more than satisfy its customers: It must delight them.

These demands mean that the manufacturing enterprise must constantly evaluate its business strategy and fine-tune its processes as needed. It must be able to

- leverage its core design and manufacturing competencies and pursue new business opportunities while outsourcing noncore activities;
- implement new production strategies rapidly (mass customization, lean manufacturing, and so on); and
- predict how change will affect operational constraints, such as resource availability on the shop floor.

Correct and timely information is key to meeting these goals, and information technology—database management systems, enterprise resource planning systems, and simulation and computer-aided design tools—has become indispensable to most manufacturing enterprises. As Figure 1 shows, information is the lifeblood of the enterprise, and IT is central to all activities. Indeed, IT can be thought of as the great market equalizer: It is available simultaneously to companies, irrespective of their size and (generally) their location. Consequently, what technology an enterprise adopts—although important—is not as important as how that enterprise uses it.1

This is, of course, a well-accepted notion for the business enterprise. However, the manufacturing industry has recently begun to also define success by how effectively a manufacturing enterprise selects and integrates an IT solution to realize its corporate vision. Integration is particularly challenging because the manufacturing environment is highly dynamic, and the models and data that support diverse manufacturing activities, including design, planning, simulation, and tracking differ widely in format.

Nonetheless, we have seen several successful integration efforts. We have also seen how this integration is opening up a new role for IT: that of change catalyst. In one case study, Terry Manufacturing, which makes uniforms for both the US Department of Defense (DoD) and McDonald’s, was able to use IT to institute shared production. In a formal agreement with the DoD and McDonald’s, Terry agreed to continue to supply McDonald’s while simultaneously meeting unpredictable surges in DoD demands (such as military mobilization). Shared production meant that Terry had to be able to rapidly redirect resources originally dedicated to the manufacture of McDonald’s uniforms to accommodate unexpected shifts in the demand for DoD uniforms. It meant that Terry had to anticipate where bottlenecks would occur. This in turn meant that Terry had to have a
plan for reassigning existing resources, training additional operators, and identifying opportunities for outsourcing production.

Central to Terry's successful implementation of shared production was the Enterprise Modeling Framework (EMF), Georgia Tech's research testbed for exploring enterprise integration technologies. The main benefit of the EMF is that it provides integration across tools, not just across functional areas, as in typical enterprise resource planning systems such as SAP's R/3. The EMF helped Terry by providing a way for it to integrate its information systems and optimize resource allocation through accurate and rapid simulations.

The EMF has been used in several other case studies involving apparel companies. In these case studies, a primary benefit was that information systems could be designed more quickly and inexpensively.

**WHY SHARED PRODUCTION?**

A flexible, adaptive enterprise constantly seeks opportunities and new paradigms to stay successful. It must be able to respond to changing market demands quickly and efficiently by distributing cost and risk. To become agile, an enterprise must introduce new business models that promote distributed manufacturing, collaborative product development, and integrated supply-chain management—and it must do so in partnership with its suppliers, customers, and sometimes competitors.

This is the impetus for shared production—a capability that benefits customers, the enterprise, and the entire supply chain. The customer benefits from access to a steady base of suppliers with the necessary knowledge to manufacture the products needed and with the capability to rapidly ramp up the supply when there is an unanticipated surge in product demand. The DoD, for example, needed quick response to mobilization.

The enterprise benefits because it can diversify its products and markets. Moreover, because its employees will be cross-trained in the manufacture of diverse products, skill levels will grow. The enterprise can then rapidly reassign employees as needed, which makes it more efficient and competitive. The benefits ripple across the entire supply chain because each link in the chain must also become agile enough to derive the benefits. Moreover, this agility gives members in the supply chain the ability to change partners. The sidebar, "From Supply Chains to Value Webs," describes how this flexibility has evolved.

**ENTERPRISE MODELING FRAMEWORK**

The EMF consists of a methodology for modeling the three major facets of an enterprise—function, information, and dynamics—and the software tools to implement the methodology. It has three main model types:

- **Function.** These models capture both existing activities and what-if and desired scenarios. The As Is function model lets the enterprise understand existing activities by observing the flow of data and materials and seeing the resources needed to carry them out. The To Be function model represents the desired state—typically a product of evaluating alternative business strategies during business process reengineering.
- **Information.** This object-oriented model comprises entities such as operators, equipment, orders, and design. It captures—in a structured format—the information required to carry out enterprise activities. Here there is only a To Be model because when enterprises reengineer their processes, they typically want a fresh perspective. The focus is thus only on what is needed to realize the vision. Thus, the information model is essentially a schema of the information system that will support that vision.
- **Dynamics.** The dynamics model captures the time-varying behavior of the enterprise's functions and information. It provides a way to analyze enterprise operations through simulation and, as a result, lets users more easily allocate resources.

The EMF's main goal is to let users integrate enterprise activities by overlapping these three models. Such integration is key to the successful operation of any enterprise that must reconfigure and redeploy its resources. The EMF lets users classify enterprise models according to the functional area they depict (manufacturing and sales) and/or the tool they support (databases and discrete-event simulation). Users can thus seamlessly integrate tools within functional...
areas—tools that have traditionally been islands of automation. They can, for example, integrate a design tool (in the function model) with a simulation tool (in the dynamics model).

Another benefit of the EMF is that users can integrate models without redundancy. In a typical manufacturing enterprise, part of the information is shared among several IT tools and part is used by (or is meaningful to) only some of the tools. Many tools (databases, simulators, and financial systems) need information about part types, but only the simulator needs the statistical distribution that results from part arrivals and machinery failures. The EMF offers a modular modeling methodology—a build-as-you-go paradigm—that first captures five types of information common to multiple IT tools: material flow, dataflow, control flow, resources used, and data structure. Users can then build on this core information to include requirements for specific applications.

Figure 2 shows the typical process stages in developing an enterprise model using the EMF. Although the figure shows a unidirectional arrow, the process is highly iterative. After the To Be function model, the path taken depends on the goal of the modeling effort. If the focus is to design and implement an information system, the user would move from information modeling directly to RDBMS code generation. However, if the modeling goal was to explore alternatives for parts flow on the shop floor, the user would move from function modeling to a simulation path after developing the To Be function model. Finally, if the goal is to reconfigure the enterprise operations and set up an information system, the user will execute both RDBMS code generation and simulation. Thus, EMF provides the desired degree of flexibility to accommodate a variety of user needs and modeling goals. The entire process can take anywhere from six months to a year, depending upon the scope of the reengineering effort, among other factors.

**Function and information models**

The function model is based on the IDEF0 (US Air Force's Integrated Computer-Aided Manufacturing Definition, version 0) methodology, which has been around since the mid-1970s and is widely used in aero-

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**From Supply Chains to Value Webs**

IT solutions for manufacturing have been evolving to enable the manufacturing enterprise to meet its growing challenges successfully. Information exchange, which began with highly individualized conversations between artisans and their customers, has roughly followed the evolution of manufacturing over the past three decades.

The mainframe, introduced into manufacturing in the 1960s, provided the necessary support for the information needs of large and relatively static enterprises. In the late 1970s, businesses began to run specific applications (such as inventory management and material requirements planning), which they had either purchased or had their IT groups develop in-house.

In the 1980s, with increased competition among manufacturers, customers wanted greater product choice and demanded a higher degree of customization. IT began to move from a supporting to an enabling technology—making it easier to implement cellular manufacturing, which enterprises used to produce smaller lots of more diverse products. The advent of client-server computing enabled manufacturing to build its own systems.

Although these systems met the specific needs of the plant or division, they did not integrate well with each other, a situation that led to islands of automation. Generic IT standards for data access and manufacturing-specific standards, such as the Standard for Exchange of Product Data (STEP), solved some of the problems associated with integrating disparate IT solutions for manufacturing.1

1. The 1990s have seen IT—and more specifically the Internet—give birth to a new business paradigm, the value web.2 In this paradigm, companies within a value web add value to the product, process, or service delivered. All the companies in the web have a multitude of relationships with one another: They can variously act as suppliers, buyers, partners, and competitors. The traditional concept of supply or value chain will gradually give way to this new paradigm. Supply chains are too linear; the multidirectional interactions in a value web are more representative of today's business world. A chip manufacturer, for example, might supply microprocessors to some computer makers, complete motherboards to others, or even a complete system to be marketed by a third party under a different name.

In this era, the manufacturing enterprise demands innovative and well-integrated IT solutions. For example, Boeing is radically restructuring its IT infrastructure to meet its customers' demands. Part of the restructuring involves integrating its manufacturing and related solutions, including enterprise resource planning (Baan), factory floor (CimLink), product data management (SDRC), forecasting (i2 Technologies), and product configuration (Trilogy).3 This restructuring is expected to pay off by cutting Boeing's time to deliver a commercial airplane from 36 months to anywhere between eight and 12 months. It will also allow Boeing's customers to locate and order spare parts and expedite their delivery.

**References**

space and other manufacturing industries. IDEF0 uses hierarchical cell decomposition to represent an enterprise's functions.

We chose IDEF0 over other activity-modeling methodologies for several reasons. Some methods, such as process flow charts, are not hierarchical, which makes it hard to understand large models that cover multiple functional areas. Others, such as dataflow diagrams, allow hierarchical decomposition but do not distinguish between data and control flow and omit information on the resources that functions require. Finally, many activity-modeling methods are hard to understand; IDEF0 has few primitives and its graphical representation of functions means that users at many levels can understand them and thus have a common basis for communication.

To derive the EMF information model, we enhanced the IDEF1x (IDEF version 1 extended) model by including object-oriented concepts such as specialization and aggregation hierarchies. The information model also comprises the knowledge and heuristics used to carry out different enterprise functions. Users can maintain this knowledge as constraints integrated with the EMF models (assertions and rules) or as separate knowledge-based systems built using tools such as rule-based expert system shells. This integration of constraints is not possible with other information models.

The EMF can capture two types of constraints. Assertions constrain the ways in which an application can change the entities in a specialization hierarchy. When such an entity is created or deleted or one of its attributes is updated, the EMF checks the entity's class and all its generic classes for assertions. Checking proceeds from the most generic class; entities in a class must conform to the constraints imposed by their generic class.

ECA (event-condition-action) rules dictate what happens after an event. When an event occurs, either from database triggers or rule-based reasoning, the EMF checks conditions. If conditions are satisfied, it initiates the appropriate actions. For example, when a part arrives in the input buffer (event), the EMF checks to see if the machine is available to perform the required operations (condition). If so, it engages the machine, which processes the parts (action).

When the heuristics or reasoning rules involved in performing an operation are extensive, EMF users can create or use tools to model them—essentially building intelligent assistants. With these tools, modelers can implement the rest of the information system from the three EMF models.

Dynamics model

Simulation is a popular way to study an enterprise's dynamics to make decisions about matters such as resource allocation. Typically, simulation is carried out as a distinct activity and is not closely integrated with the enterprise information system, even though information about the enterprise is critical input to the simulation. For obvious reasons, it is better to integrate process and resource information with the simulation tool.

To accomplish this, the EMF provides tools that let users integrate the function, information, and dynamics models without redundancy. Indeed, EMF users develop the dynamics model as an extension of the function and information models.

Figure 2. Stages of EMF modeling. The modeling process begins with the As Is function model and leads to the To Be function model. From there it is highly flexible and depends on the modeling goals, modeler's experience and availability (and accessibility) of business personnel to participate in the modeling process. The three paths depicted in the figure follow unique goals. In the red path, the goal is to design and implement an information system. In the blue path, the goal is to explore alternative parts flows. In the green path, the goal is to reconfigure operations and set up an information system.
A small team of researchers from Georgia Tech and personnel from Terry Manufacturing used EMF to define and implement this strategy.

The EMF allows for the automatic generation of Siman code for simulation. Siman, a simulation package from Systems Modeling Corp., has animation capabilities (provided by the Arena program) that let models effectively show manufacturing personnel many kinds of results, such as how process changes can affect machine use.

The dynamics model can capture important differences between flow shops and job shops, the two main shop-floor paradigms. A flow shop usually produces only a few products and introduces new ones relatively infrequently. EMF users explicitly model the flow shop process plan as part of the function model by extending the definition of each activity with dynamics information, thus saving time during the modeling process. A job shop, in contrast, produces multiple products simultaneously, and new, one-time-only product orders are common. To accommodate these frequent changes, EMF users attach the job shop process sequence to the entity representing the product; that is, the plan is modeled as part of the information model.

CASE STUDY

The DoD buys about $1 billion of apparel every year. Because apparel manufacturing is labor-intensive, the DoD relies on a supplier base of small- and medium-size enterprises. Shared production and integrated IT solutions are critical if the DoD is to develop, nurture, and maintain a stable base of defense apparel suppliers into the 21st century.

In 1991, Terry Manufacturing, a small business enterprise, entered into a shared production agreement with the DoD and McDonald’s. It agreed to increase its supply of battle dress uniform coats by 20 to 60 percent to meet possible DoD demand surges if a mobilization should occur, yet maintain the supply of fast-food uniforms McDonald’s required.

To effectively carry out its agreement, Terry had to be able to rapidly shift resources and/or acquire new ones to increase production when the DoD needed more coats. It had a three-step strategy. The first step was to develop a plan that described various activities involved in implementing shared production. This included reassigning existing resources, training additional operators for specific operations, and identifying opportunities for outsourcing production.

The second step was to analyze the information needs of the various enterprise activities and design and develop an information model that supported the activities identified in the first goal.

The third step was to use IT to integrate the activities identified in the first goal with sales, planning, manufacturing, payroll, and other core enterprise activities. The idea was to satisfy this goal through a shared database that would answer questions such as

- Which resource will be the bottleneck if we have to ramp up the supply to the DoD by, say, 25 percent?
- What is the degree or amount of ramp-up we can achieve with the available resources?
- How should the shop-floor resources be reconfigured to meet the surge?

A small team of researchers from Georgia Tech (which included us) and personnel from Terry Manufacturing used EMF to define and implement this strategy. Applying the EMF process stages in Figure 2, the team developed a comprehensive function model of the areas associated with shared production. They then used the function model to identify and evaluate business strategies, such as outsourcing and employee cross-training. From this function model, they developed an information model to design and implement a shared database that would provide consistent information to personnel (shop-floor supervisors, payroll personnel, and so on). Finally, they used the information captured in the EMF models to generate discrete-event simulation code in Siman. The code helped Terry Manufacturing determine the resource needs for different levels of battle dress uniform coat production.

Function model

The As Is function model captured the major set of activities required to make shared production easier. These include

- planning and providing additional operators,
- ensuring that machines are available,
- ensuring that materials are available,
- planning for storage and shipping,
- ensuring that funds are available,
- making contingency plans for commercial customers.

The team decomposed each of these top-level functions to identify the lowest level individual activity that must be carried out to accomplish that overall function. For example, the function “Plan and provide additional operators” consisted of

- providing operators for cutting,
- providing operators for sewing,
- providing operators other than those for cutting and sewing.

Simulation and analysis of the As Is function model made it clear that Terry could increase its production up to 20 percent without outsourcing, acquiring new machines, or hiring new operators. However, to do so it would have to redeploy resources away from McDonald’s, so it needed a contingency plan to main-
tain its commercial supply (the last top-level activity in the As Is function model).

If Terry were to increase its shared production capability beyond 20 percent, it would need additional avenues such as outsourcing and augmenting existing resources. The top-level functions in the To Be function model were thus

- Identify potential satellite plants according to their ability to perform some or all production operations.
- Negotiate with potential satellite plants.
- Plan for shared production in satellite plants.
- Plan for shared production in own plant.
- Plan for integration with satellite plants through electronic data interchange.

The battle dress uniform coat is a relatively complex garment, requiring 55 assembly operations. These operations are typically divided into groups to produce garment subassemblies, including collars, pockets, and fronts. The subassemblies are sewn together in the sequence defined in the process plan to eventually create the entire coat. Thus, the groups of operations to create subassemblies could be outsourced if necessary. In this way, apparel production is similar to the production of automobiles in which components, such as seats, are outsourced and the auto manufacturer finally assembles the vehicle.

Because of the coat's complexity, once Terry chose the satellite plants, it had to develop detailed plans for their effective participation. This activity is a decomposition of the third function, “Plan for Shared Production in Satellite Plants,” which has five subactivities:

- Identify operations for satellite plants.
- Assign operations and order levels for satellite plants.
- Plan for inspection and retraining of operators in satellite plants.
- Communicate orders to satellite plants.
- Select trainers.

Terry Manufacturing would perform the critical operations in producing battle dress uniform coats—those that require special equipment and operator skills—while assigning others to the satellite plants. It therefore needed a plan for training the satellite plant operators in selected operations and in quality control, and it needed some way to communicate order levels, inspection procedures, and training plans to the satellite plants. To effectively use its resources, Terry Manufacturing would train its own personnel, who would in turn train the satellite plant operators.

When the subassemblies from the satellite plants were brought to Terry Manufacturing and integrated into the production sequence, Terry needed some way to assure their quality. The activity “Plan for shared production in own plant” in the top-level activities of the To Be function model covers this requirement.

**Information model**

The information model represented the information entities associated with shared production as attributes, entity interrelationships, and constraints. It captured information about operators, machines, materials, inventory levels, vendors, customers, customer orders, quality reports, process plans, and the plants' (both Terry's and the satellites') capacities. Figure 3 shows one view—the manufacturing resources view—from the model's 27 tables. There are five views in all, including customer order management, process plan, plant description, and raw materials procurement.

The team chose a two-tiered client-server architecture for system development. They reasoned that the tools needed to build the system were not complex. They also did not feel scalability was an issue for an organization the size of Terry Manufacturing. Until recently, tools for developing three-tiered, distributed applications were proprietary, expensive, or not mature enough.

Since this case study, however, developments in components and distributed computing technologies have made three-tiered architecture compelling even for small businesses because of its modularity and scalability. (In fact, about the same time as the Terry Manufacturing application, two other EMF users implemented business logic in separate modules and used a logical three-tiered architecture.) The team at Georgia Tech tested and debugged the information system and sent it on to Terry personnel for evaluation. The Georgia Tech team used Terry's input on the interface and system functionality to fine-tune the system. Overall, the information system clearly demonstrated the completeness of the EMF information model in capturing all the development and implementation requirements.

**Dynamics model**

The aim of the dynamics model and associated simulations was to

- Identify the bottlenecks in the current system and design a balanced machine outlay that would have no queue buildup.
- Extend the balanced setup for output rates from about 120 to 170 percent of the existing rate and determine the resources required to meet surge requirements.
- Validate the model by comparing the simulation results with the actual data.
The ability to automatically generate Siman code was a significant advantage in modeling a process that required so many distinct assembly operations. Also, changes in part-arrival rate, process time, resources employed, and so on, do not require repeated and redundant changes to the database and to the Siman code generated. It is easy to make such changes using forms that come with the EMF. The EMF provides two sets of forms for this purpose; one, shown in Figure 4, is to add dynamics information to a function definition. Another is to add a process sequence to an entity.

Terry Manufacturing was able to effect a significant transformation in its operations and remain in business through the successful use of the EMF. Figure 3 shows the manufacturing resources view of Terry Manufacturing’s information model, which captures the relationships among the manufacturing resource entities. For example, an Operation can be performed on a Workstation with the capability denoted by the entity WS_Capability. The Operation can be performed by an Operator with skills represented in the entity Operator_Skill. Thus, this view provides the framework for evaluating various approaches to reassigning operators and machines to meet surge requirements. This view is one of five in the information model.

Figure 4. The EMF forms for specifying dynamics. The user defines the activity for simulation using the form on the left and defines the simulation parameters using the form on the right.
as a viable and reliable model supplier to both the defense and civilian markets. This success story should not be unusual. The tools and practices are readily transferable and have been successfully implemented in other manufacturing enterprises.

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