and dissemination of specific new products or technologies. Generally private/public-based consortiums are promoting these investigations, with federal research dollars helping to sustain the effort. Several national programs, largely led by HUD and the Department of Energy (DOE), have resulted in marked improvements in residential technology.

#### Building America

The DOE program labeled “Building America” is aimed at reducing the overall energy use of new homes through design and construction improvements. DOE has formed a partnership with four other groups supporting the same objectives and acts as a “catalyst for change.” The other groups are the Building Science Consortium, the Consortium for Advanced Residential Buildings (CARB), the Hickory Consortium, and Integrated Building and Construction Solutions (IBACOS).

**The Building Science Consortium** works to produce energy-efficient, cost-effective, single-family home designs in 12 states. A private consulting firm based in Boston, the Building Science Consortium heads a team of five industry members and four building partners, including Pulte Homes (Nevada and Arizona) and Shaw Homes. Reports indicate that energy savings of 50–60 percent over typical regional building practices are provided at a small cost increase over normal construction techniques.

With building partners Ryan Homes and Beazer Homes, **CARB** focuses on taking a builder’s existing house plan and formulating an architectural solution that produces a more efficient mechanical and structural system. Of the four completed prototype homes, energy savings are reported to be between 20 and 35 percent over project control houses. CARB’s Web site (www.carb-swa.com) specifically requests submission of housing designs and innovations that can be integrated into the residential construction industry in the near future.

**The Hickory Consortium** is led by a team of energy and environmental design experts who work towards producing more sustainable construction practices that result in significant energy savings. Focusing their work on multifamily housing, including factory-built modular housing, the Hickory Consortium has recently completed work on the Cambridge Co-Housing Development in Cambridge, Massachusetts. This community has shown early energy savings of up to 50 percent over the Massachusetts Energy Code (prior to the adoption of the 1995 Model Energy Code).

The fourth team currently composing the Building America Program is **IBACOS**. Its Web site (www.ibacos.com) states that “IBACOS serves as a catalyst for the delivery of new ideas, products and processes to the residential building market.” IBACOS is using a three-tier approach to achieve its goal: delivery of ideas, delivery of products, and improvement in process.

The Building America program uses a systems engineering approach that models the house holistically instead of looking at each individual subsystem separately. This systems approach allows segments of the building industry that would normally work independently of one another to function in a cooperative fashion.

Design and construction decisions using a systems approach incorporate a process of weighing the overall final benefits obtained against short-term subsystem considerations. This type of critical thinking has led to ideas such as placing ductwork within the conditioned space, thus reducing insulation needs; using advanced modularization concepts; and enabling an overall reduction in mechanical system size due to the benefits of a tight building envelope (www.eren.doe.gov/buildings/building_america).

**PATH—Partnership for Advancing Technology in Housing**

PATH is another national private/public joint venture in the residential construction arena. HUD acts as the federal administrator but many other government agencies are partners in the 10-year project. A Presidential directive formally initiated PATH on May 4, 1998, with the aim of drastically improving "the quality, cost-effectiveness, durability, safety, and disaster resistance of housing in the United States." In fact, PATH lists its four main goals as follows (www.pathnet.org/goals.html):

- *Affordability:* Reduce the monthly cost of new housing by 20 percent or more.
- *Energy efficiency and durability:* Cut the environmental impact and energy use of new housing by 50 percent or more, and reduce energy use in at least 15 million existing homes by 30 percent or more.
- *Durability:* Improve durability and reduce maintenance costs by 50 percent.
- *Disaster resistance and safety:* Reduce by at least 10 percent the risk of loss of life, injury, and property destruction from natural hazards, and decrease by at least 20 percent residential construction work illnesses and injuries.

The PATH operating plan for fiscal year 1999 states, "During the next decade, the partnership aims to develop approaches, innovative housing component designs and production methods that will reduce by 50 percent the time needed to move quality technologies to market." These technologies will make it possible to produce housing that is affordable and attractive (www.pathnet.org/about/opplan.doc). Partners for the PATH project include large homebuilders, product/material providers, and academic institutions that are working to research and develop new technologies in the housing industry.  PATH and its partners have worked to catalogue over 150 distinct technologies and have held field evaluations and national demonstrations for many of these innovations.

Technology development for PATH is sponsored with mandated federal funds and grants, along with active searches for new and better ways to solve existing housing problems. PATH's commitment to refurbishing existing housing through weatherization is helping to raise the energy-efficiency of many homes. It is interesting to note that one major objective of PATH is to reduce the "monthly" cost, not the overall cost, of a new home by 20 percent. PATH's goal here seemingly is to maximize the long-term affordability of the home. Government sponsorship of higher debt-to-income ratios for mortgage applicants is mentioned as one non-technical means of making housing more affordable.

Each of the PATH program's goals is broken down in an extensive organizational chart. These charts describe the attainable steps, or actions, that need to be taken over the next few years. PATH's progress report from April 1999 states, "Each of the actions in the plan is targeted at meeting both the PATH operating objectives as well as the overall goals of the PATH program." See the PATH Web site for a more complete list of future actions ("A Report on Progress Toward Meeting the Objectives Outlined in the Operating Plan for the Partnership for Advancing Technology in Housing [PATH]," April 22, 1999, available at www.pathnet.org/about/progrpt/intro.html).

## INDUSTRIALIZATION IN OTHER INDUSTRIES

Today, manufacturing and retail industries alike have pioneered change into the information age. The affordability, portability, and power of computer systems have increased the number of stakeholders who can access and manipulate project data. This new change has led to the resurgence of U.S. manufacturing in the marketplace. In addition, advanced three-dimensional object modeling, CAD, and computer-aided machinery have raised the level to which a product can be consistently and accurately produced. These value-adding processes allow manufacturers to compete on a world-class level.

This section examines some of the lessons of industrialization from the manufacturing industry and assesses potential application of industrialized manufacturing techniques in residential construction. In particular, ideas that focus on enterprise-wide business-support systems (IT), process and production management tools, and assembly industrialization techniques are reviewed. These include JIT manufacturing, supply chain management, material/resource planning systems, and design-for-assembly systems.

### Just-in-Time Manufacturing

In the manufacturing industry, much research and effort has been made towards eliminating product inventories and waste. One program, the JIT manufacturing system, is believed to have started in the mid-1970s with Toyota Motor Company in Japan (Schroeder 1993). However, Schonberger (1982) suggests that JIT may have actually originated in the Japanese shipbuilding industry 20 years earlier. Nevertheless, the JIT manufacturing system has helped many U.S. and foreign companies increase their overall profitability. Ford, General Motors, John Deere, Mercury Marine, Black & Decker, Rockwell, Honeywell, and IBM are only a few of the U.S. companies utilizing this management technique.

Schroeder (1993, p. 662) defines JIT as "an approach which seeks to eliminate all sources of waste, anything which does not add value, in production activities by providing the right part at the right place at the right time." Meredith and Shafer (1999, p. 302) refine this definition to three basic tenets:

- minimizing waste in all forms,
- continually improving processes and systems, and
- maintaining respect for all workers.

To achieve this tightly knit system, Hernandez (1989) states there are two main principles that should be followed for JIT manufacturing: use only quality materials and make a conscious effort to reduce lot sizes to one. Some of the gains experienced in the implementation of a JIT system include lower inventories, quicker product throughput, and higher-quality products.

"JIT takes its name from the idea of replenishing material buffers just when they are needed and not before or after" (Meredith and Shafer 1999, p. 302). To develop this replenishment cycle, the JIT system uses the *Kanban* (the Japanese word for "card" or "signal") system to pull parts from one work area to the next. The rules of the *Kanban* system entail the use of a pull-system replenishment logic, the production of the right amount at the right time, the production of defect-free parts, and the implementation of continuous improvement processes (Chausse, Landry, and Pasin 1997).

Additionally, partnerships with component suppliers have played a key part in developing a successful JIT system. When companies are willing to team up with their suppliers, the quality, convenience, and economics of scale take over. General Motors' JIT system focuses on early supplier selection, family of parts sourcing, long-term relationships, and paperwork reductions in receiving and inspection for its success (Schroeder 1993, p. 679).

Many commercial and large residential construction companies are currently pursuing a JIT system for their production units. However, the value of JIT can be seen in the entire construction realm, from multibillion-dollar federal projects to small, residential remodeling jobs. The key is a combination of two doctrines established by the manufacturing industry. First, lot sizes must be reduced to one. This solution is probably the most simple to implement for a residential homebuilder. In manufacturing, customers often order products in large quantities. It is not uncommon for some manufacturers to fill orders for thousands or even millions of goods for a single customer. In construction, on the other hand, homes are usually sold to individual homeowners. It is very easy to adapt a system where the customer drives the production lot size to one. This production lot size reduction will lead to easier project scheduling, reduced project cycle times, and increased profits through lower inventories. In addition, mass customization, a feature held as a competitive edge in the manufacturing industry, will be easier to accomplish.

The second ideal that must be adopted is the implementation of a close-knit relationship between the material/product supplier and the constructor. This solution is much more difficult for the residential builder. The residential construction market is highly fragmented. However, efforts must be made by construction companies to form key alliances with their vendors and suppliers. Only with partnerships like those found at General Motors and Bose will quality and significant cost savings be realized. In fact, supply chain management is the key to implementing all three key success factors (enterprise-wide business support systems, process and production management tools, and assembly industrialization techniques) in industrializing the residential construction site.

## Supply Chain Management

"Supply chain management" broadly describes a system that monitors and controls all aspects of production. Meredith and Shafer (1999, p. 285) define supply chain management as "the supply, storage, and movement of materials, information, personnel, equipment, and finished goods within the organization and between it and its environment." Palevich (1997, p. 1) defines the term similarly: "[Supply chain management] encompasses all of those activities associated with moving goods from raw materials through the end user. This includes sourcing and procurement, production scheduling, order processing, inventory management, transportation, warehousing, and customer service. Importantly, it also embodies the information systems used to monitor these systems."

Supply chain management has become a technology-based approach to increase a company's or an industry's return on investment. Whether electronic data interchange (EDI), bar coding and scanning, or use of the World Wide Web, technology appears to be the key enabler to supply chain management. In addition, supply chain management can be used with other production and manufacturing management technologies to facilitate the information flow from raw materials to consumers.

Two studies in Appendix A, Supply Chain Management Case Examples, detail how supply chain management has helped industry. The first, a study in the textile manufacturing industry, explains how several key EDI standards were established by the Textile Apparel Linkage Council (TALC) to help facilitate communication between different parties. The second, a study at Hardware Wholesalers Inc., shows how supply chain management is be implemented in a product distribution network.

In the "information age," it has become fact that those companies that manage and control information flow quickly and accurately increase their chance for success. The construction industry is a perfect example of the importance of information management. Software tools that perform document management and project scheduling are all but overflowing the product shelves. However, these tools are internal systems. To reap the benefits of full information flow, constructors and suppliers alike must work on creating a system by which communication can flow from the manufacturer all the way down to the craftsmen and laborers who install the product in the field. Initiatives like A/E/C XML, a unified descriptor language for use in the construction industry, must create a common dialect that all parties (architects, engineers, constructors, and manufacturers) can speak. Partnerships between constructors and manufacturers must establish the value of implementing a supply chain management system. Immediate benefits include up-to-date product data and specifications (e.g., size, weight, MSDS), possibilities for customization, and increased on-time delivery. Additionally, a supply chain management system would enable all parties to reduce costs through the elimination of both work duplication and labor idle time.

## Material and Resource Planning Systems

Over the past 20 years, the development of resource planning systems has quickly generated a plethora of software solutions that attempt to monitor, control, and plan the amount of inventory within the manufacturing industry. Materials requirements planning (MRP), manufacturing resource planning (MRPII), and enterprise resource planning (ERP) systems all attempt to control raw material, finished product, and work-in-progress inventories. Additionally, the more complex (enterprise-wide) systems look at integrating more and more management functions within the resource planning tools.

### Materials Requirements Planning System

The heart of the MRP is its inventory control power. The MRP system releases manufacturing and purchase orders for the right quantities at the right times to support the master schedule. This system launches orders to control work in process and raw materials inventories through proper timing of order placement. However, the MRP system does not include capacity planning (Meredith and Shafer 1999). There are three main inputs into an MRP system-including the master production schedule (MPS), the bill of materials (BOM), and the inventory master file. "The master production schedule is based upon actual customer orders and predicted demand. This schedule indicates exactly when each end item will be produced to meet the firm and predicted demand" (Meredith and Shafer 1999, p. 268). The BOM is an engineering document that can be "represented as a symbolic exploded view of the end items' structure" (Hax and Candea 1984, p. 441). This detailed component breakdown is used in a process called "parts explosion." "The process of parts explosion will determine all the parts and components to make a specified number of [production]

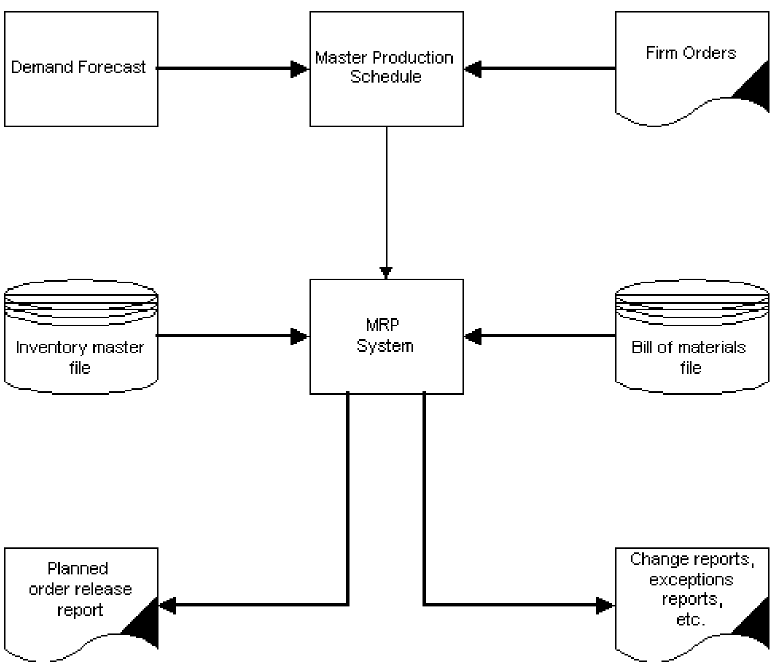


**Figure 2.5:** A materials requirements planning system schematic. *Source:* Meredith and Shafer 1999, p. 276.

units" (Schroeder 1993, p. 625). MRP systems access the BOM information to learn exactly what materials will be needed at what times and in what quantities (Meredith and Shafer 1999). The last part, the inventory master file contains detailed information regarding the exact part numbers, quantities, slated uses, costs, and lead times are generally included in the inventory master file records. Figure 2.5 shows an adapted schematic of an MRP system detailed by Meredith and Shafer (1999).

**Manufacturing Resource Planning System**

An MRPII system is "used to plan and control all manufacturing resources: inventory, capacity, cash, personnel, facilities, and capital equipment. In this case the MRP parts-explosion system also drives all other resource-planning subsystems in the company" (Schroeder 1993, p. 626). If there is not enough capacity, either the capacity or the master schedule is changed. MRPII systems have a feedback loop between the order launched and the master schedule to adjust for capacity availability (Schroeder 1993, p. 626). Forecasting, customer orders, engineering data control, purchasing/receiving/stores, and plant maintenance all serve as inputs into the scheduling process. Both purchasing/receiving/stores and plant maintenance also serve as feedback loops to ensure proper non-production work items will be performed in time with the production schedule.

In short, MRPII systems attempt to incorporate accounting, sales, engineering, and many other functional areas into their planning strategy. "Once this information is available, the purchasing, capacity planning, and operations scheduling components take over to produce purchase-order requirements, route the product through operations, generate capacity requirements by individual operations, and load and schedule operations for production" (Meredith and Shafer 1999, pp. 276–77). Figure 2.6 shows what components make up a typical MRP II system. Most MRP II systems are tailored to each company, and therefore some modules may be found in one company that may not be found in another.

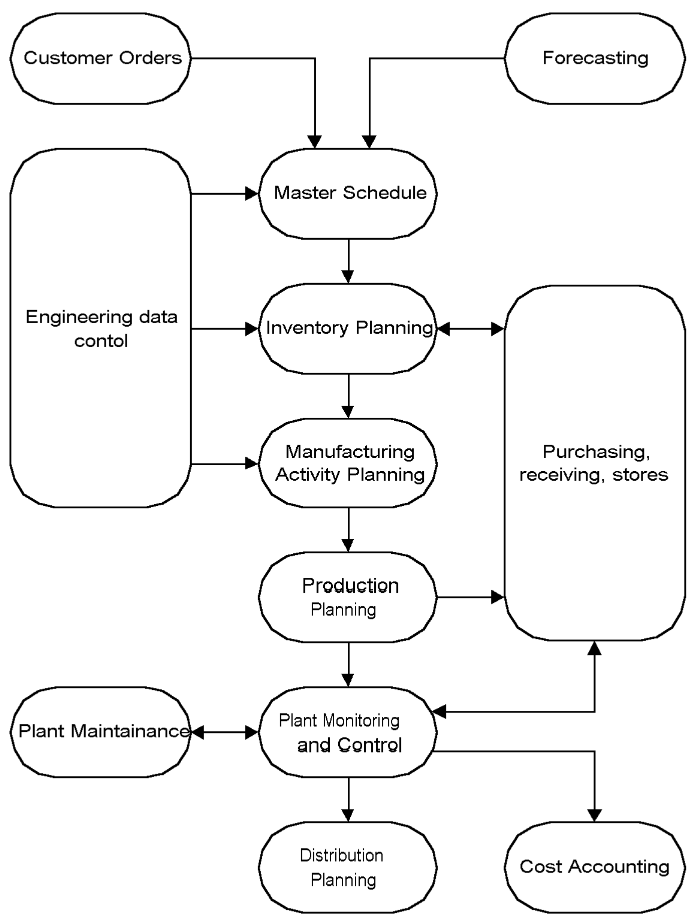


**Figure 2.6:** Typical MRP II system and its modules. *Source:* Meredith and Shafer 1999, p. 276.