MATERIAL PLANNING

Lawrence E. Kinney

Lawrence E. Kinney *is manager of software development and process engineering in AT&T Communications Products, Denver, Colorado, where he is responsible for developing process and business software systems, and for manufacturing process engineering. He is certified in production and inventory management (CPIM) by the American Production and Control Society (APICS). He holds a B.S. in technical management from Regis College, Denver, Colorado, and joined AT&T in 1970.*

This article is divided into three main sections: an introduction to the manufacturing problem that caused material requirements planning (MRP) and manufacturing resource planning (MRP II) to be developed; an overview of the theory, strategies, and components of MRP, including the master production schedule (MPS) and bill of material (BOM); and a discussion of how MRP has been put into practice at the AT&T Denver Works.

Introduction

American industry has learned—often painfully—that where labor costs are concerned, foreign competition often has huge advantages. New technologies and manufacturing techniques are dramatically increasing direct labor productivity. Management and staff support are being trimmed to increase white collar productivity. But it is increasingly evident that even these actions are not enough to permit effective competition. Improving material-related costs and product quality are additional prerequisites.

Inventory carrying costs vary from company to company, depending on the elements included. Generally they range from 25 to 35 percent of the inventory value. Increasing inventory turnover—the *velocity of material*—reduces the average level of inventory and its carrying costs. JIT (Just-In-Time) has become a panacea for inventory reduction and quality improvement. Unfortunately, JIT does not plan ahead; it only reacts to current demands. Large variations in volume or product mix exacerbate the lack of planning in JIT. To take advantage of JIT's quality benefits, a planning system must provide the right parts at the right time, from vendors far away, without high inventory levels.

MRP and MRP II presently provide the most effective ways to plan supplies of raw materials and component parts. The acronyms MRP and MRP II are extensively—and often interchangeably—used in American manufacturing. MRP is material requirements planning, and MRP II is manufacturing resource planning: the latter encompasses the former to include a wider range of factory operations.

The World Before MRP. In the early 1960s, the most accepted technique for managing inventory used various reorder point models, i.e., replenishment approaches that were heavily influenced by tech-

Panel 1. Terms and Acronyms in This Paper

APICS	American Production and Inventory Control Society
ATO	assemble-to-order
AVL PRM	*available to promise*: quantity available to promise for independent demand orders each week. This information is needed to provide realistic schedules when assigning schedules to independent demand orders consistent with availability in the MPS.
BIN	Quantity of finished items in a storeroom
BOM	bill of material
CLT	*cumulative leadtime*: MLT + leadtime to get the longest leadtime component. Planning and storeroom time can be added. With accurate leadtime information, any increase to the MPS for an item inside the timeframe will cause expediting. A decrease will cause excess inventory or de-expediting.
CRP	capacity requirements planning
end item	a product sold as a completed item or repair part, or as any item subject to customer orders or sales forecasts
DEP DMD	dependent demands calculated by the MRP system
EOQ	economic order quantity
ETO	engineer-to-order
IMF	item master file
IMPAC	Integrated Manufacturing, Planning and Control
IND FCT	independent demand forecast
IND DMD	independent demand orders
IPM	integrated pull manufacturing
ISD	information systems development
JIT	just-in-time
klingon	a software development that modifies or adds features to a core software system but is separate from it
MLT	*manufacturing leadtime*: standard shop time for manufacturing the item
MPS	master production schedule
MPU	master planning unit
MRP	material requirements planning
MRP II	manufacturing resource planning
MTO	make-to-order
PEC	price element code
PERT/CPM	Program Evaluation Review Technique/Critical Path Method
PLN ORD	*planned shop orders*: shows dates and item quantities, offset by MLT, needed to fill demands not satisfied by BIN, WIP, and SCH REC. Some systems allow the planner to freeze planned orders, so only manual intervention can change them. This line is often referred to as the master schedule for the item, because the planned orders are furnished to the MRP logic section of the system for explosion into requirements for subassemblies and component parts.
PRJ AVL	Projected availability in the bin after supplies are received and demands are satisfied. Negatives indicate the plan is not doable. The master scheduler should consider replanning the material plan.
SBA	storeroom balance accuracy
SCH REC	*Scheduled receipts*. When a shop order is created for item manufacture, it has a schedule for delivery to bin after completion. This element shows the schedules for delivery from WIP to bin, based on the current open shop order schedules.
SFC	shop floor control
S/S	*safety stock*: the item quantity needed to protect the plan from supply and demand uncertainty
TOR	turnover ratio
WIP	*work-in-process inventory:* quantity item in process in the shop, regardless of state of completion

niques for calculating economic order quantities (EOQ). (EOQ is the least-total-cost quantity of a purchased item, including order placement, transportation, storage, and inventory carrying costs.) Traditional thinking taught that lower inventory investment could be obtained only at the expense of customer service levels.

Reorder point techniques required forecasts of demand through replenishment leadtime, and assumed the forecast demands would consume available stocks. (*Replenishment leadtime* is the time from recognition of need to receipt of material.) Because both supply and demand have uncertainties, *safety stocks* often were used to protect operations from risk. When a component inventory was projected to reach the safety stock level or reorder point at leadtime, a replenishment order would be placed.

This traditional approach has many problems. Reorder point model forecasts assume uniform demand over time, but very few manufacturers experience uniform demand patterns. Replenishment leadtimes in the electronics assembly industry were long, averaging over 13 weeks; many extended to 20 weeks or more. Each member of a supply chain would use *interval* to insulate against uncertainty. (*Interval* is the time from receipt of the customer order to the time it is shipped.) Backlogs of orders were considered good, for they provided a "warm, fuzzy feeling" about short-term business volume. Expediting—i.e., placing short-interval orders and pulling orders—was the rule rather than the exception.

Also, in an environment with many components and subassemblies, the demand for "number crunching" was astronomical. Without powerful computers, calculations were performed at scheduled intervals that made the system unresponsive to the need for change. As with any system involving extensive manual calculation, errors were frequent.

Errors, infrequent and inadequate planning, and long intervals caused numerous stockouts (i.e., shortages) as well as high inventories. An inventory management cycle was all too common. Unacceptable stockout levels caused more inventory to be ordered; then, excess inventory caused top management to declare stock reductions, leading to new stockouts. Customer service deteriorated and overtime grew. Pressure to eliminate stockouts drove overordering behavior, with repeated cycles of increased inventory and new stockouts.

Burgeoning inventories were only an irritant in the early 1960s when interest rates were running under 4.5 percent. But they caused a crisis when interest rates increased to double-digit percentages in the 1970s. Inventory also consumed cash that could have bought capital equipment sorely needed to keep up with accelerating technological change. Better inventory management techniques became essential. MRP introduced a new set of tools and techniques, supported by faster, less expensive computer resources.

MRP vs. MRP II. The fundamental difference between order point techniques and MRP is *time phasing*, i.e., using current and predicted independent demands to drive timely demands for components. MRP is a time-phased reorder point system for independent demands—i.e., for items unrelated to other items—such as customer orders and service part orders. This method replaces the continuous, smooth-demand assumption used in order point models. *Dependent* demands are calculated by an MRP system as a result of its view of independent demands.

MRP requires certain inputs for its calculations:

- Master production schedule (MPS)
- Bill of material (BOM)
- Inventory status
- Replenishment leadtimes
- Manufacturing leadtimes.

The last three inputs frequently come from an item master file (IMF) with information for each part in the system. The MPS, BOM, and IMF are often considered part of an MRP system though, in the strictest sense, they are simply inputs to the MRP process. For practical purposes,

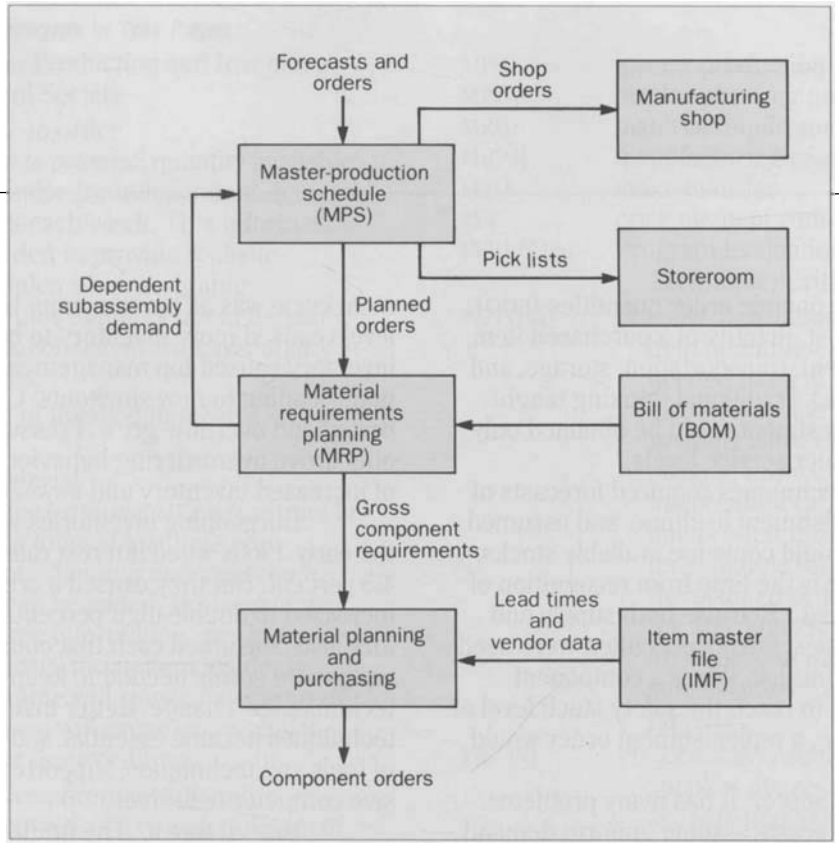

Figure 1. Schematic illustration of the basic MRP system.

these functions—as well as storeroom and procurement functions—must be considered integral subsystems for a working MRP system (see Figure 1).

MRP examines time-phased demands from the master schedule, and breaks them into their component parts, using BOMs for this "explosion." These requirements are then "netted"—i.e., reduced—by available inventories. The result is time-phased demands for components that must be satisfied by placing orders for the right amounts at the right time. This is the function called *material planning*.

As MRP logic replaced earlier techniques to manage manufacturing inventories, it became evident that MRP as described above was not enough. MRP assumed infinite capacity, both in the manufacturing facility and from vendor supply. In the real environment of finite capacities, additional tools were needed to manage execution of the plan.

There was little or no provision for "closing the loops," i.e., for a process to feed back the feasibility of the plan provided by the higher level functions. For example, if Purchasing cannot provide a component requested by the MRP system, that data is provided to the master scheduler, who determines what end products will be affected. As a result, customer orders, the production plan, and the business plan are changed to reflect realistic information. This is called *replanning*.

In the early 1980s, the term *MRP II* was used to encompass MRP and additional techniques to correct MRP's shortcomings. These techniques include capacity requirements planning (CRP) and shop floor control (SFC). The cost of establishing and maintaining the data required for CRP and SFC is high. Furthermore, CRP and SFC tend to lead to excessive replanning. This disrupts customers, shop operations, and vendors. Therefore, many attempts to implement MRP II have been unsuccessful. Using MRP for planning, and JIT techniques to manage the manufacturing operation (execution), have been successful at the Denver works.

This article is devoted to MRP planning functions. The reader can further explore MRP and MRP II via the literature on the subject.[1-3]

SAMPLE MASTER PRODUCTION SCHEDULE

Part No: XYZ Major Subassembly
MLT: 2 CLT: 16 WIP: 50 BIN: 135 S/S: 25

	CURR	WK 2	WK 3	WK 4	WK5	WK6	WK7	WK8	WK9	WK10
Ind fct:	0	0	0	100	100	100	100	100	100	100
Ind dmd:	89	103	61	65	22	3	0	0	0	0
Dep dmd:	43	269	304	280	300	300	300	300	300	300
Prj avl:	81	59	44	0	0	0	0	0	0	0
Avl prm:	0	0	0	35	78	97	100	100	100	100
Sch rec:	53	350	350							
Pln ord:	0	336	400	400	400	400	400	400	400	400

Figure 2. Sample MPS grid with 10 weekly "buckets," combining major data elements on one screen.

MRP Planning Theory

Since MRP requires software, some tend to view it as a software system. Many commercial software systems and hardware platforms perform MRP functions. There are also customized and in-house developed systems. Each software system redefines MRP according to the the expediencies and compromises chosen by the programmers or designers, and their knowledge of the subject.

One manufacturer will have more use for some features and functions of MRP than for others. There are many manufacturing dimensions that affect the requirements for an MRP system, including product complexity, product optionality (i.e., the customer's ability to order different configurations), "make" strategy (discussed below), or process manufacture (e.g., of semiconductor devices) versus assembly manufacture. MRP systems that try to satisfy all extremes for all dimensions of manufacturing are both expensive and difficult to install, use, and maintain. They have more data elements, screens, and reports than any one user would need, but somehow there is always something missing. This is the user's ticket to the software enhancement "merry-go-round."

Most companies—unable to afford the expense or time involved in custom development—make the painful choice to buy a system. It is important that the software selection process be thorough, and that an ongoing survey of available software be maintained. Changing to a new MRP system should be treated like any other business tools procurement decision.

Master Production Schedule. The MPS receives all demands for product and translates those demands into planned orders that are conveyed to the MRP logic section of the system. The format, features, and functions of the MPS vary widely among software systems: the MPS discussed below is an example. An explanation of an MPS suited for complex option product assembly operations is described in the next section.

The MPS is a time-phased schedule of end items and subassemblies. (An *end item* is a product sold as a completed item or repair part, or as any item subject to customer orders or sales forecasts.) Each end item and subassembly in the master schedule has its own part number, and is called a *planning unit*. The demand for end items combines independent demand orders (i.e., customer orders, distribution replenishment orders, and service part orders) and forecasts. As demand orders are received and scheduled, they replace the forecast. *Dependent demand* is demand derived from higher order demands (end items or higher level subassemblies). Demand in the MPS for subassemblies is a combination of

dependent demands calculated by MRP logic and independent demand (generally service part orders).

As was noted earlier, there are as many variations of MPS as there are systems. Figure 2 shows an MPS grid that combines several important data elements on one "screen." Ten weekly "buckets" are shown—current Week 1 through Week 10. The part shown is a child subassembly to a parent end item. It has independent demand from field technicians for repairs of the parent end item. This example is just a section of an MPS that can have as many as 104 weekly buckets showing the forecast over two years. Extended forecasting is required to pass forecasted volume changes to internal clients, such as Engineering or Finance, and to vendors.

In Figure 2, the calculation of the current week (CURR) planned order is the difference between supplies and demands through Week 3 (current week plus 2 weeks' manufacturing leadtime), if demand exceeds supply. Supply is:

WIP (50) + BIN (135) + SCH REC (753) = 938.

Demand is:

S/S (25) + IND DMD (253) + DEP DMD (616) = 894.

Because no additional units are required for Week 3, there are no planned orders for the current week.

Future week planned order calculation is illustrated for Week 4. Projected available supply here is 44 units. To cover demands of 100 units IND FCT and 280 units DEP DMD, 336 more units must be available in Week 4. Therefore, the system plans to start 336 units in Week 2.

Obviously, manual analysis of the data for many active items is a chore. Here, then, as in other areas of an MRP system, exception reporting is a requirement. The system needs to identify problem areas (e.g. negative PRJ AVL) to the planner for detailed analysis and corrective action.

Bill of Material. The BOM (also known as the *product definition master* or *product structure*) defines the relationship between an end item and subassemblies, and their respective component parts and subassemblies. End items and subassemblies are called *parents*, and the components and subassemblies used in their manufacture are called *children*. A subassembly is a child to its parent end item or parent subassembly, and a parent to its child subassemblies and components. Each hierarchical parent-child relationship is a level in the bill. See Figure 3 for an illustration of a three-level bill of material.

Information in the BOM file must include the:

- Parent part number
- Child part numbers
- Quantity of each child part required to make the parent
- Date each child is to become effective or removed from use in the bill (amounting to date control for scheduled engineering changes).

The bill may also include dropout and yield percentages, delivery destination, and engineering revision level, i.e., the design version represented by the bill.

MRP Logic. MRP logic uses the MPS as its time-phased source of demands, represented by planned orders in the MPS. These demands are "exploded" to generate gross requirements, i.e., the time-phased quantities of children needed to make the time-phased planned orders for a parent, without considering available inventories of the children. (*Exploding* here means translating parent into child components via the BOM.)

Current inventory and scheduled receipts of the children are then subtracted from gross requirements to provide net requirements. The children that are component parts receive no further attention from the MRP logic; but children that are subassemblies go through another iteration to generate gross requirements. This process continues until the bottom of each BOM is reached. Dependent demands for subassemblies are displayed on the MPS. Component parts are collected from their various bill explosions, so the material planner sees one stream of demands for each component.

This process can be long and require substantial

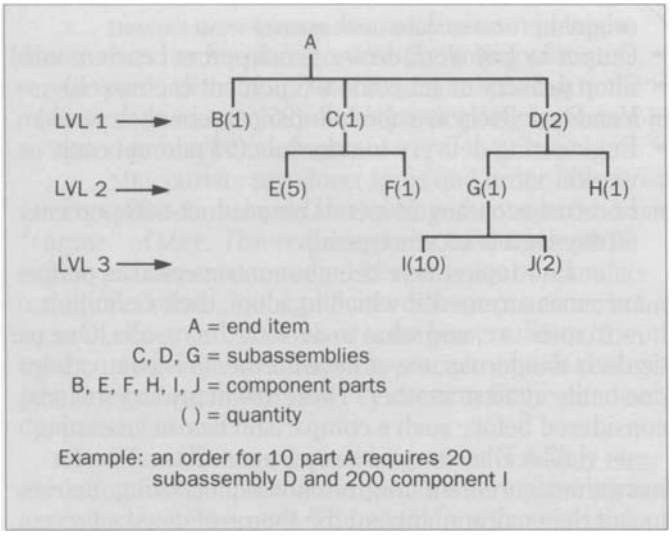

Figure 3. Schematic of the three-level bill of material, defining the relationship between an end item and subassemblies, and their related component parts and subassemblies.

computer resources. Although many companies take pride in the complexity (i.e., levels) of their bills, minimizing the number of BOM levels can save time and money. Level proliferation also has more serious consequences than just computation:

- Each level requires an assigned leadtime. Planned leadtimes rarely are accurate, and tend to be inflated. This is particularly true in systems with weekly buckets. For example, if a subassembly has a manufacturing leadtime of two days, the MLT must be set either to zero or one week. In multilevel bills, inflated leadtimes are additive. This causes dramatic overstatements of manufacturing leadtime for the end item. On the other hand, daily bucketed systems are not a panacea because they create the illusion of precision and cause unnecessary disruptions.[4]
- Standard MRP logic requires shop orders (scheduled receipts from WIP) and receipts into storerooms—to relieve open shop orders—for each level in the bill. Maintaining the proliferation of shop orders adds overhead—they must be manually adjusted to reflect changes in demand. Storerooms are expensive to operate because terminals, transactions, storekeepers, security, floorspace, and storage facilities are required.

Material Planning. *Material planning* describes the activity of utilizing gross and net requirement information for each component part from the MRP explosion. The time-phased dependent demand data is compared with scheduled receipts from vendors, and decisions are made based on policies such as ABC classification, minimum and multiple order quantities, and vendor reliability. (*ABC classification* differentiates components into three inventory classes, using criteria such as unit cost, dollar volume, or leadtime. "A" items receive more attention than "B" items. "C" items are sometimes managed by the system, while the other classes receive much manual attention. A typical breakdown of times would have 20 percent in "A," 40 percent in "B," and the remainder in "C.") The action generally will be to place orders (through Purchasing, if a separate function), cancel orders, push orders, or pull orders. As noted earlier, placing short-interval orders and pulling orders up is known as *expediting*. Similarly, canceling or pushing orders are *de-expediting* activities.

Material planning is similar to master scheduling because it attempts to balance supplies and demands. The differences are that material planning generally deals with dependent demand and with more items than the MPS, and interfaces with outside sources of supply.

Material planners often feel, justifiably, that they are in a no-win position. They must respond to changes in demand from the MPS to protect customer service (increased demands) and to protect investment (decreased demands). They are constantly expediting or de-expediting as demands change. They are held responsible for resolving stockouts and preventing them in the future. And they are held responsible for component overstocks.

Shop Order Release. Planned orders in the master schedule also represent future plans for releasing orders to the shop. When the planned order is released by the master scheduler, it becomes a shop order (i.e., a manufacturing or work order), with a scheduled receipt date. In the MPS, it moves from the PLN ORD line to the SCH REC line in the MPS grid illustration.

This release also triggers a *pick list*, known in AT&T as a *select*. The pick list has a one-level explosion of the planning unit that informs stock selectors in the storeroom about part number, description, quantity, schedule for delivery to shop, delivery destination, and storeroom bin location.

Many manufacturers do not see their storerooms as workcenters, though in a traditional MRP installation all components are received into and issued from them. The storeroom is a critical link between the material plan and its execution. The most advanced manufacturing process can be stalled by a storeroom that does not deliver the right parts to the right place at the right time.

Performance Measurement. Consultants and MRP II literature dwell on performance measurements (the term *metrics* has become popular in AT&T) as a critical element in its successful implementation. Metrics can serve as both goal setting and progress evaluation tools. One popular approach has been to establish classes of performance—A, B, C, and D—with class "A" as the pinnacle of success.

The following metrics, with a suggested Class A performance level, are characterized as the "basic pieces of data that must be accurate if the formal system is to work."[5]

- Inventory (95 percent accuracy)
- Bills of material (98 to 99 percent accuracy)
- Routings (95 percent accuracy)
- Master schedule (95 percent by item produced during the month)
- Shipping dollars (100 percent shipped within the month)
- Delivery performance (95 percent delivery against the original promise date each week)
- Output by key work center (+/- 5 percent each month)
- Shop delivery to schedule (95 percent each week)
- Vendor delivery to schedule (95 percent each week)
- Engineering delivery to schedule (95 percent each week)
- Forecast accuracy (depends on product—90 percent 60 days in advance is typical).

Few topics have been as controversial as performance measurements: which to adopt, their definition, how to measure, and what to do with the results. One particularly dangerous use of measurements is comparing one entity against another. There are many factors to be considered before such a comparison has any meaning.

AT&T has moved away from a Class A performance measurement program toward localizing metrics to suit the environment and the theme of constant improvement. It would be unfair to dismiss the claim that the current state of performance metrics in AT&T is an evolutionary step that probably would not have occurred unless there had first been a structured corporate Class A program. The performance metrics used in the Denver Works will be discussed in a later section.

Additional Considerations

There are two significant areas critical to effective MRP operation that are not well-covered in the literature. The first is *storeroom operations*, the second is *independent demand order management and MPS interface.*

Storeroom Operations. Standard MRP logic requires storeroom transactions for each level of the bill of material. In other words, components are received in a storeroom, stored, issued to the shop, assembled into subassemblies or end items, and shipped back to a storeroom. Subassemblies are issued to the shop (with component parts, if required) to make higher-level assemblies, and are delivered to a storeroom—and so forth. The process of receiving, managing, and issuing material in storerooms is left to the MRP system implementer or software designer.

Demand Order Management and Interface. Independent demand order management (including customer, service parts, distribution stock) and interfacing to the master production schedule are particularly important in an option product environment.

MRP purists say storerooms and order interfaces are important, but should be developed outside the basic "engine" of MRP. The requirements for a basic MRP engine are common among different types of manufacturing operations, but significant differences occur in the areas of order and storeroom management. Thus, the most cost-effective solution is to procure a basic MRP system, integrating it with other systems to fit the needs of the particular user.

Though storeroom management is mainly an execution function, the storeroom is where planning and execution systems meet. There will be some discussion of the planning side of this interface in the next section.

Make Strategies. There are several different make strategies possible in an MRP system. The strategy used for a given product is driven by engineering drawings, product complexity, product optionality, customer ordering process, and distribution strategy.

Engineer-To-Order. *Engineer-to-order* (ETO) is a strategy that supports a "job shop" environment. It involves creating a new BOM for each customer order (drawings may be provided by the customer). Manufacturing a custom milling machine is an example. Each customer order is scheduled individually in the MPS. Raw materials and component parts are ordered as customer orders generate requirements through MRP. Unless the manufacturer, anticipating orders, chooses to stock some long-leadtime parts, the interval to the customer will be at least equal to the manufacturing interval plus the longest component procurement leadtime (i.e., the cumulative leadtime).

Make-To-Order. *Make-to-order* (MTO) is a process that makes standard items. Therefore, new bills do not have to be engineered each time a demand order is scheduled. End item forecasts drive orders for component parts. Manufacturing does not start until a demand order is received. Sometimes this make strategy is also known as *build-to-order.*

Assemble-To-Order. *Assemble-to-order* (ATO) is an extension of MTO that minimizes customer order interval by building subassemblies to stock in anticipation of customer orders.

Make-To-Stock. *Make-to-stock* (MTS) is a strategy for standard products that are shipped into a distribution system in anticipation of customer orders. This off-the-shelf approach gives the customer the shortest interval. Generally, production levels are driven by stock replenishment orders from distribution warehouses.

These approaches—except for ETO—are not conducive to short-interval manufacture of option products without excessive inventories. Techniques that allow these objectives to be met in the MTO and ATO environments are described in the next section.

MRP At The Denver Works

In 1984, the Denver Works was a place of considerable new and changed design introduction, strong growth of flagship product demands, and an archaic approach to inventory control. The MRP system implemented in the early 1970s had the basic MRP logic, a BOM system, a primitive MPS, a storeroom system, and a component ordering system. Its weakest part was its MPS.

Over the years, these systems accumulated a surrounding set of klingons. (*Klingon* is a term coined by the AT&T Integrated Manufacturing, Planning and Control [IMPAC] developers in Warrenville. It represents a software development that modifies or adds features to, but is separate from, a core software system. In this way, the functionality of a system can be changed to fit local needs. This avoids the difficulties in negotiating change to the core system and delays in core system development.)

Production control operated the system; personnel were selected by seniority. Indeed, seniority was the only entrance requirement, and training took place on the job. There was little or no recognition that MRP, MRP II, and a profession called "materials management" existed.

The inventory turnover ratio was 2.4—this meant the average inventory item was in the factory for 21 weeks. Turnover ratio (TOR) is a metric that has evolved into a key indicator of performance in management of inventory investment:

$$\text{TOR} = \frac{\text{period output}}{\text{average inventory for period}}$$

TOR denotes the number of times per period (usually a year) inventory is turned over. Higher TOR means higher inventory velocity, lower average inventory, and lower inventory carrying costs.

The relationship between TOR and inventory carrying cost as a percent of output (C) is:

$$C = \frac{0.3}{\text{TOR}}$$

AT&T's rule of thumb is that the numerator value—the cost of carrying a dollar of inventory for a year—is 30 percent. Based on this formula, inventory carrying costs at the Denver Works in 1984 were 12.5 percent of output, based on a TOR of 2.4. Obviously, this was an unacceptable situation.

In 1984, the Denver Works was approached by a corporate group chartered to implement MRP II throughout manufacturing. MRP II had been identified as the strategy to correct excessive inventory investment. As a result, a full-time Denver Works implementation team was formed with a team manager, a training and education manager, an implementation manager, and 11 specialists from various disciplines.

The team's charter was to implement MRP II systems and practices aimed at attaining Class A performance with respect to a set of metrics defined by the Corporate group. Once data collection processes were implemented to calculate these metrics, it was clear that the Denver Works was far from Class A in each.

People, The Foundation. While the software system selection process was taking place, there was a massive program to prepare the workforce for MRP:

- Voluntary on-site education in MRP II theory was conducted for all employees outside business hours, at no expense to the employee. The program was aimed at helping people pass the American Production and Inventory Control Society (APICS) professional certification program. Over 20,000 hours of classroom education were delivered in six modules to more than 500 people from every functional organization. Over 50 people are now fully APICS certified.
- Professionalizing the materials management workforce began in 1985. Incumbent employees were offered the opportunity to move to a professional classification that required performance evaluation and salary compensation commensurate with performance. Everyone elected reclassification. Seventeen people were hired into materials management, representing a mixture of new graduates from an area college and people with industry experience.
- The materials management work environment was upgraded from an open area with tile floors, desks lined up in rows, and dumb terminals, to two-person carpeted cubicles equipped with mainframe-linked personal computers and printers.
- The first supervisory level (Section Chief) was eliminated, and all personnel in each department reported directly to second-level managers.

The professionalization effort, along with implementation of new information systems, worked so well that materials management at the Denver Works is today producing superior results with 25 percent fewer personnel than at the beginning of the MRP implementation. The reductions were accomplished through promotions, transfers, and attrition.

Software Selection and Training. In early 1986, the Denver Works selected an AT&T-developed MRP system, IMPAC—(Integrated Manufacturing, Planning and Control)—based on its functionality, development support, and because it was already installed and working at another AT&T location, the Oklahoma City Works.

IMPAC is currently operating at four major AT&T

manufacturing locations: Oklahoma City, Denver, Columbus, and Merrimack Valley. Software development, systems engineering, and support operations are centralized in Warrenville, Illinois.

Three hundred people—including storeroom personnel, master schedulers, and material planners—were trained on IMPAC during the first half of 1986. This 7,800 hours of training was conducted during business hours, using a test copy of IMPAC.

Data Accuracy. The importance of accurate data in an MRP system cannot be overemphasized. Once robust processes for measuring accuracy of storeroom on-hand balances and BOMs were in place, it was apparent that both databases were only 70 to 80 percent accurate.

Storeroom balance accuracy (SBA) is important because the system uses the data for each component to calculate net requirements driving component orders. If the balance is overstated a stockout will occur, because the material planner will not order enough components—by the amount of the error—to satisfy future requirements. When a corporate SBA software system was installed, storeroom management implemented an accuracy improvement program that has consistently produced balance accuracy above 98 percent.

BOM accuracy is even more important, for SBA only affects net requirements once, but a bill error affects *all* future requirements. Corporate guidelines for audit and reporting bill accuracy are still in use. Here, too, accuracy is above 98 percent.

Project Management. The implementation project was managed through a matrix process. The project team was responsible for education and training, all implementation-related expenses, scheduling planning meetings with the functional users, documenting meetings, collecting and publishing policies and procedures, and overseeing progress among groups. The overseeing function was important in bringing together diverse points of view among organizations such as master scheduling, material planning, the operating shops, customer service, and information systems development (ISD).

Representatives from each functional area met weekly with the project team to review progress and upcoming milestones. PERT/CPM (Program Evaluation Review Technique/Critical Path Method) was the project tracking methodology and tool. Only high-level tasks and milestones were established beyond a three to six-month horizon; it was deemed futile to attempt detailed plans beyond that in a dynamic project of this kind.

Migration Strategy. To test IMPAC in the Denver Works environment, a simple make-to-stock product was selected as the pilot. Conversion software moved data from the existing systems to a test copy of IMPAC, and users both tested and familiarized themselves with operations. After this shakedown period, the production IMPAC system was initialized with this same product in March 1986.

Over the next four months, additional non-option products were converted to IMPAC. The users from the storeroom and material planning encountered serious problems. Both organizations were having to use two systems, creating confusion and extra work. The solution was to move all storeroom and material planning functions to IMPAC from the existing systems. This change allowed the existing storeroom and material planning modules to be "turned off," and required that demands from the existing MRP logic be added to IMPAC demands. This became known as the *two system fix*, and was implemented in October 1986.

Initially, when IMPAC came to the Denver Works, it was unable to manage high-option products. Option product migration required designing systems that would feed the IMPAC MPS with forecasts and orders for both apparatus (e.g., circuit packs) and for equipment (e.g., carriers and cabinets). A local development was implemented in December 1986 that allowed flagship product circuit pack migrations to be completed by February 1987, and all remaining Denver products—including equipment—by the end of that year.

Demand Management. There are two approaches to managing option product such as the Definity® PBX in

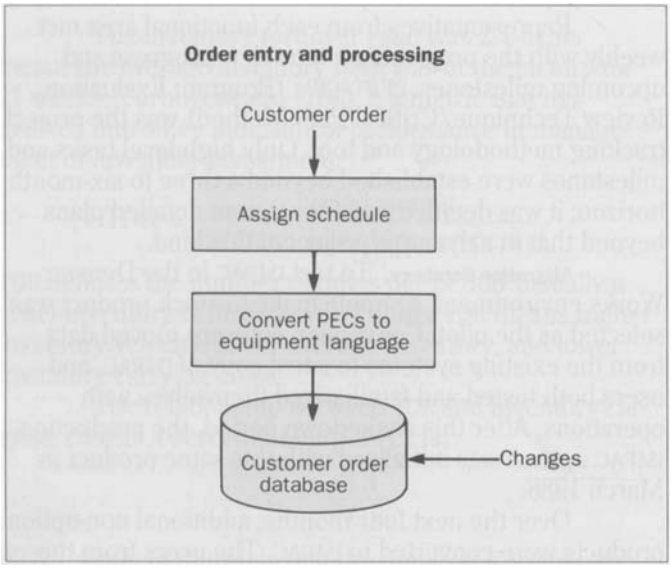

Figure 4. Schematic of order entry and processing, showing the flow from customer order through the customer order database.

an MRP system. One is to create a BOM for each customer configuration, and master–schedule the part number for that configuration. The other is to master–schedule subassemblies that are options, but contain no options themselves. The Denver Works chose the latter approach; details of how this was achieved are described by Kinney, Clancy, Foo, and Lindemulder elsewhere in this issue.[6]

Customer orders for new PBX systems and additions to existing systems are received daily as price element codes (PEC). A local order-processing system converts the PECs to comcodes (i.e., 9-digit numeric part numbers) and equipment drawing language, and establishes the orders on the customer order database, with a predetermined schedule (see Figure 4). This conversion takes place overnight, updating the customer order database with new orders, shipments, schedule changes, and configuration changes.

The IMPAC/MPS contains a schedule screen for each subassembly (i.e., planning unit) that can be required in a customer configuration. Collaboration with product designers has resulted in equipment drawing structures that lend themselves to the planning unit approach. There are only about 2,000 planning units—i.e., buildable options such as circuit packs, carriers, or cables—for all Denver Works products.

Each night, all open orders on the customer order database are captured and provided to the MPS. The MPS also receives a combination of these open orders and unconsumed forecasts (see Figure 5), representing the "best guess" of demands at any given time. A best guess is needed, for customer orders are not always available when component parts are ordered from vendors.

Each option product (e.g., the Definity PBX) has one or more typical configurations known as master planning units (MPU). At the Denver Works there are 20 MPUs that must be forecast and consumed by orders. The MPU for Denver's most complex product, System 85, has 720 planning units in its typical configuration.

One frequently asked question is: *How can you schedule customer orders the night you receive them without checking material availability?* There are three basic approaches to scheduling customer orders in a MTO/ATO environment:

1. Examine the projected availability of subassemblies needed for each order, or even the projected availability of the components that make up these subassemblies for each order. Aside from the resources needed for such an analysis, time is consumed between getting a customer order and assigning a schedule. In a competitive, short-interval environment, this time is not available.
2. Provide schedules that equal or exceed cumulative leadtimes. Because this would frequently be over 13 weeks, this would be an unacceptable alternative.
3. Option overplanning (explained below).

The first two approaches drive a tendency to lock in schedules. A responsive manufacturer has a dynamic

customer queue, and cannot afford to lock in a schedule. Flexibility and responsiveness are competitive weapons, not burdens to be avoided.

The Denver Works method is to overplan the options with the most demand volatility. Those options that vary significantly from the mean per-cabinet demand have their rate of use in the typical configuration set above the mean rate of use. For example, if circuit pack *X* occurs an average of 5.1 times per cabinet, and has a standard deviation of 3.2, the typical bill would forecast circuit pack *X* at about 10 per cabinet. Obviously, this approach results in overplanning component parts for the volatile options. These component surpluses reside in the component storeroom, not the shop, because material is issued to the shop based on customer orders.

There is a useful side effect to ensuring that components stay in the storeroom until the last minute. It is generally recognized that there are benefits from minimizing component clutter by designing as much component commonality as possible into products. Denver Works and its design labs have reduced their component database from 38,000 to under 10,000 active components in the last five years. Therefore, there are many *crossover* components, i.e, those shared by different planning units. When components are not committed too early, component commonality provides flexibility to give customers their desired schedules.

Option overplanning allows immediate and confident scheduling of customer orders, and allows flexibility in responding to the need for schedule change, short interval orders and configuration changes.

The demand management process described here is among the most important elements in successfully implementing MRP at the Denver Works.

Separation of Planning from Execution. Instead of complex, expensive MRP II strategies, the Denver Works elected to use JIT techniques to manage shop operations. Because JIT can work only if it has the right materials at the right time, materials management focuses on planning to make this happen. The Denver system intentionally separates planning from execution wherever possible.

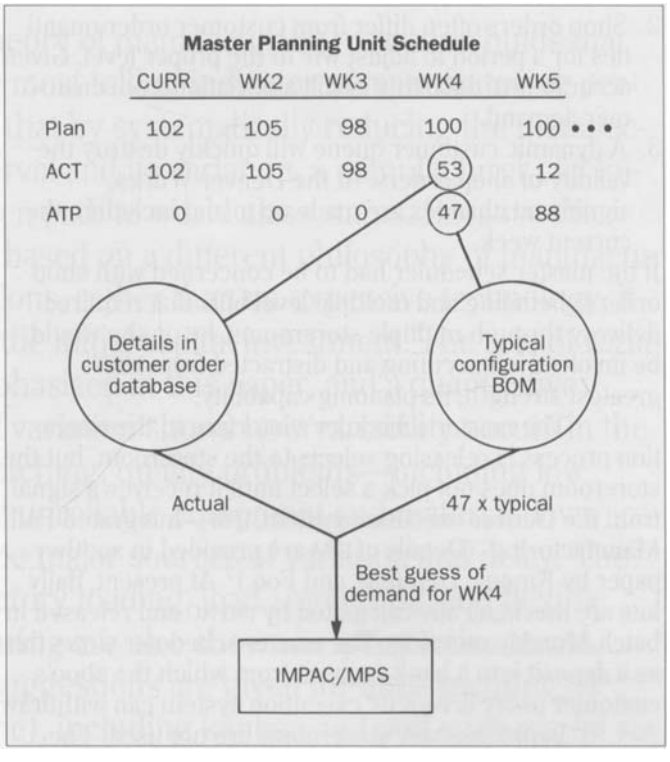

Figure 5. Master planning unit schedule, showing how it contains a combination of open orders and unconsumed forecasts that represent a "best guess" of demands at any given time.

IMPAC generates shop orders for each select (i.e., pick list) released to the component storeroom. Each shop order has a due date: the scheduled date for delivery from WIP to a storeroom. There are three reasons for shop order quantities and due dates not to coincide with customer demand:

1. Shop orders are often released in quantities rounded, by policy, to some multiple to simplify material handling. Customers do not order this way.

2. Shop orders often differ from customer order quantities for a period to adjust WIP to the proper level. Given accurate WIP data, this is still a deviation from customer demand.
3. A dynamic customer queue will quickly destroy the validity of shop orders. At the Denver Works, significant changes are made up to and including the current week.

If the master scheduler had to be concerned with shop order scheduling and multiple level bills that required delivery through multiple storerooms, he or she would be involved in executing and distracted from MRP's greatest strength, its planning capability.

The master scheduler's interface to the execution process is releasing selects to the storeroom, but the storeroom does not pick a select until it receives a signal from the Denver execution system, IPM—Integrated Pull Manufacturing. (Details of IPM are provided in another paper by Kinney, Denning, and Foo.)[7] At present, daily lots are mechanically calculated by IMPAC and released in batch Monday morning. The master scheduler views this as a deposit into a bank account from which the shop's customer order driven JIT execution system can withdraw.

In-process MRP storerooms are not used. The requirement of IMPAC to ship subassemblies to in-process storerooms is circumvented by a development, called *backflushing*, that mechanically decrements WIP for all subassemblies when the customer order is delivered. There are in-process inventory buffers to support customer order-driven JIT execution, but these do not require software systems.

Results. Implementing the MRP system at the Denver Works involved hundreds of people from all disciplines, including operating, engineering, accounting, and human resources. IMPAC support personnel from Warrenville were instrumental during the migration. Some of the key changes in results are:

	1985	1989
TOR	2.4	>10.0
Customer Interval (wks)	10	1 to 3
Scrap (percent of output)	5.5	<1.0

Though much of the credit for Denver's success belongs to those who implemented MRP and those who use it, the results above would not have been possible without the execution systems and manufacturing process improvements that make the planning effort pay off.

References

1. D. W. Fogarty and T. R. Hoffman, *Production and Inventory Management*, Southwestern Publishing Co., Cincinnati, Ohio, 1983.
2. George W. Plossl, *Production and Inventory Control: Principles and Techniques*, 2nd edition, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1985.
3. Joseph Orlicky, *Material Requirements Planning*, McGraw-Hill Book Company, New York, 1975.
4. George W. Plossl, *Production and Inventory Control: Applications*, George Plossl Educational Services, Inc., Atlanta, Georgia, 1983, pp. 229-232.
5. O. W. Wright, *MRP II: Unlocking America's Productivity Potential*, Oliver Wright Limited Publications, Inc., 5th edition, Williston, Vermont, 1983.
6. L. E. Kinney, J. P. Clancy, G. Foo, and C. Lindemulder, "Design for Material Logistics," *AT&T Technical Journal*, Vol. 69, No. 3, July/August 1990, pp. 61-76.
7. L. E. Kinney, E. H. Denning, and G. Foo, "Integrated Pull Manufacturing," *AT&T Technical Journal*, Vol. 69, No. 4, July/August 1990, pp. 110-116.

(Manuscript received April 16, 1990)