

INVENTORY MANAGEMENT:

Principles, Concepts and Techniques

Materials Management / Logistics Series

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by

John W. Toomey



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PREFACE

While teaching the APICS Certification Review Course for Inventory Management, I am reminded of the changes in the field since I took the exam over twenty years ago. At that time emphasis was placed on lot sizing, safety stocks, forecasting methods, and ordering techniques. Material requirements planning was in its early days and the dependent demand time-phased logic was covered to a greater degree in the MRP module. The present day review course, published in 1994, devotes about one-third of its contents to distribution, manufacturing environments, and Just-in-Time; factors not considered an important part of inventory management in the 1970's. These changes reflect today's business goals calling for efficient lean operations across the entire supply chain from raw material to the final customer.

The goal of this book will be to explain the dynamics of inventory management's principles, concepts, and techniques as they relate to the entire supply chain (customer demand, distribution, and product transformation processes). The interrelationships of all functions will be defined. The book concentrates on understanding the many ramifications of inventory management. In today's competitive business environment, inventory management has proven to be most critical.

This book is directed to inventory management practitioners to assist them in better understanding the body of knowledge required to operate in today's competitive environment. It is also directed to those in related fields of the business world. Almost all functions such as sales, engineering, and accounting have an impact and are impacted by inventory management. The book will assist in the training of four year and community college students as well as APICS CPIM (Certified in Production and Inventory Management) candidates. As such it will not only be a textbook but also a desk reference for those employees responsible for controlling inventories, and thereby assist in reducing cost, improving customer service, and maximizing capacity.

The book is organized to first overview the basics of inventory management (Chapter 1). Cost concepts which both drive and measure inventory management decisions are explained in Chapter 2. The basics of independent demand control are covered with Forecasting (Chapter 3), Inventory Reliability (Chapter 4), Order Quantities (Chapter 5), and Replenishing Independent Demand (Chapter 6). Systems controlling dependent demand are explained in Replenishing Dependent Demand (Chapter 7) and Master Production Scheduling (Chapter 8). Distribution Management and Distribution Resource Planning are detailed in Chapters 9 and 10. The activity or execution functions of inventory management

(Purchasing and Manufacturing) are spelled out in Chapters 11 and 12. Supply Chain Management is outlined in Chapter 13. Chapter 14 defines the many interrelationships of all the related functions.

Each chapter concludes with a case study and suggested solution. The case studies tell the story of a growing company, Smith Industries, and the related inventory management problems it had to address. The problems addressed relate to the subject matter of the chapter.

I would like to acknowledge the encouragement received from Eugene Magad of Harper College and Gary Folven and Carolyn Ford of Kluwer Academic Publishers. After two books I have learned that it can be a long road to completion. I want to also give special thanks to those who were of so much assistance in their technical reviews of the subject matter. They are Brian Carroll of Engineering Systems Associates, Roger Dykstra of Manufacturing Management Associates, Robert (Pat) O'Donnell of Hearth & Home, and Tom Setlik of Tempel Steel Company. The reviewers have been invaluable in their suggestions and corrections.

Finally, I would like to give special thanks to Joan Toomey, proof reader extraordinaire.

John W. Toomey

Chapter 1

OVERVIEW

INVENTORY MANAGEMENT DEFINED

The American Production And Inventory Society (APICS) defines Inventory Management as the branch of business management concerned with planning and controlling inventories. The role of Inventory Management is to maintain a desired stock level of specific products or items. The systems that plan and control inventories must be based on the product, the customer, and the process (either manufactured or purchased) that makes the product available. The cost of maintaining inventory throughout the entire process is a hidden cost, but nevertheless becomes part of the product cost.

The “supply chain” of a product is the process from raw material through the final product available to the end user and with linkage of all supplier-users involved in the process. The cost of inventory of a given product is the sum of the inventory costs of all parties in the supply chain. A manufacturer of an assembled product may purchase all the components and demand “just-in-time” delivery of those components from the suppliers. The assembled product may be sold through retail stores that purchase and stock in large quantities due to favorable discounts from the manufacturer. The direct cost of inventory for the manufacturer may be relatively small based on a one day supply of components, one day of work in process, and five days of finished goods. The hidden cost of inventory in the supply chain will

be the cost of the components. To assume that the suppliers will absorb the cost of inventory is naïve. Any supplier that does not pass on the cost of inventory will be in jeopardy of going out of business. Many may not be aware of their inventory costs but are well aware of the total costs (including the inventory costs) which can be the determinant of the selling cost. The cost of keeping the finished goods at a minimum is the cost of the quantity discount offered to the retailer.

The balance sheet of a company shows inventory as an asset since it is owned by the company. Other assets listed are such items as cash, accounts receivable, equipment, buildings, and grounds. The real value of these assets are dependent on how they are used. A machine purchased for \$1,000,000 and shown on the balance sheet for that amount is overstated if the machine is idle because the intended product failed in the marketplace. An accounts payable listing \$400,000 may be overstated if proper reserves for bad debts have not been established. The true value of the land might be much higher than what is listed in the balance sheet if the buildings were torn down and the land converted to commercial or residential real estate. An old manufacturing facility may be almost “written off” to a low value while it continues to produce a profitable product for the company.

Inventory is properly listed as an asset because it is owned by the company but like the examples listed above its value may be suspect. The listed value of a high fashion item may be accurate as long as the item is in style but can be grossly overstated when styles change. One must wonder how “Nehru jackets” were valued during the high of their short-lived popularity. Finished goods based on accurate costs are truly a valuable asset if they serve the customer as safety stock for forecast error or if they assist the manufacturing process as the leveler of lumpy demand. However, the same finished goods based on accurate costs is not a real asset but a liability if there is more than what is required to meet the intended purpose such as safety stock, efficient distribution or load leveling. The money invested in the excess inventory could be better utilized in other endeavors such as debt reduction, product development, process improvement, etc. The same rule applies to other investments such as lot size (cycle) stock or work in process buffers. If the inventory is needed, it is an asset. If it is not really needed, it is a liability. The Just-In-Time or Lean Manufacturing approach reduces the amount of inventory required to meet operational goals. Programs to improve forecasting will reduce the amount of safety stock required to meet desired customer service levels.

The high cost of money in the late 1970s and early 1980s forced a reevaluation of the benefits of inventory investment. The conflict that must be resolved is how much is a company willing to invest for customer service and efficient operations.

INVENTORY FUNCTIONS

The primary function of inventory is to serve the customer. The inventory may be finished goods, MRO items, or service parts that are carried in a distribution system. When the term customer service is used, it must be thought of from the customer's viewpoint considering such factors as availability in the right quantity, at the right time, in the right place, and at the right cost. The distribution system may call for carrying the item at the point of manufacturing such as a spare (service) part produced in a production lot that also is to serve an assembly requirement. At the other end of the distribution spectrum an item may be carried at a retail location far removed from the point of manufacture such as a drill sold by a hardware store after being made in China and passing through both central and regional warehouses.

Inventory planned and carried as safety stock serves as a buffer covering demand fluctuations, forecast error, and supply error. Although the monthly forecast may be quite accurate, the customers probably will not order in nice even daily increments and those short term fluctuations must be allowed for. Chances are the forecast will not be that accurate; one of the primary principles of forecasting is that it will be wrong. Anticipated forecast error, expressed as a standard deviation, can be calculated and covered through planned safety stock. Supply error can be caused by late or short quantity delivery by the supplier or the manufacturer. These errors are the result of such things as quality or capacity problems. Supply error may be buffered through either safety stock or safety lead time. The end result of planned safety lead time is the same as planned safety stock - additional inventory.

Lot size balances the cost of setting up a manufacturing order or ordering a purchased item against the cost of inventory investment. The term cycle stock is used to define this inventory. In the manufacturing environment a relatively large lot size is required if there are high set up costs; an undesirable situation not only because of inventory investment but the negative effects on operations. The setup cost of the purchased item may be unknown to the buyer but when the supplier is offering favorable quantity discounts, the supplier is covering the cost of setup in its operation. Thus a large purchased lot size is covering high setup costs at the supplier's facility rather than at the manufacturer's.

Work in process (WIP) inventory is that inventory that is in various stages of completion throughout the manufacturing process. Part of the WIP is the cycle stock mentioned above. In assembly operations, components, either purchased or manufactured, may be considered as work in process stock. The function of work in process stock is to make the work flow in as

level a manner as possible while allowing for efficient manufacturing operations. The stages of WIP may be “waiting” such as a work order waiting to be moved from one operation to the next, a component “waiting” to be assigned to an assembly order, an order being “moved” to the next operation, an order in “queue” at an operation waiting to be worked on, and finally an order being “setup and run”.

If products are of a seasonable nature such as snow blowers or children’s toys with unusually high Christmas demand, higher than normal levels of either finished goods or work in process inventories may be required for a period of time. These additional inventories allow both product availability when needed, along with a reasonable level of manufacturing operations. Vacation shutdowns or plant expansions may also require similar build-ups of inventory.

INVENTORY GOALS

The primary goal is to minimize inventory investment while still meeting the functional requirements. If the existing safety stock level of a finished goods item, with normal distribution, is allowing a service level of 99.7% and a service level of 98% is satisfactory, the safety stock can be reduced by one-third. On the other hand if the existing safety stock is allowing only 84% service and 98% is required, the safety stock must be doubled. If the customer service commitment is one day delivery from local distribution centers, the decision must be made as to where to carry safety stock. The added cost of carrying safety stock at each distribution center must be compared with the additional air freight that would be spent if the safety stock is carried at a regional distribution center or a central supply location.

Improved forecasting and process reliability will allow for inventory reductions and still will maintain the desired level of both customer service and manufacturing efficiency. A reduced variation of demand from forecast due to improved forecasting will calculate to a reduced standard deviation and therefore less safety stock required to maintain a desired service level. Improved process reliability can be achieved through on-time delivery and improved quality on the part of suppliers as well as the manufacturing operation. This improvement will allow reduced levels of raw material, component, and subassembly safety stocks without adversely affecting the manufacturing operation.

Reducing the costs of setups and ordering will allow a reduction in lot sizes (cycle stock). Working toward a goal of a lot size of one may not be achievable, but if lot quantities can be realistically reduced to a lot-for-lot calculation, all in-process inventory can be consumed at the next level of manufacture and, consequently, a significant reduction in total work in

process. A reduction in work in process translates into reduced lead time and therefore greater flexibility of manufacturing. Simplifying the bill of materials such as the elimination of subassemblies (collapsing the bills) or not stocking the subassemblies but moving to the next level (phantom bills of material) will not only reduce work in process and lead time, but will assist in synchronizing the production operations. Effective process flow for repetitive production can be best accomplished through setup reduction, bill of material simplification, and operation synchronization. The end result is efficient manufacturing with minimum inventory investment.

To achieve these goals, a concerted, continuing inventory management effort is required. This effort must involve all disciplines within the organization. An understanding of the basic principles and techniques is a requirement for all. Engineering's design of both the product and the process will affect the inventories needed for manufacturing. Duplication of part numbers will cause excess inventory. Manufacturing's ability to "make the product flow" will affect the work in process inventory. The cost of large lot sizes can be much greater than the savings in direct labor. The marketing of the product will determine the distribution network and the resulting finished goods inventories. Excess safety stock levels and unneeded warehouse stocking will cause additional inventory investment without improving customer service.

FUNCTIONAL CLASSIFICATIONS

The type or classification of inventory is a consideration in how that inventory will be managed. An end item or finished good is a completed product that is sold to a customer. If it is sold from stock, it will be in inventory based on a forecast. It may be a completed product such as an automobile or a machine tool or as simple a product as a replacement bolt. Upon completion of the manufacturing process (making the end item), the end item is transferred to the Finished Goods Inventory. How long the item is in finished goods is dependent on the manufacturing lot size, safety stock, customer demand, and the distribution system. A custom made item may be in stock for only the short time taken to process the customer invoice, while a make-for-stock item that is marketed through a multilevel distribution system may be around for months.

A subassembly is an assembly that is built to be used in a higher level assembly that may be an end item or another subassembly that in turn will be built into a higher level assembly. Modules that are used in modular bills of material can be high level subassemblies such as an automobile transmission that is not only used in planning bills of material, but is also built and stocked for assemble-to-order operations. In some assembly

operations, a subassembly may be built and immediately moved to the next assembly level. In this situation the subassembly is coded as a “phantom or transient bill of material” which allows the MRP to drive or blow through the subassembly in the explosion process but still allows the system to stock the subassembly for service usage or assembly overruns.

A component is a single item that may be either purchased or manufactured and is planned for use in a higher level of a bill of material. In the defining of a product structure, any item going into a higher level (the Parent) such as raw material, purchased parts, fabricated parts, or subassemblies are considered components. Therefore an item may be a component at one level and a parent one level down. In managing inventory, it would seem best to consider individual categories such as raw material, purchased parts, manufactured parts, or subassemblies. While all components may be grouped together for accounting purposes, their different features call for separate management consideration. A part may be a component for an assembly and also may be stocked for usage as a service part and, therefore, serving a function as a finished good. When a combined usage part of this nature is maintained as a single stockkeeping unit (SKU), there is often confusion concerning management controls.

Items may be purchased as finished goods, such as rakes for a hardware store; as components, such as bolts for automobile assembly; or as raw material, such as bar stock for machining. The purchase of a raw material for a manufacturing operation may be the first step in the beginning of a very long supply chain, while the purchase of finished goods for a retail operation can be considered the entire supply chain.

Work in process (WIP) is that inventory in various stages of completion in the manufacturing process from raw material up to and including the last operation prior to transfer to finished goods. It may be controlled through a work order that has collected all material as well as labor and overhead costs up to the present stage of completion. While some accounting systems may include unassigned components (those parts not attached to a work order) to work in process, inventory management is better handled by assigning them to separate classifications. In a rapid assembly environment, parts may be picked from stock, assembled, and transferred to finished goods without ever having been considered work in process.

A stand alone inventory classification is MRO: maintenance, repair and operating supplies. While not an integrated part of the supply chain, MRO inventory can represent a major investment and should be subject to inventory management goals and proper systems.

The key word in classifying inventory is functional, that is, “what is the purpose of this inventory”.

INDEPENDENT AND DEPENDENT DEMAND

Independent demand is that demand that has usage based on marketplace requirements rather than related to other items' demand. The market demand for consumer goods such as television sets or automobiles is an example of independent demand. The demand for electric motors produced for sale to a refrigerator manufacture would be considered independent demand by the manufacture but would be a dependent demand in the refrigerator manufacture's system. Another example of independent demand, although not marketplace generated, would be items manufactured for destructive testing.

Dependent demand is demand that is based on requirements of other items in the manufacturing process and with the relationship defined in the bill of material. The requirement of the "component" is based on the demand of the "parent". The end item is the parent of the subassembly, while the subassembly may be the parent to a fabricated part and two purchased parts. The fabricated part is the parent of the raw material required to make the part. The usage rate (independent demand) of the end item may be 100 units per week, while the dependent demand of a component may be 1200 units every 12 weeks due to lot sizes in the manufacturing process. The demand of the component may be 1900 units every three weeks if the component has more than one parent: because it is used in more than one assembly or subassembly.

An item may have both dependent and independent demand such as a part with both assembly and service requirements. The assembly requirements are dependent on the parent in the bill of material, while the service requirements are based on the independent demand of the marketplace. The inventory management of the combined demand can be a challenge not only from a planning point of view, but also the execution and physical control of both requirements.

The example of the independent demand of the electric motor to be sold to the refrigerator manufacturer perhaps should be reconsidered in that, while it is an independent demand from the viewpoint of the motor manufacturer, it is a dependent demand (a purchased subassembly) from the viewpoint of the refrigerator manufacturer. In the supply chain concept or the JIT concept of the supplier being an extension of the manufacturing process, the demand for the motor should be considered dependent. Giving full consideration to the supply chain, the refrigerator itself may be considered as dependent demand in the Master Production Schedule if the requirements are based on the independent demand of the distribution centers in the distribution system.

INVENTORY SYSTEMS

The system that controls the inventory must be compatible with the goals, functions, and demands of the particular inventory. The best control method for maintaining the stock of pencils at the corner drug store is much different from the system required for control of raw material for the manufacture of automobile engines.

An end item with forecasted level usage might best be controlled by an Order Point (or Reorder Point) system. The order point will be based on the forecasted usage during the replacement lead time. In some situations there will be an additional allowance for safety stock or safety lead time. If the forecasted usage is not level but lumpy, or if the item is being controlled in more than one location, the Time-Phased Order Point (TROP) system is appropriate. TROP systems are based on the MRP logic of time-phasing and offsetting net requirements. In some situations the Periodic Review system of control which calls for a fixed replacement period and varied replacement quantities might be more practical than an order point system which calls for fixed quantities and varied replacement periods. Hybrid systems using features of both periodic review and order point systems are practical in some environments.

Dependent demand items are controlled through Material Requirements Planning (MRP) systems. MRP determines requirements of all components at each level through explosion of the bills of material with the requirements “netted out” and time-phased over the horizon of the plan. The plan makes recommendations to release both purchasing and manufacturing orders as well as suggestions to reschedule open orders. Some dependent demand items such as inexpensive hardware are best controlled by simple visual systems like two-bin or marked reorder levels. Visual controlled items are still listed on the bill of material for costing and informational purposes but are not coded for MRP control.

Distribution Requirements Planning (DRP) is a system that through the use of MRP logic relates the requirements of the branch warehouses to the manufacturing or central supply center at the Master Production Schedule (MPS) level. Distribution Resource Planning which considers resources as well as requirements is also referred to as DRP. DRP is playing an important role in the increasing attention paid to the supply chain.

Systems based on Just-In-Time concepts and techniques are effective inventory management tools. While MRP is still used for inventory planning, the actual execution of the system is accomplished through pull systems using various signals such as cards or containers.

There have been efforts to design systems that control or at least understand all of the participants in a total supply chain. Enterprise

Resource Planning (ERP) is a system that attempts to do planning based on supply and demand information taken across the entire network. The goal of this system is to balance supply and demand at each transaction point in the supply chain. It involves company-to-company interfacing using electronic communication techniques such as Electronic Data Interchange (EDI).

The successful execution of the system controlling the inventory, be it Reorder Point, Time-Phased Order Point, Material Requirements Planning, Distribution Requirements Planning, or Enterprise Resource Planning, is dependent on an understanding of the capacity required to meet the plan.

A system that measures critical manufacturing capacity at the master production scheduling level is rough-cut capacity planning (RCCP). Measuring capacity at the work center level is accomplished with capacity requirements planning (CRP). Both of these systems run in conjunction with material requirements planning programs. Creating a critical bill of resources and comparing anticipated demand to the critical resources can be effective in certain environments. Capacity measurement of trading partners in the supply chain can be most difficult, and often is dependent on experience or the word of the partner.

Examples of system utilization are:

- Reorder Point Control. A privately owned bookstore.
- Time-Phased Order Point Control. A lawn mower retail store.
- Material Requirements Planning. A machine tool manufacturer.
- Distribution Requirements Planning. A national hardware chain.

CASE STUDY SMITH GAS GRILL COMPANY

Joe Smith, a young man in his early twenties, learned his trade as an appliance repair man working for a department store chain. Unable to afford college full time, he continued his education at night taking a variety of business courses with the goal of obtaining a Bachelor's degree. In 1981 he decided that his career path within the department store chain would take him nowhere and that a change was in order. Joe decided to use his repair background and start a business of his own. He determined that while the major appliance repair business seemed crowded, there was no one specializing in the repair of outdoor gas grills. Since gas grills were, for the most part, an uncomplicated appliance to repair plus the fact that Joe saw an

expanding market for the product, he established the Smith Gas Grill Co. Although his initial plan was to run a repair business only, he named the company with the thought in the back of his mind to some day sell complete outdoor grills and possibly manufacture them.

The first year of existence (1981) was a period of establishing the business and a period of slow growth for the Smith Gas Grill Co. Joe already owned the tools required for gas grill repair and his personal car was used for company business. Gas grill manufacturers issued recommended repair parts' lists which were used for purchasing minimum quantities of repair parts. The largest investment was the advertising cost of announcing the business in local newspapers. Joe also visited the major appliance retailers and home building contractors to introduce himself and make them aware of his availability as a sub-contractor or an overload resource. The income for 1981 was only \$17,000 but the fourth quarter contribution was \$7,000 which indicated a favorable growth rate. The level of business for the first quarter of 1982 increased to \$10,000 as the Smith Gas Grill CO. name became better known. Joe decided it was time to expand the business and in the second quarter he hired and trained a repair man, and in the fourth quarter another repair man was added. The business continued to operate out of Joe's garage and basement. A panel truck and additional tools were purchased for the company. Joe found himself spending more time managing the business with such tasks as customer service, scheduling repair orders, ordering repair parts, and maintaining the truck. With his accountant's assistance he learned to maintain the personnel data required for payroll and tax requirements. As the level of business continued to increase, so did the problems of repair part shortages.

As 1983 began, Joe realized that the business could no longer be run "by the back of an envelope" and that activities such as operations, accounting, and inventory management should be formalized. The initial problem was what would be the best process to define the future needs of the Smith Gas Grill Co.

CASE STUDY - SUGGESTED SOLUTION

Prior to formalizing the activities of the company, the goals of the organization should be determined. The long range goals, 5 to 15 years, are not easily defined at this time and should be viewed in the broadest sense so as to allow flexibility in the future. A suggested action would be to incorporate the company rather than remaining an individual proprietorship. The mid-range goal of the company, 2 to 5 years, will be dependent on the forecasted level of business for that period as well as any planned diversification of products or service. Once the mid-range goals are

established, the resources required to meet the goals must be considered. These resources would be personnel as well as the anticipated financial needs for equipment and operating capital.

The immediate goals should be:

1. The establishment of a cost system consisting of a simple balance sheet and profit and loss statement.

2. Written formal personnel procedures. They need not be complicated, but it is best that employees have a clear understanding of their benefits as well as management expectations.

3. An inventory control system. Repair parts should be controlled by a simple reorder point system which will require the maintenance of a perpetual inventory. Since the number of active parts are relatively small at this time, the data can be manually controlled and the manufacturers' part numbers can be used at this time. It should be understood that with the growth of the business, the system will eventually call for computerization as well as a part numbering system specific to the Smith Gas Grill Co.

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Chapter 2

COST CONCEPTS

COST ACCOUNTING

Cost accounting is that branch of accounting that determines both the estimated and actual cost of the product. These numbers are used for inventory valuation and selling price considerations. The marketplace is the usual determinate of selling price but the product cost is an obvious consideration. Cost management is the additional activity of measurement and analysis.

The estimated cost of an item in inventory might be \$10 and based on a quantity of 80 units, the inventory valuation would be \$800. If the product sold for \$12/unit and all 80 units were sold, the sales would be \$960, the inventory reduced by \$800, and a gross profit of \$160 realized. The gross profit is calculated prior to consideration of selling and administrative costs. If the market value of the product was only \$9, the inventory value of \$800 for the 80 units would be overstated and should be reduced to reflect the real value of the product. The determination of the estimated cost of \$10/unit is cost accounting while the inventory write down could be considered cost management.

Another example of cost management is the comparison of actual to estimated costs. The control of estimated costs is accomplished through the use of a standard cost accounting system. The American Production and Inventory Control Society (APICS) defines a standard cost accounting system as a system that uses cost units determined before production for estimating the cost of an order or product. If a home builder builds one house at a time, the actual costs are easily determined. The cost system must only capture the actual land, material, and labor costs. However if 10 homes are under construction at the same time, certain indirect costs such as

purchasing, labor administration , and supervision must be allocated to the homes under construction.

It is the same situation in a manufacturing operation, in that direct material and direct labor can be charged directly to the product but indirect costs must be allocated. The standard cost of an item is the estimated or targeted cost of that item considering both direct and indirect costs. The direct cost of a manufactured item is the direct material and direct labor while the direct cost of a purchased item is the purchased cost. The indirect costs are manufacturing and materials overhead. Overhead cost elements are such things as material handling, supervision, supplies, energy, depreciation, building ,and taxes. The allocation (or absorption) of overhead to multiple products can be most difficult. The fixed overhead rate of an item may be based on the budgeted (or anticipated) fixed overhead related to the expected units to be produced. The variable overhead rate has historically been based on relating the budgeted overhead to the standard (or expected) direct labor. The problem here is that direct labor, due to increased mechanization, is becoming a lesser part of the total cost. An alternative calculations now in use is relating the budgeted overhead to the expected machine hours. In the early stages of consideration is the concept of relating anticipated overhead cost to the manufacturing lead time of the product. Variance analysis is comparing the actual cost to standard cost.

VARIANCE ANALYSIS

Direct material and labor costs are collected against specific shop (work) orders and compared to the corresponding standard cost. The resultant difference is the cost variance - favorable or unfavorable. The standard labor cost for an item requiring nine operations in seven work centers might be \$2.10/unit. If a shop order for 200 units was produced and a total of \$455 was collected, the labor variance would be an unfavorable \$35.

$$\$455 - (200 \times \$2.10) = \$35$$

The above data along with similar information from other shop orders will be gathered by work center to determine the effectiveness of each work center relative to the established standards. While the labor variance is a measure of efficiency, it must be questioned if this measure has been over emphasized to the detriment of quality and proper inventory management. A long manufacturing run may, due to "economy of scale", allow for a favorable labor variance, but that positive number is of little value if there was more produced than reasonably required or if the quality was questionable.

The material price variance is based on the difference of the standard (anticipated) cost of the product compared to the actual cost at the time of purchase. It is a good measure of what is happening in the market place but,

as with labor variance, care should be taken in how the numbers are used. Pressure should not be placed on either the purchasing operation or the suppliers for price reduction at the expense of quality or delivery.

Overhead variance which is an indirect cost requires analysis in that the variance may be due to either spending efficiencies or unanticipated volumes or both. A favorable volume variance will come about when the standard overhead was based on an anticipated 2,000,000 manufactured units and the actual requirements turned out to be 2,230,000 units. The total overhead cost will be “absorbed” by 2,230,000 units rather than 2,000,000 units. The favorable variance could be cancelled or reduced if the efficiency variance of the operation was unfavorable due to added unanticipated costs because of the unexpected volume. Adding to the complication may be when the total number of units required is in line with estimates but the product mix is different than the planned mix. Some product lines call for higher levels of overhead such as supervision or maintenance operations.

Mechanization may reduce the direct labor required for a product and if overhead is allocated based on direct labor, the overhead charged to that product will be reduced. However that mechanization, while reducing direct labor, will not reduce total overhead. It may even increase overhead. Since the effected product with reduced direct labor, will be charged with less overhead, other products may end up with increased overhead. This dilemma is being addressed by relating overhead allocation to factors other than direct labor.

ACTIVITY-BASED COSTING

Activity-based costing (ABC) is an alternate approach to cost management in that it is a cost accounting system that accumulates costs based on activities performed and allocates these costs to products or projects. It is an attempt to allocate overhead costs on a more realistic basis. ABC traces activities performed on the products and reclassifies the costs by types of work (activities), rather than by accounting categories..

The following example shows how ABC can give a more realistic picture to cost activities. Company A produces two products: Product 1 and Product 2. Product 1 has been produced for years and is at this time represents 80% of sales. Due to the experience factor, it requires little attention and is easy to make. Product 2 is the product of the future and, although representing 20% of sales, requires much more staff attention due to the “growing pains” of the product. Both products require the same amount of direct labor, the same amount of machine time, and are in process the same amount of time. Therefore, in a conventional cost accounting system, relating anyone of the three factors to overhead costs, will cause Product 1 to absorb 80% of the

overhead costs when in reality Product 2 required 80% of the overhead rather than the 20% charged to the product.

An ABC system would collect the overhead activities such as engineering, quality control, production control, and supervision, and charge their costs to the products rather than to a department. The results would then charge Product 2 with 50% of the overhead rather than 20%. While the ABC system will give a realistic picture of what is happening, there can be some standard cost consequences that must be addressed.

CONVENTIONAL STANDARD COST CALCULATION

Annual Sales

PRODUCT 1 = 8000 units PRODUCT 2 = 2000 units

Standard Direct Labor

PRODUCT 1 = \$2.00/unit PRODUCT 2 = \$2.00/unit

Annual Budgeted Overhead = \$ 60,000

Total Annual Direct Labor

PRODUCT 1 = 8000 x \$2.00 = \$16,000

PRODUCT 2 = 2000 x \$2.00 = \$4,000

Total = \$20,000

Overhead Rate = \$60,000/\$20,000 = 300%

Standard Cost (based on overhead allocation of 300% of direct labor)

PRODUCT 1		PRODUCT 2	
Material	\$3.00	Material	\$3.00
Direct Labor	\$2.00	Direct Labor	\$2.00
Overhead	<u>\$6.00</u>	Overhead	<u>\$6.00</u>
Total	\$11.00	Total	\$11.00

STANDARD COSTS BASED ON ABC ALLOCATION

ABC allocated 50% of the overhead cost of \$60,000 to each product.

Standard Overhead

PRODUCT 1 = \$30,000/8000 = \$3.75

PRODUCT 2 = \$30,000/2000 = \$15.00

Standard Cost (based on ABC allocation)

PRODUCT 1		PRODUCT 2	
Material	\$3.00	Material	\$3.00
Direct Labor	\$2.00	Direct Labor	\$2.00
Overhead	<u>\$3.75</u>	Overhead	<u>\$15.00</u>
Total	\$8.75	Total	\$20.00

While ABC allocation may give an accurate picture of existing activities, there can be problems with respect to both inventory valuation and product pricing. Newer products that are in the initial phases of production will require greater staff effort, at least for a period of time. In today's fast paced development environment, this month's new product may be considered mature six months from now. Conventional standard costing systems may still be required for inventory valuation, but the benefits from an ABC system may be great enough to warrant the maintaining of two systems.

ABC systems will supply superior cost control, performance measurement, and strategic decision-making data. Most important is management's ability to translate the information supplied by the ABC system. In the example above, it is understood that PRODUCT 2 will require more effort than PRODUCT 1, but is the \$20 ABC cost reasonable and can it be expected to approach the standard cost of \$11 in the future? An ABC system will often indicate that low volume items are more costly than shown in the conventional system. This is an example requiring a strategic decision. Can the low volume items be made in a more efficient manner, and if not, should they be dropped from the line? Perhaps the decision should be made to continue the production at least temporarily as the items' production does help in absorbing fixed overhead. The problem with this strategy is that you might end up with a plant full of fixed overhead absorbers.

Data from ABC systems can be of assistance in the determination of alternate product design decisions. The market potential of two or more products can be balanced against the cost of design and implementation. In some situations, the knowledge gained by more accurate costing, may bring about design changes that reduce high-cost activities.

In summary, ABC systems may not replace the conventional standard cost systems but they can give superior data to allow effective cost management.

LIFO AND FIFO

LIFO means last in, first out, while FIFO means first in, first out. In the physical control of inventory, if shelf life is a consideration, relief (or usage) of the "last in" items can be most critical. LIFO and FIFO considerations play a major role in the costing of inventory when actual cost of the item is used for valuation, as compared to systems that utilize standard costs.

When actual costs are used, every item transaction entering the item into inventory is valued based on the latest cost of that item. In a LIFO system, every transaction relieving the inventory is based on the cost of the “last in” item. The following is an example of LIFO inventory cost control.

Receipts were as follows:

January -	100 units @ \$5.00 received =	\$500.00
February-	100 units @ \$5.50 received =	\$550.00
March -	<u>150 units @ \$6.00 received =</u>	<u>\$900.00</u>
Total	350 units	\$1950.00

Shipments (cost of goods sold) were as follows:

April - 200 units	
	150 units @ \$6.00 = \$900.00
	50 units @ \$5.50 = \$275.00
May - 120 units	
	50 units @ \$5.50 = \$275.00
	<u>70 units @ \$5.00 = \$350.00</u>
Total	320 \$1800.00

Remaining inventory value:

$$350 - 320 = 30 \text{ units @ } \$5.00 = \$150.00$$

FIFO inventory accounting using the same transaction activity as in the LIFO example would show the following.

Receipt calculation the same as LIFO \$1950.00

Shipments (cost of goods sold) were as follows:

April- 200 units	
	100 units @ \$5.00 = \$500.00
	100 units @ \$5.50 = \$550.00
May- 120 units	120 units @ \$6.00 = <u>\$720.00</u>
Total	320 \$1770.00

Remaining inventory value:

$$350 - 320 = 30 \text{ units @ } \$6.00 = \$180.00$$

An analysis of the above example shows that in an inflationary period, (the costs were increasing), LIFO accounting, as compared to FIFO, causes

- 1) A higher cost of sales and therefore
- 2) Reduced profits and taxes as well as
- 3) Less remaining inventory value.

In a deflationary period, the result of LIFO would be exactly the opposite; reduced cost of sales, increased profit, and higher remaining inventory value.

With either LIFO or FIFO inventory accounting, it may be possible, through the management of purchases, to adjust stated profits for the year. This might be desirable for purposes of such things as taxes, bonuses, or stockholder satisfaction. Switching back and forth between LIFO and FIFO must be within rules established by the IRS. The actual withdrawal of items from inventory need not correspond to the costing of the items in the transaction. LIFO is often used solely for the purpose of reducing taxes, while a second internal system is used for measurement and control.

INVENTORY VALUATION

Items in inventory may be valued based on:

1) LIFO and FIFO costing systems in which receipt to inventory is based on actual cost, while withdrawal to cost of goods sold is determined by either LIFO or FIFO system logic.

The inventory valuation is shown on the LIFO and FIFO examples on the previous page.

2) Standard cost systems which are based on a predetermined estimated cost. In a standard cost system, the difference between actual cost and standard cost is reported as a variance and is not included in the valuation. Both receipt to inventory and relief to cost of goods sold is based on the standard cost. Changes in standard costs will cause an inventory revaluation. These systems are most often used in manufacturing operations.

If in the previous example, the standard cost was \$5.60, the inventory value would be $30 \times \$5.60 = \$168.00$.

3) Average costing systems call for the constant recalculation of values based on the latest weighted averages. This system is practical only in a stable environment with relatively few items in inventory.

The average costing system in the example would be based on the following calculation:

January - $(100/350) \times \$5.00 = \$1.43$
February- $(100/350) \times \$5.50 = \$1.57$
March - $(150/350) \times \$6.00 = \underline{\$2.57}$
Average cost - $\quad\quad\quad = \$5.57$

The inventory value would be $30 \times \$5.57 = \$167.10$.

4) Replacement cost systems value the inventory based on the estimated cost of the next purchase. This system can be useful in periods of escalating costs for planning cash flow. Due to tax reporting requirements, this system would not meet conventional financial reporting needs.

If the estimated cost of future purchases was \$7.00, the inventory would be valued at $30 \times \$7.00 = \$210.00$

Inventories may be controlled through either periodic or perpetual systems. A periodic system is based on costing out physical counts at both the beginning and ending periods. The cost of goods sold is calculated by adding purchases to the beginning inventory and subtracting the ending inventory value. The advantage of the periodic control system is less record keeping and is practical for inventories of low cost, high volume items. This advantage has become less meaningful due to technology developments such as scanners and bar code readers which reduce record keeping efforts.

A perpetual inventory control system calls for maintaining a record of each item with every entry or withdrawal transaction recorded. The advantages of a perpetual system are:

- 1) Detailed information is always available allowing for inventory control of each item
- 2) The record of cost of goods sold is more accurate since it is not calculated and can be audited.
- 3) Physical inventories are not required for control.

Manufacturing inventories are maintained in three separate accounts. They are consistent with the manufacturing process flow and are as follows:

- 1) Material Inventory. This category may carry both raw material and purchased parts that have not yet become part of the manufacturing process. The items are valued based on purchased price, with in some cases, an adjustment for freight costs. Additions are based on purchases and withdrawals are at time of transfer to the manufacturing process.

2) Work in Process (WIP) Inventory. These are goods that have started in the manufacturing process but have not yet been finished and transferred to finished goods. Their cost is based on the material released to production plus the labor and overhead charged to the items up to the end of the accounting period. Relief is accomplished at the time of transfer to finished goods.

3) Finished Goods Inventory. This account carries those completed items in stock awaiting shipment to customers. Their value is based on the cost of manufacturing.

Control of work in process accounts is accomplished through either Job-order costing or process costing. Job-order costing consists of collecting all costs against a specific order assigned to the job. The costs are added as the order moves through the manufacturing process. In process costing, all costs are collected during a specified period and charged to work in process. The total number of units produced is also maintained but the costs are not identified with a specific product or work order. Which system to be used depends upon the nature of the manufacturing process. Process costing requires less record keeping but is not practical when manufacturing products that are not similar to each other with respect to costs or process.

INVENTORY-PROFIT RELATIONSHIP

Inventory values are carried on the balance sheet as assets and are balanced against liabilities. The act of writing down (reducing inventory) will have a negative effect on profits. The write down will be treated as expense on the income statement. The converse is to increase profits when an inventory is written up.

In the financial policy management of inventories, there can be conflicting goals. A policy which maximizes the inventory value will have a positive effect on profits, and therefore a good report to publish to the media and the stockholders. The negative effect of this action is higher taxes to be paid and an unfavorable effect on cash flow. Many companies prefer LIFO inventory valuation on the assumption that there will normally be some inflationary pressures and therefore, in a favorable economy, reported profits and taxes will be minimized. If the economy falters, inventory can be reduced, and with the reduction based on the lower cost values, reported profits maximized. The tax rate may be lower and, even if not, the payment has been postponed during the period of the more favorable economy.

In some situations, selling prices are based on the value of the item being sold. Basing the cost on a LIFO basis will call for a higher price. Whether

this is good or bad depends on the situation. Some companies prefer the FIFO method of costing because it will have a favorable effect on reported profits, as well as in many situations, matching the actual goods being sold.

Inventories may have to be written down due to such things as obsolescence, physical deterioration, or a market value that is less than the inventory value. Annual physical inventories or cycle count adjustments will also have an effect on inventory values, either favorable or unfavorable.

ACCOUNTING-BASED DECISIONS

Accounting data will be, either directly or indirectly, involved in almost every inventory management decision. As we move through this book, studying various inventory management concepts and actions, it will be shown that relevant costs must be known and considered.

Chapter 4 discusses the cost involved with carrying safety stocks. Desired safety stock levels are based on customer service requirements and forecast reliability. Once the desired level of safety stock is calculated, the cost of carrying the inventory must be determined and weighed against the desired service level.

In chapter 5, lot sizing methods are reviewed. Lot size considerations are based on balancing the cost of setting up the order with the cost of carrying the inventory. In the determination of production order quantity, costs for machine setup, paperwork preparation, and setup scrap must be calculated. Purchase order lot size cost considerations include supplier selection and review, receiving and inspection, and purchasing paperwork such as blanket purchase orders and requisitions. The cost of carrying inventory requires knowing the cost value of the inventory and an estimation of the “cost of money”, which may be based on either the cost of borrowing (interest rates) or the opportunity value of money. In some purchasing decisions, the value of a quantity discount must be balanced with the cost of carrying additional inventory.

One of the features of MRP II covered in chapter 7, is the system’s power to extrapolate an estimate of inventory investment over the horizon of the planning system. These estimates are useful in the determination of future cash flow and borrowing needs.

Chapter 9 includes the cost of distribution. The distribution network is normally based on the needs of the customer and the cost of transportation. What also must be considered in defining the distribution network is the cost of carrying distribution inventories and the cost of the distribution operation. Another consideration is at what locations, within the distribution network, should safety stock be carried. This decision will be based on the cost of carrying safety stock at each location compared to the cost of emergency air freight.

Purchasing Management, discussed in chapter 11, includes the “make or buy” decision process. While the cost to buy is relatively easy to determine, comparing the buy cost with the make cost can be complicated. The standard make cost usually covers (absorbs) some fixed costs that will remain even if the decision is to buy the product.

CASE STUDY SMITH GAS GRILL COMPANY

In February, 1983, the Smith Gas Grill Co. experienced a negative cash flow due to the seasonal nature of the business. Joe Smith encouraged his two employees to take their vacations during this period, but he still had to meet the payroll. He estimated that the business would need a cash infusion of \$5,000 to cover the slack period. Although the money could have been borrowed from the bank, he decided to incorporate the business and invest his own money to cover the cash shortage. 5000 shares of stock, with a par value of \$1.00/share, were issued and all shares were sold to Joe which established him as 100% owner and also made the needed \$5,000 available.

With the assistance of his accountant, Joe established financial accounting mechanisms, which would meet GAAP (Generally Accepted Accounting Principles) requirements. The goal was to complete a balance sheet as of the end of 1983 as well as a profit and loss (income) statement for 1983.

Assets consisted of:

1. The truck purchased in early 1982 for \$9,000. It was decided to use straight-line depreciation based on a six year life or a rate of \$1,500 per year. Therefore the truck had a net value of \$7,500 going into 1983.
2. There was \$4,000 in a cash account at the bank, which would be needed to cover expenses in the anticipated slack period in the beginning of 1984.
3. Accounts receivable from customers was \$400.
4. Although a perpetual service parts inventory system was started in 1983, a physical inventory was required at the end of the year. This was due to the lack of uniform operating procedures and controls in the new system. The items in stock at year-end and valued at their purchased price equalled \$900

Liabilities other than stockholders' equity consisted of:

1. Accounts payable to suppliers equalling \$800.
2. Remaining loan on the truck was \$4,000.

The revenue in 1983 was \$81,000. In that year repair part purchases were \$3,600. The beginning of the year estimate for the parts' inventory was \$400 compared to the year-end figure of \$900. Hand tool expenditures were \$2,000 and, due to the tools' short life, this cost was expensed rather than treated as an asset. Joe's two employees were paid a total of \$33,000 and Joe paid himself \$18,000. Employee related costs of social security, worker compensation, state unemployment, and liability insurance totalled \$11,600. That year administrative costs, including the accountant's fee, telephone costs, and stationery, were \$8,200. Truck maintenance costs were \$1,200. The income tax rate was 38% of profit.

Based on the above data, a profit and loss statement for 1983 had to be calculated as well as a balance sheet as of December 31, 1983. The year-end physical inventory of parts indicated a problem with inventory accuracy. Some of the parts in inventory had been made obsolete by technical changes by the grill manufacturers. These parts could be used but the newer parts cost less to replace. Some parts were common to grills of different manufactures but it was difficult to identify the commonality since the parts were carried in inventory based on the manufacturers part numbers. As the business grew, the number of inventory transactions posted to the manual system were taking up more and more of Joe's time. He found that record keeping was taking up as much time for a \$0.02 part as a \$15.00 part. In addition to the generating of financial statements, an inventory management plan was needed.

CASE STUDY - SUGGESTED SOLUTION

The financial reports generated could look like the following:

PROFIT AND LOSS STATEMENT
SMITH GAS GRILL COMPANY
1983

Net Sales	\$ 81,000
Expenses	
Labor	51,000
Employee related costs	11,600
Replacement parts	3,100
Truck maintenance	1,200
Truck depreciation	1,500
Hand tools	2,000
General administrative	<u>8,200</u>
Total Expenses	78,600
Income Before Taxes	2,400
Income Taxes	900
Net Income	<u>\$1,500</u>

BALANCE SHEET
SMITH GAS GRILL COMANY
YEAR-END - DECEMBER 31, 1983

Assets

Current Assets

Cash	\$ 4,000
Receivables	400
Parts inventory	<u>900</u>
Total Current Assets	5,300

Property

Truck	9,000
Accumulated depreciation	<u>(3,000)</u>
Total Property	6,000

Total Assets	<u>\$ 11,300</u>
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Liabilities & Equity

Current Liabilities

Accounts payable	\$ 800
Truck loan	<u>4,000</u>
Total Liabilities	4,800

Stockholders' Equity

Common stock	5,000
Retained earnings	<u>1,500</u>
Total Equity	6,500

Total Liabilities & Equity	<u>\$11,300</u>
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In 1984, the Smith Gas Grill Co. will have to address the inventory management problems of physical inventory inaccuracy, increasing numbers of transactions, and questionable part numbers' identification. Parts must be

defined in a way to handle interchangeable parts supplied by different manufacturers, when the parts have different names and slightly different purchase prices. The definition should also include a way to classify the part with respect to investment value and importance.

The solutions to the above problems will all require additional information data which will make the manual system quite cumbersome to operate. The introduction of reasonably priced desktop computers in the 1980s allows for the planning and installation of a computerized control system. The system should call for:

1. A part numbering system based on non-significant part numbers. The part description should be generic and a standard cost based on the average expected purchase price.
2. A method of part number classification (such as ABC) to allow differing methods of inventory control and cycle counting.
3. Inventory control software that will maintain perpetual inventories, open orders, ordering controls, and usage history.

When the system is installed, a simple cycle counting routine should be initiated in order to improve inventory accuracy. The part number classification feature can assist in the determination of the frequency of specific part counting. Part classification can also be used to define the inventory control method. Inexpensive parts may easily be controlled by a two-bin system while remaining parts are controlled by a system requiring perpetual inventories.

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Chapter 3

FORECASTING

FORECAST REASONING

A forecast is an estimate of future demand and is an absolute requirement for inventory planning. An exception could be if the product is made or purchased to order. Even in this situation, an estimate of future requirements would still be needed for capacity and/or financial planning. An accurate forecast will allow improved customer service, as well as better inventory and capacity management.

The forecast may be based on mathematical treatment of historical data, judgmental estimates, or a combination of both. Forecasts cover long, mid, and short range time periods and may be expressed by total product line, product families, or individual items. Depending on the time range and item grouping, the forecast may be in units or dollars. The forecast will interface with business, marketing, manufacturing, distribution, and financial planning systems.

PRINCIPLES OF FORECASTING

When planning a forecast, there are certain principles that should be considered:

1. The forecast will be more accurate for groups. Total units or dollars sold are easier to forecast than specific products. The forecast that a company will sell a total of 2500 laths next year might be useful for cash flow information, but there must be more details for manufacturing planning. If there are 100 different laths produced from a combination of 12 modules (subassemblies), forecasting the 12

modules will be more accurate than forecasting 100 laths and will meet the needs of the manufacturing planning system.

2. The forecast will be more accurate for the short term. The farther out you go, the less accurate you are. Every effort should be made to reduce the cumulative lead time required for the planned item. The cumulative lead time is the total planned length of time to produce and distribute an item. It is the longest combination of events, the critical path, necessary for product availability.
3. The forecast will be wrong. Although there will be a forecast error, it is most important to have an estimate of that error. Through mathematical techniques, it is possible to estimate the probability of error. For example, the forecast of weekly demand may be 100, but based on past deviations from average, the actual demand may be expected to vary from plus or minus 6, 98% of the time.
4. The forecast should be tested before using. There are many models to use for forecasting and it is recommended to test the various techniques based on the same past history. The technique or model that worked best in the past will most likely work best in the future.
5. The forecast is no substitute for actual demand. As there will be a degree of error in any forecast, reducing lead time as much as possible, so as to allow actual demand history to have a greater impact on the forecast, is most desirable.

DEMAND PATTERNS

In tracking demand history, the data will indicate one of five patterns or combinations of the five, that may apply. The five time series patterns are:

1. Linear. The activity will follow a straight-line (linear) pattern, such as the growth of hamburger sales.
2. A Trend Pattern. A pattern that indicates a trend over and beyond the linear pattern, such as a product demand that is growing due to not only population growth, but also to superior quality.
3. A Cyclical Pattern. An example is a product with a life cycle of 3 years and therefore a replacement cycle of 3 years. The business cycle may also be considered.

4. Seasonal Pattern. Examples are lawn mower sales in the spring and snow blower sales in the fall.
5. Random Happenings. This is irregular and difficult to understand. A broken windshield is an example of factors causing random happenings.

An understanding of the patterns will assist in the determination of what forecasting technique should be used.

FORECASTING METHODS

The forecasting method utilized will depend on the data sources available and their applicability to anticipated future demand. If there is a reliable demand history of a product, and it is anticipated that in the future there will be no unusual outside factors affecting the products performance, the product demand history can be the forecasting source. This method is the “quantitative-intrinsic” method in that the forecast will be a computational projection based on the historical pattern of the product data. The forecast demand of a breakfast cereal could well meet this criteria. The future demand of home appliances may relate less to past product sales than to new housing starts. In this situation the forecasting source, new housing starts, would be “quantitative-extrinsic” with the forecast being a computational projection based on patterns of external data. In some situations, such as a new product, there may be no reliable historical data available. The forecasting method then must be “qualitative” which involves intuitive or judgmental evaluation.

Before using intrinsic data to forecast, the data must be reviewed and perhaps modified. There is always the possibility of data recording error, although this type of error has been reduced through system controls such as check digits and the use of bar coding. Demand filters (explained later in this chapter) will catch many recording errors. Demand data must be based on requested order quantity and shipment date, not the quantity actually shipped (perhaps short), nor the actual shipping date (perhaps late). A legitimate abnormal demand in a period must be evaluated to determine the reason for the demand and what effect it might have on the forecast.

Extrinsic data should be used when its’ influence overrides intrinsic data. An example could be an economic factor such as an anticipated recession. While some products, such as food items, may be recession proof, others such as automobiles, are strongly affected by an economic slump and therefore, the forecast of a recession must be considered. Another example of an extrinsic factor can be the effect of a long range weather forecast on seasonal products. The intrinsic data of snow blower sales may cover

normal expected winter sales, but if the long range weather forecast calls for unusually high snow falls, this data must be considered. Demographic data relative to the last five years' birth-rate will have a strong influence on the sale of children's clothes. A competitor's new and improved product is another example of an extrinsic factor for data consideration.

Lacking either intrinsic or extrinsic data that can be used in the forecasting process, qualitative methods are required. Although there were sales data available relative to business computers, this information was of little use in forecasting the growth of personal computers. One qualitative method is the management estimate which may be intuitive or judgmental. Although subject to human error, this method may have to be the way to go when there is no alternative data available. The success of this method is dependent on the judgment of the management forecaster. A second method of qualitative forecasting is market research. This is a more scientific and expensive approach to estimating future demand. The advantage of market research, compared to management judgment, is that there is more attention paid to the marketplace.

Many forecasting situations call for consideration of all three methods. A replacement tire manufacturer may have intrinsic data indicating a positive sales trend. An extrinsic factor to be considered is new car sales three years ago. This consideration is based on historical data that shows that the highest level of tire replacement is for three year-old cars. A qualitative judgmental factor for consideration is that the original equipment tire quality has improved and therefore tire life may increase from three to four years.

SYSTEM DESIGN

The initial step in the design of a forecasting system is the determination of what to forecast. If the desired projection is for long-range business planning covering capital investment and facilities, the system should forecast total anticipated volume expressed in dollars. The forecast will be heavily qualitative (judgmental) and will extend five to ten years. It will be in quarterly or yearly increments.

For production and/or manpower planning, as well as budgeting, a mid-range forecast should be by product family and may be expressed in either dollars or family units. The methods utilized may be a combination of both qualitative and quantitative, and may be expressed in monthly or quarterly increments. The forecast will normally cover a two year period.

A short-range forecast is required for material and inventory planning. It will be primarily based on quantitative methods, expressed in weekly increments, and will extend out one year. The forecast will be in finished goods in a retailing environment, assembled units in a make-to-stock environment, subassemblies and common parts in a assemble-to-order

environment, and by resource and possibly raw material in a make-to-order environment.

In the design process, the historical demand pattern of the subject should be determined and the decision made as to forecast method. Depending on the forecast requirements and the available data, various combinations of qualitative and quantitative (both intrinsic and extrinsic) should be considered.

FORECASTING TECHNIQUES

The techniques used will be dependent on the forecast requirements, the patterns of past history, and the availability of the data.

If there are no radical changes anticipated for the future and the activity is relatively constant, a simple average may be used. If the past 6 months is determined to be the base period, the following is an example.

<u>Month</u>	<u>Demand</u>
February	36
March	38
April	39
May	38
June	42
July	<u>40</u>
	$233 \div 6 = 38.8$ monthly forecast

If the forecaster using the above data decided to use a moving 3- month average, the forecast would be:

<u>Month</u>	<u>Demand</u>
February	36
March	38
April	<u>39</u>
	$113 \div 3 = 37.6$ monthly forecast

<u>Month</u>	<u>Demand</u>
March	38
April	39
May	<u>38</u>
	$115 \div 3 = 38.3$ monthly forecast

<u>Month</u>	<u>Demand</u>
April	39
May	38
June	<u>42</u>
	$119 \div 3 = 39.7$ monthly forecast

<u>Month</u>	<u>Demand</u>
May	38
June	42
July	<u>40</u>
	$120 \div 3 = 40.0$ monthly forecast

The moving average method using the same data as the simple average, indicated a positive trend in the level of activity.

If the most recent history seems to give a more accurate view of the future, a weighted average can be used. An example using the same 6-month history is:

<u>Month</u>	<u>Demand</u>	<u>Weight Factor</u>	
February	36	0.11	3.96
March	38	0.12	4.56
April	39	0.14	5.46
May	38	0.17	6.46
June	42	0.21	8.82
July	40	<u>0.25</u>	<u>10.00</u>
		<u>1.00</u>	

Weighted average = 39.26

The weighted average of 39.26 is less than the last rolling average of 40.00 due to the weighted average giving the most weight to the last demand (July = 40).

Exponential smoothing is a method of forecasting based on the weighted average technique, requiring the maintenance of two numbers only — the last forecast and the actual demand for the last period. The advantage of exponential smoothing is the simplicity of the calculation as well as avoiding the necessity of carrying historical demand data. This technique was especially useful when records were manually maintained, but even with computer maintenance, it is a practical approach to understanding and applying weighing factors. The formula for basic or first-order exponential smoothing is:

$$\text{New forecast} = \text{Old forecast} + \alpha (\text{Last period demand} - \text{Old forecast})$$

The α is the weighing factor where an α of 0.1 gives little weight to the last actual demand and 0.4 gives much weight to the last actual demand.

An example of increasing demand and a α factor of 0.2 shows;

Old forecast = 80

Demand last period = 86

$$\begin{aligned}\text{New forecast} &= 80 + 0.2(86 - 80) \\ &= 80 + 1.2 \\ &= 81.2\end{aligned}$$

If the demand was less than forecast (last period actual = 76) and the α factor = 0.15, the calculation would be:

$$\begin{aligned}\text{New forecast} &= 80 + 0.15(76 - 80) \\ &= 80 - 0.6 \\ &= 79.4\end{aligned}$$

When there are trend influences to be considered, second-order smoothing, which allows for the trend effect, may be used. The details of this equation will not be covered in this book.

When product data indicate a seasonal pattern, a seasonal index should be computed by the following calculations:

1. Determine the average monthly demand for all months of data.
2. Total the demand by month for all 12 months

3. Compute the seasonal index by dividing the monthly total demand by the average monthly demand.

The following is an example of seasonal indexing.

<u>Month</u>	<u>Year 1</u>	<u>Year 2</u>	<u>Year 3</u>	<u>Total</u>	<u>Seasonal Index</u>
January	14	15	17	46	0.475
February	16	18	19	53	0.547
March	18	20	22	60	0.619
April	25	29	33	87	0.898
May	31	37	41	109	1.125
June	47	52	59	158	1.630
July	61	68	65	194	2.002
August	60	54	50	164	1.692
September	47	40	33	120	1.237
October	29	25	21	75	0.774
November	19	17	16	52	0.537
December	<u>16</u>	<u>15</u>	<u>14</u>	<u>45</u>	<u>0.464</u>
Total	383	390	390	1163	12.000

The average 3 month demand = $1163 \div 12 = 96.93$ which is then divided into each month's 3 month total.

If in Year 4 of the above example, the annual forecast is 420 and is to be integrated with the seasonal index, the calculation would first determine the monthly average forecast ($420 \div 12 = 35$). This average forecast would then be related to the seasonal index.

Month	Seasonal Index	Forecast
January	0.475	17
February	0.547	19
March	0.619	22
April	0.898	32
May	1.125	39
June	1.630	57
July	2.002	70
August	1.692	59
September	1.237	43
October	0.774	27
November	0.537	19
December	0.464	<u>16</u>
		420

The calculated seasonal index can be integrated with other forecasting techniques by deseasonalizing current data, projecting in a deseasonalized mode, and then reseasonalizing the forecast.

Focus forecasting is a system that tests a number of techniques or models for each item to determine which technique would have been the most accurate in forecasting the last period. With focus forecasting, the most successful technique for the past is then used for the future forecast. One product may have been best forecasted for the last 3 months by increasing the previous 3 months demand by 5%. Another product might have been best forecasted by using exponential smoothing with a .2 α factor.

Focus forecasting started by using simple models which were easily understood, such as the next quarter will be 110% of the same quarter demand last year. The techniques have since been increased to include both exponential smoothing with varying α factors and other more complex models. The accuracy of the forecasts are measured, based on the mean absolute deviation (MAD) of the observed values to forecast.

The following is an example of using a focus forecasting approach to estimate the 4th quarter 1999, based on the history of the previous 11 quarters.

	QTR 1	QTR 2	QTR 3	QTR 4
1997	120	110	140	90
1998	140	140	168	108
1999	130	102	126	?

After a review of the various relationships, it would seem that the greatest correlation is between the 3rd and 4th quarters of 1997 and 1998.

$$1997 \quad 90 \div 140 = .643$$

$$1998 \quad 108 \div 168 = .643$$

Based on the above relationship, the 4th quarter 1999 forecast would be:

$$126 \times .643 = \underline{81}$$

ERROR MEASUREMENT

Although the forecast will not be perfect, it is important to continually review results so as to minimize the error. Once satisfied that the forecast is as accurate as possible, the task is to measure the error so as to anticipate future deviations. A proper error measurement will assist in improved forecasting as well as allowing for deviation or safety stock planning.

In reviewing forecast performance, the first step is to try to understand the reasons for deviations. Basic data review may indicate readings that differ from forecast due to data-entry error or unexpected factors such as sales promotions or unusual weather. These readings should be identified and corrected. If there is a change in the demand pattern of a product, the forecast technique in use should be reviewed. An example could be a product that in the past has a linear growth pattern, but due to product improvement, has experienced an additional upward trend. This situation could call for switching from a moving average technique to exponential smoothing. Once the necessary adjustments have been made, it can be assumed that the remaining deviations from forecast are normal random variations. These forecast errors are best managed through proper measure and control.

If the deviations from the forecast are on both the negative and positive sides in similar amounts, the forecast is considered to have little or no bias. The error can then be measured through a standard deviation or a mean absolute deviation (MAD) calculation. Initial determination of the degree of variation from the forecasted number is achieved by the recording of the detailed data that determined the average. If a forecast of 4,200 was based on the following data, the standard deviation calculation would be as follows:

<u>Period</u>	<u>Actual</u>	<u>Forecast</u>	<u>Deviation (D)</u>	<u>D²</u>
1	4,000	4,200	- 200	40,000
2	4,300	4,200	+100	10,000
3	4,200	4,200	—	—
4	4,400	4,200	+200	40,000
5	4,000	4,200	-200	40,000
6	<u>4,300</u>	<u>4,200</u>	<u>+100</u>	<u>10,000</u>
	25,200		800	140,000

$$\text{Average} = 25,200 \div 6 = 4,200 = \text{Forecast}$$

$$\text{Standard deviation} = \sqrt{\frac{\sum D^2}{N}} = \sqrt{\frac{140,000}{6}} = \sqrt{23,333} = 153$$

Based on statistics of a normal distribution, the actual number will be within three standard deviations 96.86% of the time.

In this situation the expected range would be

$$4,200 \pm (3)(153) = 3,741 \text{ to } 4,659$$

and 97.72% of the time, the actual number will be within two standard deviations and the expected range would be

$$4,200 \pm (2)(153) = 3,894 \text{ to } 4,506$$

and 84.13% of the time, the actual number will be within one standard deviation and the expected range would be

$$4,200 \pm 153 = 4,047 \text{ to } 4,353$$

The planned safety stock is a function of the standard deviation and the desired service level. In the above example, if the desired service level was 98%, the calculated safety stock would be twice the standard deviation or $(2)(153) = 306$.

A calculation, easier than the standard deviation calculation but giving similar results, is the mean absolute deviation (MAD). The Mad is the average of the absolute deviations. Based on the data in the above example the MAD calculation is

$$\text{MAD} = \frac{\sum D}{N} = \frac{800}{6} = 133$$

The standard deviation is approximately 1.25 times the MAD. In the example, the standard deviation would approximate to

$$133 \times 1.25 = 166$$

compared to 153. The larger the number of actual readings (N), the closer the two methods of calculations will be. However measured, the deviations from forecast should be continually monitored.

TRACKING SIGNAL

Once a forecast is in effect, a tracking signal measurement should be taken on a continuing basis. The purpose of this measurement is to signal when the validity of the forecast may be in doubt due to a bias of the forecast. Bias is the tendency of the forecast to be above or below the actual observations. The mean absolute deviation (MAD) is the average amount of forecast error, but does not consider the direction of the error. The same holds true for the standard deviation. The tracking signal calculation, by considering the cumulative sum of the errors, will indicate when the forecast is not tracking within tolerance. The tracking signal calculation is

$$\text{Tracking signal} = \frac{\sum \text{Cumulative forecast error}}{\text{MAD}}$$

A tracking signal greater than 4 or 5 indicates a high bias and is a signal to review the forecast. Based on the next 10 observations, following the forecast of 4,200 calculated earlier, the result would be

<u>Period</u>	<u>Actual</u>	<u>Forecast</u>	<u>Deviation</u>
7	4,300	4,200	+100
8	4,400	4,200	+200
9	4,300	4,200	+100
10	4,100	4,200	-100
11	4,300	4,200	+100
12	4,400	4,200	+200
13	4,100	4,200	-100
14	4,200	4,200	—
15	4,300	4,200	+100
16	<u>4300</u>	<u>4,200</u>	<u>+100</u>
Total	42,700		

$$\sum \text{Absolute deviations} = 1100$$

$$\sum \text{Cumulative forecast errors} = 700$$

$$\text{MAD} = 1100 \div 10 = 110$$

$$\text{Tracking signal} = 700 \div 110 = 6.4$$

These results would call for a recalculation of the forecast to

$$42,700 \div 10 = 4,270$$

DEMAND FILTER

Data collected for forecasting review can be monitored through a demand filter. Any reading greater than 3.2 standard deviations or 4 MAD will only happen 0.07% of the time (7 out of 10,000). A demand filter set at this range, will highlight for review any readings above or below the established value (such as 4 MAD). In the original example of a 4,200 forecast and a MAD of 133, the demand filter limits would be

$$4,200 + 4(133) = 4,732$$

and

$$4,200 - 4(133) = 3,668$$

Any readings less than 3,668 or more than 4,732 should be reviewed for data entry error, and if the reading is then determined to be valid and reasonable, both the reason for the unusual number and its effect on the forecast should be reviewed.

CASE STUDY SMITH GAS GRILL COMPANY

In 1984, with the addition of a computer control system, a part numbering system, cycle counting, and part number classification, the inventory records could now be considered as under control. The system was maintaining perpetual inventories and collecting usage history. Part replacement was controlled by a basic reorder point formula based on anticipated usage during the replacement lead time. Part shortages still existed due to either unplanned usage levels, late supplier delivery, or both. Parts' purchasing increased 35% while suppliers were also increasing their stated lead times.

The economy in 1984 was in a positive mode and the level of business for the Smith Gas Grill Company was growing at even a faster rate than the economy. The annual sales rate was increasing from the 1983 level of \$81,000 to close to \$110, 000 in 1984. A third repair person was hired and trained as was a part time records clerk. Some grill repairs required replacement of subassemblies rather than individual parts. Joe Smith

determined that if he could purchase individual parts and have the subassembly operation done “in house” expenses could be reduced for both the company and the customer. The problem was that “in house” was really in Joe’s house, where with the increased level of business, space was at a premium. The short term solution to the space problem was the renting of a 4000 square foot facility in an industrial park. This was considered short term in that Joe wanted to be an owner rather than a renter. Looking ahead, there was the possibility of retail sales of both parts and gas grills. The industrial park location did not lend itself to the retail business. Initial investigation for the building or purchasing of a new facility indicated that, to obtain bank financing, a long range business plan would be required.

The ability to look into the future (forecasting) was necessary for not only financing a new facility but also to gain greater control of inventories. A history of parts’ requirements existed, but there was no history of subassembly requirements. The only data that might be relevant to long term planning was the basic sales and profit history of a three year old company.

CASE STUDY - SUGGESTED SOLUTION

The forecasts required for the Smith Gas Grill Company will call for using the three basic forecasting methods. The long term business plan will call for a qualitative assessment. The data available from the three year history of the company does not address the future plans for expanding into the retail business. The management (Joe Smith) has no real experience in the retail end of the business. Therefore a market research effort will initially be required to determine the market potential for gas grill and repair part sales. Once the total market potential over the next five years has been projected, a management estimate of what share of the market the Smith Gas Grill Company might experience will be required. The expected profit from the retail sales would be the next judgmental management estimate. Finally, the effect of the retail business forecast would then be added to the estimate of the anticipated growth of the existing grill repair business.

Inventory control performance has suffered due to poor data in the reorder point calculation. The problems are:

1. Usage figures based on past averages that tend to be understated.
2. Supplier lead times that are increasing.
3. Suppliers not meeting their stated lead times.

Forecasted usage shows an upward trend pattern that calls for a weighted average approach such as exponential smoothing. Focus forecasting

software is also available which would continually test the many forecasting techniques and recommend one for each part number. Intrinsic data are used for these approaches.

The supply problem is best addressed by carrying safety stock. A simple safety stock calculation would be adding two weeks of anticipated usage to the reorder point. This approach would be a good starting point. In the future, safety stock calculations, based on individual part number variability from forecast, should be considered.

There are no intrinsic data for those parts required for the anticipated addition of subassembly operations. Extrinsic data, such as gas grill sales, could initially be extrapolated and be related to future internal subassembly requirements. In the future, as intrinsic data are collected on these requirements, the forecasting technique could revert to the system in use for replacement parts.

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Chapter 4

INVENTORY RELIABILITY

SERVICE LEVELS

As stated in the overview, the primary function of inventory is to serve the customer. In the determination of the service level, the customer is the direct recipient of the product. The purchaser of a screw driver set is the customer of the retailer, such as a hardware or discount house. The retailer is responsible for maintaining a stock level that will allow an acceptable service level for the customer. In off-the-shelf commodities, such as the screw driver set, a high service level is required because, if the screw driver set is not in stock, the customer has the option of going to a competitor for the purchase and he will probably do so. If the purchaser requires a specific brand of specialized screw drivers that are not stocked by all retailers, the service level requirement may not be as high, since the customer may be willing (or have) to come back when the item is in stock.

The retailer, who purchased the screw driver set from a wholesaler, is the customer of the wholesaler. The wholesaler, in turn, is the customer of the manufacturer. In a manufacturing environment, the manufacturer is the customer of the raw material or component supplier. The assembly operation is the customer of the manufacturing or purchasing function. Each organization must understand their customers' requirements in order to determine a desired service level.

The consequence of a stockout may be a backorder if the customer is served but not at the time or quantity desired. This can be a cause of customer dissatisfaction and the possible loss of future business. In the situation of the screw driver set, the result will probably be lost business. When there is a stockout in a manufacturing situation, such as assembly component shortages, inefficiency in the form of idle workers, idle equipment, or the manufacture of other items earlier than required, will

result. If a stockout can be corrected through product substitution, there may be little or no unfavorable consequences.

Service levels can be measured in a number of ways depending on customer requirements. The measurement may be related to time or quantity and may be expressed as a percentage or an absolute value. Examples of various measurements are:

1. Orders shipped on schedule expressed as a percentage and based on a definition of “on time” is a prime example. If the order ships within two days of the requested date, a company may consider this “on time
2. When there are multiple items on a shipping order, the percentage of the number of line items shipped on schedule may be the service measurement.
3. Dollar volume shipped on schedule may be measured. This measurement would be used when the concern is large order service and maximum cash flow.
4. The percentage of items in stock on assembly order pulls is an example of in house manufacturing service measurement. While a 99% fill rate may not allow assembly, the expediting requirements will be much less than a 65% fill rate.
5. On make-to-order items, the critical measure may not only consider on time, but days or weeks of delay for late shipments. 80% of on time shipments, with the remaining 20% being an average of three weeks late may cause poorer customer relations than 100% of all orders being late, but by only three days.

There may be variations on the above examples, such as measuring items shipped on schedule but in less than requested quantities. This measurement may also be affected by the decision as to when a short order is considered complete. Situations may arise as to whether the shipping date to be measured should be based on the suppliers stated lead time, the customer's requested ship time, or the agreed upon ship date. All three may be different.

CAUSE AND EFFECT

When service is not at an acceptable level, the cause of the problem must be understood before a solution is possible. The first reaction to an inventory shortage is often to “carry more inventory”. This is not always the

best solution. In a manufacturing operation, the shortage of parts may be due to a capacity problem brought on by an overloaded work schedule. To attempt to solve the problem by planning and releasing more work will hurt more than help the problem. The root cause, lack of capacity, must be solved.

When purchased parts are short, the cause must be examined. If the parts are being delivered on time, the problem is one of demand, probably an understated forecast or variability in the forecast. If the short purchased parts are late in requested delivery, there is a supply (versus demand) problem that is caused by either the supplier's capacity or the customer's reordering system. If the problem is with the reordering system, the obvious solution is to correct the system. When the cause is determined to be forecast variability, unreliable lead times, or continuing quality problems, safety stock or safety lead time may have to be the solution. How much additional stock or lead time is needed will depend on the desired service level and the ability to pay for it.

SAFETY STOCK AND SAFETY LEAD TIME

Safety stock, sometimes called reserve stock, is inventory calculated to protect against fluctuations in demand or supply. Safety stock quantities are built into the reordering system's calculation in a manner that the inventory is not planned for consumption under normal (perfect) circumstances. With the use of safety lead time, an element of time is added to the planning lead time and can be applied to manufactured or purchased parts.

Safety stock calculations can be as simple as adding 100 units to every planned item or adding 2 weeks of expected usage to each item. These broad-brush approaches are easy to calculate but give anything but optimum results. Some items, for one reason or another, may require 5 weeks of safety stock, while others, due to accurate lead times and no forecast variation, will require little or no safety stock. Also to be considered is that cycle stock, which is the result of lot size quantity, can also serve a safety stock function. An item purchased once a year only runs the risk of running out once a year and, therefore, would be expected to have a service level of no worse than 98% ($51 \div 52$) without any safety stock consideration. The most effective safety stock calculation is based on individual items being evaluated with respect to usage rate, lot size, lead time, lead time error, forecast error, and desired service level.

Safety lead time, based on a calculated lead time error rate, may relate to standard deviations of lead time error in a manner similar to safety stock based on the error rate of the forecast. If the demand rate of a product is continuous, a calculated safety stock quantity of 2 weeks usage will give the same results as 2 weeks of safety lead time. However, if the demand is discontinuous (lumpy), safety lead time is much more effective in covering

lead time error. Discontinuous usage is common in MRP calculations of dependent demand. An example would be a casting with an average usage of 100 per week but a planned demand of 800 approximately every 8 weeks. If the lead time error tends to be 2 weeks and that error is allowed for with a 2 week safety lead time, the 800 castings should be in stock when required. On the other hand, a 2 week safety stock quantity of 200 castings will be of little use in meeting the 800 casting requirement.

SAFETY STOCK CALCULATION

The following factors must be considered in calculating safety stock.

1. The desired service level. The first step is defining the service level. An example would be if an item were out of stock an average of once a year, the service level could be defined as $51 \div 52 = 98\%$ service or being in stock 51 weeks of the year. Using the same measurement, 90% service would calculate to being in stock $52 \times .9 = 47$ weeks of the year or running out of stock during 5 weeks of the year.
2. The number of exposures to stockouts per year. If an item is only ordered once, a year, it is only exposed to one stockout possibility per year. The number of exposures is the annual usage divided by the lot size of the item. If the annual usage is 12,000 and the lot size is 2,000, there will be 6 orders per year and therefore 6 exposures.
3. The adjusted service level. The desired service level is adjusted based on the number of exposures. It is the number of exposures required to be in stock for the desired service level, divided by the total number of exposures. If 96% service is required and there are 26 exposures, 24 of the 26 exposures must be in stock. The adjusted service level is $24 \div 26 = 92.3\%$. This service level will then be related to the forecast error - the standard deviation or the mean absolute deviation (MAD).
4. The forecast error. As shown in Chapter 3, the forecast error for a normal distribution can be calculated and stated in standard deviations or mean absolute deviations (MAD). If the forecast is stated in weeks, the actual and the deviation must also be on a weekly basis. The following safety factors for a normal distribution are related to various service levels.

<u>Service level</u>	<u>Standard deviation</u>	<u>Mean absolute deviation</u>
50.00%	0.00	0.00
75.00%	0.67	0.84
80.00%	0.84	1.05
84.13%	1.00	1.25
90.00%	1.28	1.60
95.00%	1.65	2.06
97.72%	2.00	2.50
98.00%	2.05	2.56
99.00%	2.33	2.91
99.86%	3.00	3.75
99.99%	4.00	5.00

Source: Adapted from Plossl, G. W., *Production and Inventory Control*, 1985

5. Adjusted deviations. When the forecast interval differs from the item's lead time, the deviation's relationship to the service factor must be adjusted. If the forecast error is based on a weekly forecast and the lead time is five weeks, the total error expected over the five week period will be greater than the expected one week error. The increased error will not be a multiple of the number of lead time weeks but will normally increase as shown below.

<u>When the forecast interval = 1 and the lead time interval is:</u>	<u>Standard deviation or MAD should be multiplied by</u>
2	1.63
3	2.16
4	2.64
5	3.09
6	3.51
7	3.91
8	4.29
9	4.66
10	5.01
11	5.36
12	5.69
13	6.02
14	6.34
15	6.66
16	6.96

Source: Adapted from Plossl, G. W., *Production and Inventory Control*, 1985

The following is an example of safety stock calculations when a 94% service level is desired. The 94% service level can be translated into 52 weeks x .94 service to equal 49 weeks in stock and 3 weeks in which there can be stockouts. The 3 allowed stockouts are the critical factors in the calculation.

- A) Assume annual usage = 5,200 units, lot size = 400 units, and
 MAD = 40 units
 $\text{Exposures/year} = 5,200/400 = 13$
 $\text{Adjusted service level} = 10/13 = 77\%$
 $\text{Safety factor for 77 \% service} = .85 \text{ MAD}$
 $\text{Forecast interval} = 1 \text{ week and lead time} = 4 \text{ weeks}$
 $\text{Adjusted MAD for forecast/ lead time difference} = 40 \times 2.64 = 105.6$
 $\text{Safety stock} = 105.6 \times .85 = 90 \text{ units.}$
- B) If the lead time were reduced to 1 week (the same interval as the forecast), the unadjusted MAD would be 40 and the safety stock would calculate to $40 \times .85 = 34 \text{ units.}$
- C) If the lot size was reduced to 100 units, the exposures would increase to 52 ($5,200/100$). The adjusted service level for 3 stockouts would be $49/52 = 94\%$. The safety factor for 94% = 1.95 MAD. The safety stock would calculate to $105.6 \times 1.95 = 206 \text{ units.}$
- D) If both the lead time reduction to 1 week and the lot size reduction to 100 units were to take place, the calculated safety stock would be $40 \times 1.95 = 78 \text{ units.}$

As shown in “C” above, reducing the lot size will reduce the average inventory due to lot size (or cycle) stock, but due to increased exposures, the safety sock will increase.

When the uncertainty is in supply timing rather than demand quantity, safety lead time is appropriate. The logic of the calculation is similar in that the actual lead time is compared to standard lead time and the deviation from standard is established. The safety factors based on lead time error rather than forecast error, can be used to determine the safety lead time. The safety lead time is added to the standard lead time and used in the replenishment system. The standard lead time is stated on the replenishment order, and if the order arrives “on time”, it actually will arrive early (by the amount of the safety lead time). The safety lead time is there to meet the requirement, in case the order arrives late.

COST OF SAFETY STOCK

In the decision making process, it is best to compare the cost of carrying safety stock with the cost of not carrying safety stock. The assumption should be made that the cost of carrying the planned safety stock is the actual cost of the stock. In inventory replenishment systems, the safety stock is planned not to be used but is always to be available. The calculation of inventory carrying cost is discussed at length in Chapter 5 in relation to lot size determination. An additional cost of safety stock is possible in dependent demand (MRP) systems, when schedule disruptions, expediting, and critical part problems, are caused by efforts to replenish safety stock when that activity that could have been temporarily delayed..

While the safety stock carrying cost calculation is not an exact science, it is more accurate than estimating the cost of not carrying safety stock. Stockouts may cause back orders, loss of present and future sales, loss of customer goodwill, and manufacturing inefficiencies, but the cost of these results is difficult to measure. Quantification of the loss of future sales is all but impossible and the benefits of goodwill are intangible.

The actual cost of safety stock may well be the result of a management decision. A service level of 99.86% may be desirable, but based on normal distribution statistics, the cost of safety stock will be 50% greater than the cost of safety stock yielding a service level of 97.72%. Management must decide if the extra 2% is worth the investment.

The relationship of the service level to inventory cost differential is shown in the following example:

The item's cost is \$5.00

Inventory carrying cost is 25% of investment

Mean absolute deviation (MAD) is 120 units

84.13% service = $1.25 \times 120 \times \$5.00 = \$750.00$ inventory

Cost of inventory = $\$750.00 \times .25 = \$187.50$

95.00% service = $2.06 \times 120 \times \$5.00 = \$1236.00$

Cost of inventory = $\$1236.00 \times .25 = \$309.00$

98.00% service = $2.56 \times 120 \times \$5.00 = \$1536.00$

Cost of inventory = $\$1536.00 \times .25 = \$384.00$

99.86% service = $3.75 \times 120 \times \$5.00 = \$2250.00$

Cost of inventory = $\$2250.00 \times .25 = \$562.50$

In this example, management should estimate the stockout cost at each level of service, even though it would be most difficult. The level of service, where the inventory costs are closest to the stockout costs, is the most appropriate level of safety stock planning.

CYCLE COUNTING

Inventory reliability problems are often the result of inaccurate records rather than supply and demand errors. While safety stock and safety lead time protect against supply and demand problems, cycle counting is a protection against record accuracy problems. Cycle counting has two basic functions:

1. Correcting inaccurate records.
2. Identifying and correcting the causes of record errors.

Maintaining accurate records requires:

- A proper system of receipts and disbursements
- Qualified personnel.
- An effective auditing system
- Error and cause correction

One method of correction is the annual physical inventory. The first step in preparation for the annual physical inventory is to clean up the warehouse and plant. Once this is accomplished, everyone agrees to maintain this high level of housekeeping from now on. (This is often forgotten within two weeks.) On the day or days of the count, all other operations cease and the counting is done by personnel who, since they do it but once a year, are not too familiar with the procedure. Individual counts must be compared with the perpetual inventory record balances. Differences must be reconciled and the record balance made to agree with the actual quantity on hand. Once completed, the accountants may be satisfied if the net change in dollar value is small, but to operating people, the critical measurement is the absolute differences in the count. Reducing product “X” by 1,000 units with a value of \$3,000 and increasing product “Y” by 1,000 units with a value of \$3,000 will not affect the balance sheet, but can cause the negative effects listed at the beginning of the chapter. The annual physical is of little help in

determining and correcting the causes of inaccuracies. The inaccuracy in a record may have been caused by a mistake made any time within the last 52 weeks and is therefore difficult to trace.

The more effective method of error correction is cycle counting. Cycle counting is a routine of counting selected items frequently and testing their accuracy. This allows for the identification and the elimination of the causes of error. The frequency of counting brings about a continuous updating of the perpetual records. Personnel assigned to the cycle counting function become familiar with the inventory system, are efficient in the counting routine, can reconcile differences, and find solutions to system errors.

Requirements for maintaining accurate inventories are:

- Adequate storage space.
- Properly planned locations.
- Orderly storage.
- Efficient transaction reporting.
- Effective locator system.

With effective cycle counting there is no need to shut down operations and the annual physical inventory is usually eliminated. The end result will be a higher degree of record accuracy at the same or less cost.

The basic control method in the cycle counting routine is the use of part number classifications. "A" class parts, which are the most significant due to cost, transaction frequency, or critical use, are counted more frequently and have tighter tolerances. "A" class parts may be counted six times a year and will be considered accurate if the count is within $\pm 0.2\%$ of the record. "B" class items may be counted four times a year and will be considered accurate with a tolerance of $\pm 1.0\%$, and "C" class items may be counted once a year and be considered accurate with a tolerance of $\pm 5.0\%$. The defining of parts' classifications and tolerance levels are dependent on the nature of the operation.

Cycle counters, with proper training and experience, can assume the role of inventory analysts as well. Their responsibilities will be to take the physical count, compare the count against the record, recount if necessary, analyze the transaction to determine the cause of error, adjust the perpetual record if necessary, and implement corrective action. Sources of error may be untrained personnel, carelessness, faulty cut-off control, incorrect documents, and/or faulty computer programs.

The number of cycle counters required will be dependent on the following factors:

- Number of items in inventory.
- Count frequency.
- Physical size of the inventory.
- Number of storage locations for each item.

As a rule of thumb in an inventory management system, a cycle counter can count and reconcile approximately 40 items per day.

Prior to initiating a cycle counting program, a control group of items representing a cross section of the items within the system should be selected. The control group items should be counted, investigated, and reconciled to the perpetual record. These items should continue to be recounted in order to determine and correct all causes of error. Once the control group is maintained essentially error free, full scale cycle counting operations can begin.

The cycle counting schedule should call for selected items to be counted each day. The number in the daily count should meet the required annual count frequency of all items. The daily grouping of items may be based on numerical part number order or by storage location, with additional consideration for zero or negative balances. An example of the results of a planned cycle count schedule is:

<u>Inventory Class</u>	<u>Number of Items</u>		<u>Annual Count Frequency</u>		<u>Count</u>
A	200	x	6	=	1200
B	1200	x	4	=	4800
C	<u>3500</u>	x	1	=	<u>3500</u>
Total	4900				9500

9500 Counts ÷ 250 workdays per year = 38 items to be counted each workday

A continuing measurement of cycle counting operations should be maintained and published in order to:

- Monitor the inventory accuracy of the system
- Motive all involved personnel
- Continuing justification of the cost of the program

Bar coding and bar code scanning equipment can help to eliminate cycle counting errors in reading, writing, and transcribing part numbers. Bar code labels are required to identify the items to be counted. Bar coding hardware and software are readily available, and the system requires minimum maintenance.

CASE STUDY SMITH GAS GRILL COMPANY

With the growth of the company, there were also growing problems with inventory stockouts. The inventory control system, still under development, consisted of a perpetual inventory record for every stocked item with reorder point control. The reorder point was based on the forecasted usage during the lead time plus a safety stock of one additional week's forecasted usage. Part numbering was based on a non-significant three digit system and with the capability to increase to four or five digits without any problems. Three items have recently experienced stockout problems.

1. The Gas Grill Burner (part number 214) was an expensive component of the most popular grill on the market. Original burners in a grill tend to wear out in a relatively short period of time. The forecast for replacement was 20 per week, the lead time for inventory replacement was 4 weeks, and the reorder point was 100 units (based on 4 weeks' lead time plus 1 week's safety stock). The purchased lot size was 100 units and the on-time delivery and quality were excellent. An initial analysis of the last 10 weeks' activity indicated an average demand of 22 per week. In spite of on-time delivery and a relatively accurate forecast, the desired service level of 98% was not being met.

2. The Venturi Tube (part number 516), although less expensive than the burner, was an important repair part in a grill. The forecasted demand was 30 per week, and the reorder point was 180 units based on a lead time of 5 weeks plus a 1 week of safety stock. The item lot size was 150 units. The

initial analysis results were similar to the burner in that the average actual demand of 30.6 was very close to forecast and the supplier delivery performance was good. A stockout was experienced last week which created quite a problem since there were no open orders and there was a 5 week replacement lead time.

3. The Valve Assembly (part number 821) was a stockout problem due to the inability to assemble the product on time. Due to the nature of grill repair, the decision had been made to assemble and stock the valve assembly “in house”. This assembly was the first manufacturing activity at Smith Gas Grill. The assembly problem was due to part shortages of both assembly components (valve #349 and knob # 279). Analysis indicated that the valve assembly forecast of 25 per week was accurate and the delivery of the two components were on time. The assembly lead time was 1 week, the lot size was 150, and the reorder point was 50 assemblies (based on 1 week lead time and 1 week safety stock).

CASE STUDY - SUGGESTED SOLUTION

1. Reviewing the details of the last 10 weeks for the Gas Grill Burner showed the following:

<u>Week</u>	<u>Actual</u>	<u>Forecast</u>	<u>Deviation</u>
1	27	20	7
2	6	20	-14
3	29	20	9
4	32	20	12
5	18	20	-2
6	30	20	10
7	9	20	-11
8	33	20	13
9	7	20	-13
10	<u>29</u>	<u>20</u>	<u>9</u>
	220	200	100

$$\text{MAD} = 100/10 = 10$$

$$\text{Tracking Signal} = (60 - 40) \div 10 = 2.0$$

While the tracking signal indicates that the forecast of 20 is valid, the Mad of 10 is the result of the high degree of deviation from week to week.

This is an indication that a 1 week safety stock may not be adequate. The following is a more detailed safety stock calculation.

- A) Desired service level = 98% = 52 weeks x .98 = 51 weeks in stock
- B) One (1) allowed stockout per year
- C) Exposures per year = 1040 annual forecast ÷ 100 lot size = 10
- D) Service level for 1 stockout per year = 9 ÷ 10 = 90%
- E) MAD of 10 adjusted for 4 week lead time = 10 x 2.64 = 26.4
- F) 90% service = 26.4 x 1.6 = 42 units

The above calculation shows, that due to the high degree of deviation, the required safety stock for a 98% service level should be 42 rather than the 1 week lead time number of 20.

2. The detailed transactions of the last 10 weeks for the Venturi tube showed the following:

<u>Week</u>	<u>Actual</u>	<u>Forecast</u>	<u>Deviation</u>
1	27	30	-3
2	32	30	2
3	29	30	-1
4	31	30	1
5	34	30	4
6	30	30	—
7	28	30	-2
8	32	30	2
9	31	30	1
10	<u>32</u>	<u>30</u>	<u>2</u>
	306	300	18

$$\text{MAD} = 18/10 = 1.8$$

$$\text{Tracking Signal} = (12 - 6) \div 1.8 = 3.3$$

The tracking signal indicates that the forecast is valid and the MAD of 1.8 is relatively small due to a low degree of deviation from the mean (the forecast). The following safety stock calculation verifies that the 1 week safety stock is more than adequate for a 98 % service level.

- A) Desired service level = 98% = .98 x 52 = 51 weeks in stock
- B) One (1) allowed stockout per year

C) Exposures per year = 1560 annual forecast $\div$ 150 lot size = 10

D) Service level for I stockout per year = $9 \div 10 = 90\%$

E) MAD of 1.8 adjusted for 5 week lead time = $1.8 \times 3.09 = 5.6$

F) 90% service = $5.6 \times 1.6 = 9$ units

The existing safety stock of 30 (1 week forecast) is more than enough to allow a 98% service level. A review of the receipts indicate on time delivery of 150 units in week 7, yet there was a stockout in week 9. This is an indication of a transaction error that has not been detected by a cycle count. A subsequent cycle count of the other stocked venturi tube showed a count of 148 over the perpetual record. This is an example of the importance of cycle counting and error correction.

3. Detailed analysis of the Valve Assembly showed a demand history similar to the venturi tube in that the MAD was 1.4 relative to the forecast of 25 assemblies per week. The tracking signal calculated to 2.9. With a reliable forecast with a low deviation from forecast, it was obvious that the problem was not with the assembly but with the availability of the components. The activity analysis of the valve component (part number 349) showed the following:

<u>Week</u>	<u>Actual</u>	<u>Forecast</u>	<u>Deviation</u>
1	0	25	-25
2	0	25	-25
3	150	25	125
4	0	25	-25
5	0	25	-25
6	0	25	-25
7	0	25	-25
8	0	25	-25
9	150	25	125
10	<u>0</u>	<u>25</u>	<u>-25</u>
	300	250	450

Detailed analysis of the other component, the knob (part number 279), indicated the same pattern.

The valve had a lead time of 2 weeks and a safety stock of 1 week. Based on a forecast of 25/week, the reorder point was 75 and the lot size was 100. When the stockout occurred, the lot size of 100 was ordered which met the reorder point requirements but did not meet the assembly demand of 150. The knob also had a lead time of 2 weeks and a safety stock of 1 week

and therefore also had a reorder point of 75. The lot size of the knob was 50 units so, when there was the stockout, two (2) lots were ordered to meet the reorder point but once again, there was not enough to meet the assembly demand of 150.

The basic problem with the component control is that these items are not independent demand items that directly relate to the forecast of the valve assembly. Their demand is dependent on the assembly requirements of the valve assembly (the parent). The assembly may have a continuous or steady demand pattern while the demand pattern of the assembly components will be discontinuous or lumpy. Dependent demand items are better controlled through a material requirements planning (MRP) system than a reorder point system. MRP will be addressed later in this book.

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Chapter 5

ORDER QUANTITIES

LOT SIZE CONSIDERATIONS

In the past, large lot sizes tended to be viewed favorably under most circumstances. This was due to the heavy emphasis on “economy of scale”, a phenomenon where larger volumes reduce the unit cost due to distributing fixed costs over larger quantities. This approach was erroneous if the demand of the item was not considered. Large lot sizes go well with high levels of demand.

Long runs (large lot sizes) have been popular with production people because with long runs, there is less production time lost due to setups, more favorable labor variances, and often a positive affect on incentive pay systems. Marketing people were comfortable with large lot sizes as there was the perception that the larger the lot size, the more on the shelf, and, therefore, a higher level of customer service. As discussed in Chapter 4, the larger the lot size, the fewer the exposures to stockouts. The risk of running out is when the inventory is planned to be at the lowest level. The above reasoning is valid, but it must be balanced with other considerations.

The basic disadvantage of large lot sizes is the cost of carrying the inventory. These inventory carrying costs consist of:

1. Storage cost. The floor space must be considered not only for finished goods and raw material, but also for the shop floor space requirements brought about by large manufacturing lot sizes. A hidden cost can be the loss of operating efficiency due to crowded conditions.

2. Physical management costs. Personnel costs are required for the physical transactions of inventory, moving material, housekeeping, and required counting as well as cycle counting.
3. Insurance and taxes.
4. The risk of obsolescence due to engineering or style changes. The risk is high in high tech industries.
5. The cost of the money invested in the inventory. This cost is the largest part of the carrying cost. In determining the cost of money for a short term investment, the cost of borrowing should be taken into account. If the money is available, and borrowing is not necessary, the loss of short term interest is the cost of the short term investment. If the cost of money calculation is for inventory policy decisions, opportunity costs should be used. The opportunity cost is the expected return from alternate investments if the money was not tied up in inventory.

The carrying cost calculation expresses that cost as an annual percentage of the inventory investment. A sample of the calculation is based on the following

Storage costs	1%
Physical management	3%
Insurance and taxes	3%
Obsolescence risk	2%
Opportunity costs	<u>24%</u>
Total	33%

Since the above calculation is based on estimates, the 33% carrying cost might be changed to 30% or 36%. This change would then make it more convenient to express monthly carrying charges as 2.5% or 3%. The fact that the carrying cost is an estimate, should be kept in mind when it is utilized in lot size calculations.

Another disadvantage of large lot sizes not considered in the carrying cost, is the resultant long lead times and loss of flexibility in manufacturing operations. Just-in Time (or Lean Manufacturing) which requires small lot sizes, and therefore shorter lead times, has proven to be more responsive to customer needs.

In the determination of the desired lot size, the carrying cost is balanced with the preparation cost of the production or purchase order. If the item is

manufactured, the primary cost is the start up of the job which includes factors such as equipment setup, tooling placement, assembly line changeover, and scrap resulting from the start up. Other associated costs can be order paperwork preparation and work order control. Purchase order costs include supplier selection, receiving, inspection, and accounts payable. This purchase order cost is a valid consideration in the determination of the lot size of a purchased commodity. If the purchased item is a unique product, such as a raw material casting, the real order cost is the production order cost of the supplier. When the customer does not or cannot allow for the order cost, the supplier will often compensate by encouraging larger lot sizes through quantity discounts.

All lot sizing techniques consider, with varying degrees, the balancing or the relationship of carrying costs to ordering costs. The relationship of ordering cost to carrying cost is illustrated in Figure 5-1

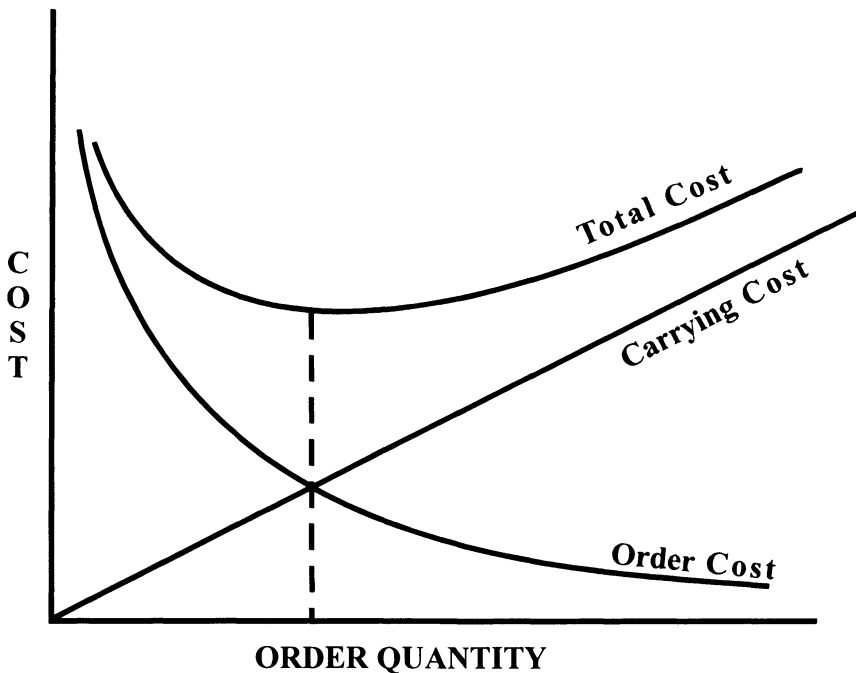


Figure 5-1

THE ECONOMIC LOT SIZE

If the lot size is small, the item's carrying cost will be minimized, but the ordering cost will be high due to the cost being distributed to the smaller quantity. Conversely, a large lot size will cause a higher item carrying cost, but will minimize the ordering cost.

$$\text{The Annual Carrying Cost} = \frac{\text{Order Quantity}}{2} \times \text{Cost of the Item} \times \text{Annual Carrying Cost Percentage}$$

$$\text{The Annual Cost of Ordering} = \frac{\text{Annual Usage}}{\text{Order Quantity}} \times \text{Cost per order}$$

*The order quantity is divided by 2, to allow an average inventory

Assuming item A with a standard cost of \$2.00, a lot size of 1,000 and a carrying cost of 30%; the annual carrying cost will be:

$$1,000/2 \times \$2.00 \times .30 = \$300$$

If item A's annual usage is 12,000 and the cost per order is \$50, the annual ordering cost will be:

$$12,000/1000 \times \$50 = \$600$$

The total annual cost for item A is:

Product cost	=	12,000 x \$2.00	=	\$24,000
Carrying cost	=		=	300
Ordering cost	=		=	<u>600</u>
Total cost	=		=	\$24,900

If the-lot size of item A is increased to 1,500, the carrying cost will be:

$$1,500/2 \times \$2.00 \times .3 = \$450$$

The ordering cost will be:

$$12,000/1,500 \times \$50 = \$400$$

The total annual cost will be:

Product cost	= 12,000 x \$2.00	= \$24,000
Carrying cost	=	450
Ordering cost	=	<u>400</u>
Total cost	=	\$24,850

The minimum total cost of ordering is expressed and calculated by the Economic Order Quantity (EOQ) formula. The low point on the order quantity curve is that point where the carrying cost equals the order cost. The formula is based on the assumption that the demands are level and continuous and that receipt is instantaneous. The formula is:

$$EOQ = \sqrt{\frac{2AS}{CI}}$$

Where A = Annual quantity, units

S = Ordering cost, dollars

C = Item cost, dollars

I = Inventory carrying cost, decimal fraction

An example of the EOQ calculation is:

Item B has a forecasted annual usage of 6000 units, a standard cost of \$2.00, a setup (order) cost of \$80.00, and an inventory carrying cost of 32%.

$$\text{The EOQ} = \sqrt{\frac{(2)(6,000)(\$80)}{(\$2)(.32)}} = \sqrt{\frac{960,000}{.64}} = \sqrt{1,500,000} = 1,225 \text{ units}$$

The EOQ formula has been used (and abused) for a number of years. Users often did not realize that:

- The carrying cost percentage is an estimate and not “cast in concrete”. A 28% carrying cost estimate might be no more accurate than 32%
- The curve determining the minimum point (the EOQ) was relatively flat at the lowest point. An EOQ of 739 could be adjusted ± 100 with minimum change to the total cost.
- Usage often is not level and continuous.

Although not perfect, the logic behind the EOQ formula (balancing order cost with carrying cost), is valid and is a consideration in lot size

determination in different situations. As an example, Just-in-Time manufacturing calls for minimum lot sizes, but this is only practical after setup costs have been minimized.

FIXED ORDER QUANTITIES

Lot sizes may be fixed quantities that have been calculated by an EOQ or determined by other factors such as die life in a manufacturing operation, a price break for a purchased item, or packaging requirements. The packaging requirements might be as small as a box of washers or as large as a freight car of industrial salt. When the quantity is fixed, the ordering frequency will vary with the demand patterns.

Table5-1 illustrates the order receipt pattern of a fixed order quantity of 150 covering 9 weeks' requirements. The visibility of requirements shown, would have been the output of a material requirements planning (MRP) system or a distribution requirement planning (DRP) system. The release dates of the orders would be dependent on the item lead times.

**Table 5-1. A Fixed Order Quantity of 150 and
Planned Order Receipts**

Week	1	2	3	4	5	6	7	8	9
Requirements	50	52	40	37	48	0	56	52	48
Planned order receipt	150			150				150	

The above fixed order quantity could have been based on an EOQ or, for instance, die life. If the EOQ was decreased to 100, due to a setup reduction program, or if the die life was decreased to 100, the order receipt pattern would have changed as shown in Table 5-2. Note that in both examples there is a remaining quantity going into week 10.

**Table 5-2. A Fixed Order Quantity of 100 and
Planned Order Receipts**

Week	1	2	3	4	5	6	7	8	9
Requirements	50	52	40	37	48	0	56	52	48
Planned order receipt	100	100			100			10	

FIXED PERIOD QUANTITIES

Fixed period quantities are based on calculating and placing orders in a predetermined fixed cycle such as every week, every two weeks, or every month. The planned order quantity received will cover the anticipated requirements of the fixed period. With this ordering technique, there is little formal analysis of inventory investment, as the system's ordering intervals are the major consideration. This method is useful in distribution or retail operations, where it is advantageous to order multiple items from a single supplier. The actual inventory to be considered may be based on a cycle count at time of order, rather than a perpetual record. If the control system calls for a target level, the order quantity will be determined by the actual demand of the previous period. If the control system is MRP or DRP based, the order quantities are reflected in Table 5-3.

Table 5-3. A 2-Week Fixed Period Requirement and Planned Order Receipts

Week	1	2	3	4	5	6	7	8
Requirements	50	52	40	37	48	0	56	52
Planned order receipt	102		77		48		108	

LOT-FOR- LOT QUANTITIES

When the period, in a fixed period ordering system, is the same as the planning interval, such as a 1-week fixed period in a system being generated weekly, the order requirements are lot-for-lot or "as required". The order quantity will match the requirements of the period being planned. In a just-in-time environment, the lot-for-lot quantities might be planned daily, with the order quantity planned being that day's requirement. The lot-for-lot technique generates minimum inventories, but is only practical when ordering (setup) costs have been reduced to a minimum. Advantages, in addition to minimum inventories, are reduced lead times and increased operating flexibility in manufacturing environments. Table 5-4 is an illustration of lot- for- lot ordering patterns.

Table 5-4. Lot-for-Lot Ordering

Week	1	2	3	4	5	6	7	8	9
Requirements	50	52	40	37	48	0	56	52	48
Planned order receipt	50	52	40	37	48	0	56	52	48

ECONOMIC ORDER QUANTITY VARIATIONS

The logic of the EOQ equation (balancing the carrying cost with the ordering cost) is valid when the demands are level and continuous. There are techniques developed to modify the EOQ logic to cover demands that are not level and continuous, but are discontinuous (lumpy).

In a manufacturing environment, the requirements of purchased raw materials and other components are dependent on the anticipated usage patterns of higher level items or assemblies (the parents) that the purchased items go into. This relationship is the subject of Chapter 7 (Replenishing Dependent Demand). A purchased casting may be the raw material component of four different machined gears. The planned work order release pattern of each gear is discontinuous. The period by period requirement of the casting will be the sum of the demands of the four gears. The following is an example of that pattern.

Period	1	2	3	4	5	6	7	8
Gear #1	100			100				100
Gear #2		70			70		70	
Gear #3	50		50			50		50
Gear #4				80		80		
Total	150	70	50	180	70	130	70	150

Three techniques that address this situation are shown below.

1. The Period Order Quantity

The period order quantity is a calculation that evolves into a fixed period requirement based on a modified EOQ. Table 5-5 shows requirements for 8 months. Based on an annualized usage of 1,200, and an EOQ calculated to be 200, the irregular planned order receipts are shown to equal 6 expected receipts for the year.

$$\frac{\text{Annual demand}}{\text{EOQ}} = \frac{1,200}{200} = 6 \text{ expected orders per year}$$

The six anticipated orders are adjusted to an ordering interval (or fixed period) of 2 months. For the first 8 months, instead of 4 orders of 200 placed in irregular intervals, 4 period order quantities are placed in a uniform pattern with varying resultant quantities are shown in Table 5-5.

**Table 5-5. Monthly Requirements and Period
Order Quantity Planned Receipts**

Month	1	2	3	4	5	6	7	8
Requirements	50	70	90	120	140	150	80	60
EOQ planned order receipt	200		200		200	200		
Period order quantity planned order receipt	120		210		290		140	

2. The Least Unit Cost

The logic of the least unit cost technique calculates the cost of the first period's requirement and then recalculates adding the next period's requirement to determine if it is less costly to add the two requirements. This iterative process continues, accumulating the order cost and the carrying cost period by period, and dividing the total cost by the accumulated units to determine the unit cost. At the point where the unit cost start to increase, the process stops and the accumulated requirements become the least unit cost lot size. Table 5-6 illustrates the least unit cost technique results..

**Table 5-6. Planned Order Receipts Based on
Least Unit Cost**

Week	1	2	3	4	5	6	7	8	9	10
Requirements	50	52	40	37	48	0	56	52	48	52
Planned order receipt	102		125				108		100	

3. The Least Total Cost

The least total cost approach, like the least unit cost technique, is an iterative process which accumulates the carrying costs and the ordering cost period by period. Rather than adding the costs and calculating the unit cost, it compares the two costs. (The logic of this approach is because the EOQ formula determines the economic lot size when the ordering cost curve and the carrying cost curve intersect.) At the point where the two costs are nearly equal, the process stops and the accumulated requirements become the least total cost lot size. Table 5-7 illustrates the results from the least total cost technique and how they might differ from the least unit cost results (above)

**Table 5-7. Planned Order Receipt Based on
Least Total Cost**

Week	1	2	3	4	5	6	7	8	9	10
Requirements	50	52	40	37	48	0	56	52	48	52
Planned Order Receipt	142			141				152		

NONINSTANTANEOUS RECEIPT LOT SIZES

The algorithm that determines the economic order quantity (EOQ) assumes instantaneous receipt. In some manufacturing environments, such as processing, the receipt is not instantaneous, but is received over a sustained period of time. An example would be a strap manufacturing operation where a 3 week requirement lot size runs and is received over a 1 week period. Figure 5-2 is an illustration of inventory movement with instantaneous receipt (the saw toothed curve) and Figure 5-3 illustrates inventory movement with noninstantaneous receipt.

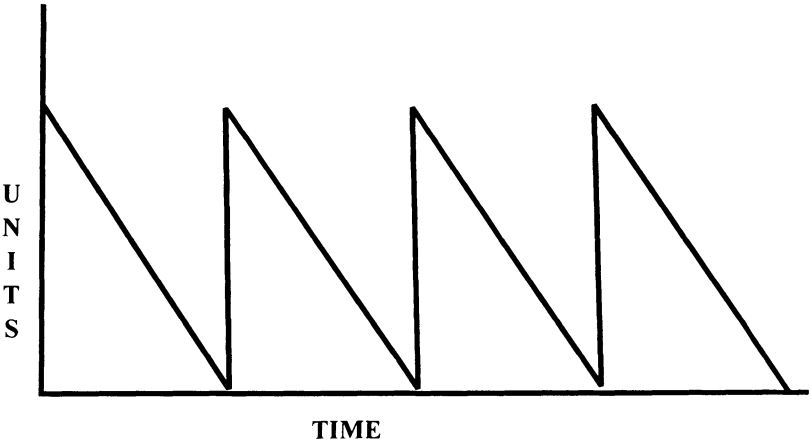


Figure 5-2

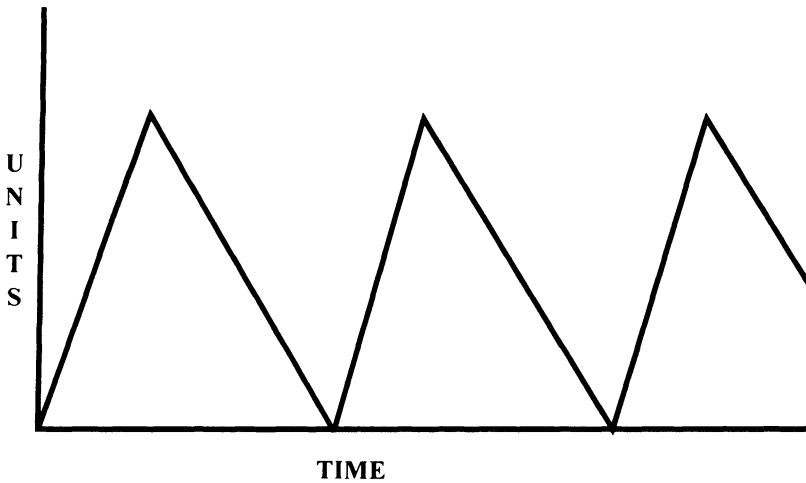


Figure 5-3

The noninstantaneous receipt lot size formula is a modification of the standard EOQ formula and is:

$$\text{Noninstantaneous EOQ} = \sqrt{\frac{2AS}{CI(1-UR/PR)}}$$

Where A = Annual quantity, units

S = Ordering cost, dollars

C = Item cost, dollars

I = Inventory carrying cost, decimal fraction

UR = Usage rate, units/time period

PR = Production rate, units/time period

An example of a noninstantaneous receipt calculation is:

Annual usage	6000 units
Unit cost	\$2.00
Setup cost	\$80.00
Inventory carrying cost	32%
Production rate	360 units/week
Usage rate	120 units/week

$$\begin{aligned}
 \text{Calculated EOQ} &= \sqrt{\frac{(2)(6000)(\$80.00)}{(.32)(\$2.00)(1-120/360)}} \\
 &= \sqrt{\frac{960,000}{.4288}} \\
 &= \sqrt{2,238,806} \\
 &= 1496 \text{ units}
 \end{aligned}$$

CASE STUDY SMITH GAS GRILL COMPANY

With the growth of business in 1985 and 1986, there were also space problems growing within the company. An additional concern was that, in spite of increased income, the cash flow was not at a desired level. A review of the financial records indicated that inventory was not only taking up space but was also tying up more dollars than desired. The \$900.00 parts inventory at the end of 1983 had grown to \$8,200 at the end of 1986. The sales history for the past four years was:

1983	\$ 81,000
1984	\$ 110,000
1985	\$ 137,000
1986	\$ 168,000

That the inventory had increased at a much faster rate than the sales growth could be partly attributed to the fact that retail sales had increased significantly compared to 1983, when for all purposes, the only income was from the repair part of the business. The increased retail sales did not explain the reduced turnover rate in 1986 compared to 1983. Although not a perfect measurement, the following inventory turnover comparisons were calculated.

December 31, 1983 Parts Inventory = \$900
 1983 Parts Inventory cost of sales for repair and retail = \$3,100
 $\$3,100 \div \$900 = 3.44$ turns per year

December 31, 1986 Parts Inventory = \$8,200
 1986 Parts Inventory cost of sales for repair and retail = \$41,600
 $\$41,600 \div \$8,200 = 5.07$ turns per year

The inventory management control software did have lot sizing features, but these features had not been utilized. The ABC part number classification

feature also had not been used up to this point. What had been visually observed was that certain parts were taking up quite a lot of space. An example was the gas grill burner (part number 214) which had an increased safety stock level from 20 to 42 due to demand volatility. (See Chapter 4 Case Study). Not only was the grill taking up space, it was one of the more expensive items in stock.

CASE STUDY - SUGGESTED SOLUTION

The decision was made to analyze the stocking policies of the more critical parts. Critical was defined as meaningful with respect to:

1. Customer service
2. Inventory investment
3. Space requirements

An analysis, utilizing the ABC classification system, indicated that A class parts constituted the critical items relative to investment and space considerations. In the customer service review, all parts had to be analyzed as a part shortage of a \$.02 nut can be just as critical as a \$50.00 burner.

The stockout review of all parts did indicate that the major availability problems were also with A class parts. This was attributed to the fact that the less expensive parts were purchased in larger lot sizes and therefore had less exposures to stockouts.

The EOQ lot size of all A class parts was calculated utilizing the inventory management software. The calculation was based on a carrying cost of 30% and an ordering cost of \$40.00. All the A class parts were purchased, so that the ordering cost was the estimate of the cost of a purchase order. The calculated EOQ lot sizes were then compared to the actual lot sizes now in use. These lot sizes had been determined by "seat of the pants" judgement, suppliers' suggestions, or suppliers' order quantity discounts. The following are examples of the individual item's analysis.

1. Gas Grill Burner (part number 214).

Safety stock = 42 units

Present lot size = 100 units

Annual usage = 1040 units

Standard cost = \$58.00

Average expected inventory = $42 + (100/2) = 92$ units

$$\text{Calculated EOQ} = \sqrt{\frac{(2)(1040)(\$40.00)}{(.30)(\$37.00)}} = 87 \text{ units}$$

Average expected inventory

(based on calculated EOQ) = $42 + (87/2) = 85.5$ units

Understanding the estimations involved in the EOQ calculation and how close the resultant expected inventories were, the decision was to stay with the existing lot size of 100 units.

2. Gas Grill Burner (part number 301)

Safety stock = 16 units

Present lot size = 100 units

Annual usage = 400 units

Standard cost = \$42.00

Average expected inventory = $16 + (100/2) = 66$ units

$$\text{Calculated EOQ} = \sqrt{\frac{(2)(400)(\$40.00)}{(.30)(\$42.00)}} = 50 \text{ units}$$

Average expected inventory

(based on calculated EOQ) = $16 + (50/2) = 41$ units

Although both burners had similar costs (\$37 versus \$42), the usage rate was for burner #301 was only 40% the rate for burner #214. The EOQ calculation indicated that the lot size for #301 should be cut in half. Both burners were supplied by the same supplier. Due to the fact that the manufacturing processes were similar and both burners shared common parts, the supplier had no problem in the reduced purchased lot size.

3. Accessory Grill Tray Table (part number 810)

Safety stock = 5 units

Present lot size = 40 units

Annual usage = 150

Standard cost = \$75.00

Average expected inventory = $5 + (40/2) = 25$ units

$$\text{Calculated EOQ} = \sqrt{\frac{(2)(150)(\$40.00)}{(.30)(\$75.00)}} = 23 \text{ units}$$

Average expected inventory

(based on calculated EOQ) = $5 + (23/2) = 16.5$ units

The grill table was a recent Smith Company design which was being fabricated by an outside contractor. When the contractor was approached about reducing the lot size from 40 to 23, he said he would have to increase his price from \$75.00 to \$78.00, due to less units to absorb his order (setup) cost.

Based on the following comparison of total costs, the decision was made to stay with the larger lot size.

	<u>Lot Size 23</u>	
Annual purchase cost	150 x \$78.00 =	\$11,700.00
Annual ordering cost	150/23 x \$40.00 =	260.00
Annual carrying cost	23/2 x \$78.00 x .30 =	<u>269.00</u>
Total Cost		\$12,229.00

	<u>Lot Size 40</u>	
Annual purchase cost	150 x \$75.00 =	\$11,250.00
Annual ordering cost	150/40 x \$40.00 =	150.00
Annual carrying cost	40/2 x \$75.00 x .30 =	<u>450.00</u>
Total Cost		\$11,850.00

As a point of interest, the contractor based his lot size of 40 units on a standard cost of \$65.00 and a setup cost of \$104.00.

$$\text{Contractor's EOQ} = \sqrt{\frac{(2)(150)(\$104.00)}{(.30)(\$65.00)}} = 40 \text{ units}$$

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Chapter 6

REPLENISHING INDEPENDENT DEMAND

INDEPENDENT DEMAND DEFINED

The nature of independent demand is that it is unrelated to the demand of any other items. The rate of use of independent demand is most often determined by the market place. Independent demand inventory is called distribution inventory while dependent demand inventory is known as manufacturing inventory. Distribution inventory is most often maintained in manufacturing finished goods' warehouses, regional distribution centers, local distribution centers, and retail outlets.

Retail item demand, such as apples in grocery stores, is independent demand just as is the independent demand for a commercial aircraft. In a make-to-stock environment, the demand for finished goods (end items) is forecasted, while the demand for make-to-order or assemble-to order items is based on customer orders. Depending on how the bills of material are structured, a module or an option may be considered an independent demand item. A part may be a component of a manufactured item (dependent demand) as well as a service or replacement part (independent demand). In this situation, the item is said to be a "combined " demand item and is treated as such in the inventory control system. Independent demand is normally forecasted, with make-to-order demand being the exception. Forecast error is usually compensated for with the use of safety stock. Demand patterns may be continuous or lumpy (due to seasonal or cyclical factors).

THE REORDER POINT

The logic of the reorder point is that material is to be reordered when the stock level of the material will be used up during the time required to bring in additional stock. The calculated reorder point (also referred to as an order point, a statistical order point, or a trigger) is that predetermined inventory level at which replenishment action is called for when the on-hand and on-order drops to or below that level. The reorder point calculation is as follows:

$$\text{Reorder Point} = \text{Anticipated demand during lead time} + \text{Safety Stock}$$

The anticipated demand is forecasted and assumed to be independent, continuous, and uniform. Discontinuous (lumpy) demand is addressed later in this chapter.

The lead time is the sum of the following:

1. Supplier or manufacturing lead time
2. The review period (daily, weekly, or monthly)
3. Purchase order or shop order preparation time
4. Receiving and inspection time

The safety stock may be based on sophisticated statistical formulas such as measuring the standard deviation and relating that deviation to the lot size, lead time, and the desired service level. On the other hand, the safety stock may be a fixed number that represents an expected demand over a predetermined period of time, such as two weeks.

The on-hand inventory record can be the result of either a perpetual inventory system or based on scheduled cycle counts of the controlled items. All open purchase and manufacturing orders must be controlled and considered in the reorder point review. The order quantity is determined by lot size policy and is not a part of the reorder point calculation.

Figure 6-1 shows the traditional sawtooth inventory profile and the relationship with a reorder point system. The example is based on the following data:

Forecasted usage rate = 100 units/week
Lead time = 4 weeks
Lot size = 700 units
Safety stock = 200 units
Reorder point = $100(4) + 200 = 600$ units

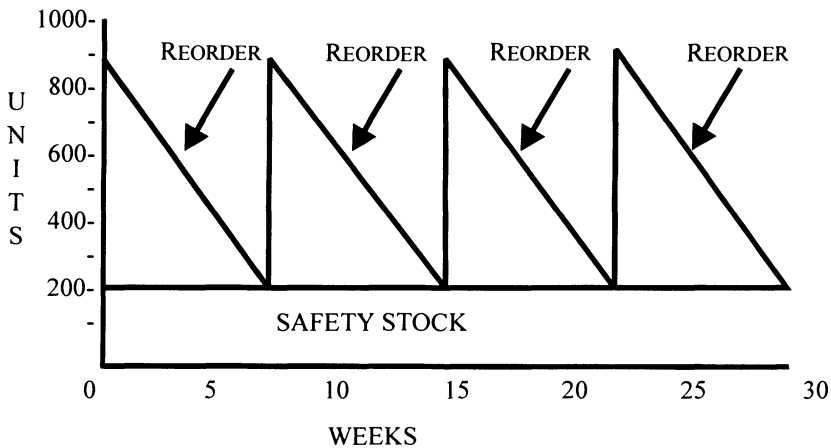


Figure 6-1. Reorder Point System "Sawtooth" Curve

The anticipated stock levels are:

Minimum stock = Safety stock = 200 units

Maximum stock = Safety stock + Lot size = 900 units

Average stock = Safety stock + $\frac{1}{2}(\text{lot size}) = 550$ units

Although the lot size does affect the quantity in inventory, it does not enter into the reorder point calculation. In the above example, if the lot size was 5200 (1 year's worth), the reorder point would still be 600 units. The reorder point is relatively easy to understand, calculate, and manage. When usage is independent and used in a consistent uniform rate, the reorder point technique will work well in inventory management. However, in many situations, the rate of independent demand is not continuous but lumpy (discontinuous). These situations require a different approach to inventory replenishment.

TIME-PHASED ORDER POINTS

The time-phased order point (TPOP) is used for the planning and control of independent demand that is not continuous. In some situations, such as Master Scheduling (see Chapter 8) and Distribution Resource Planning (see Chapter 10), TPOP will be used when demand is continuous. It often will be

used for finished goods’ and service parts’ control. The term “order point” is a misnomer in that this technique does not calculate a specific order point. Time phasing is the segmenting of inventory status by time periods. The technique uses the standard MRP logic of determining net requirements by time period. (See Chapter 7).

The demand in a TPOP system may be forecasted or based on customer orders and is listed as the Gross Requirement. Gross requirements are listed by time period over the horizon of the planning period. The Available Inventory is also listed by time period with the projection based on forecasted demands (gross requirements), as well as open and planned order receipts. The Net Requirement for the period is calculated by subtracting the projected available inventory from the gross requirement. The order quantity may be based on a fixed period, such as every 2 weeks, or a fixed quantity, such as an EOQ of 100 units.

Table 6-1 is a planning grid illustrating a time-phased order system over an 8 week period.

Table 6-1. TPOP with Lot Size = 100 and Lead Time = 2 Weeks									
Week		1	2	3	4	5	6	7	8
Gross Requirements		40	40	45	50	50	50	45	45
Scheduled Receipts		100							
Projected Available	30	90	50	5	55	5	55	10	65
Planned Receipts					100		100		100
Planned Order Releases			100		100		100		

The time phased planning data shown in the above grid illustrates not only the time-phased order system but also the logic used on MRP calculations. (TPOP was actually a by-product of MRP). The gross requirement is the anticipated demand during the period, the projected available inventory is as of the end of the period, and order receipts and releases are at the beginning of the period. Any orders due during a given week will show due at the beginning of the next week. In the above calculation, there is no planned safety stock.

PERIODIC REVIEW SYSTEMS

A periodic review system calls for the placing of orders based on a fixed cycle interval. In a small operation, all orders may be calculated and released in one day while, in larger operations, orders may be calculated and released every day with the individual items scheduled on a fixed cycle. Small retailers may use the periodic review approach using a cycle count to avoid maintaining a perpetual inventory and to concentrate on ordering on a

planned day. A larger operation may maintain a perpetual inventory, but use the periodic approach so as to order a number of items from a single source at one time. With this technique, the ordering schedule is based on planned supplier ordering patterns. The advantages with this technique are that it creates a single purchase order or requisition as well as providing the ability to order slow moving items in smaller quantities. Branch warehouses will often use this approach to place replenishment orders on a scheduled basis. With periodic review, the order quantity will vary (see Chapter 5). Orders will be placed in quantities to meet a target level.

Factors determining the target are the forecast, the lead time, the review period, and the safety stock. The review period or interval is determined by operating plans but consideration must also be given to desired lot sizes and inventory levels. If the review period is weekly, the average lot size will be one week's demand. If the review period is monthly, the average lot size will be one month's demand.

Safety stock will be higher in a periodic review system due to the fact that forecast demand variations will occur over both the lead time and the review period. If the lead time is 5 weeks and the review period is 3 weeks, the forecast demand variations will cover 8 weeks. The safety calculation (see Chapter 4) calls for adjusting the standard deviation based on the relationship of the forecast interval to the lead time interval. The lead time calculation includes the review period.

The following is an example of a target calculation.

Forecast = 200 units
Lead time = 2 weeks
Review period = 3 weeks
Standard deviation (1 week) = 20 units
Standard deviation (5 weeks) = $20 \times 3.09 = 60$ units
Desired service level = 95%
Safety stock = $60 \times 1.65 = 99$

Target = Forecast x (Lead time + Review period) + Safety stock
= $(200 \times 5) + 99 = 1099$ units

At the time of review, the sum of the on hand and on order inventory is subtracted from the target to determine the order lot size. In other words, the user is ordering up to target. If in the above example, the on hand inventory was 552 units and there were none on order, the order quantity would be $1099 - 552 = 547$ units.

Figure 6-2 is an illustration of the inventory profile for the above example. The assumption is made that the future weekly demand will exactly meet the forecasted 200 units. Although the target is 1099 units, the

highest expected inventory would be 699 (the target less the demand during the 2 week lead time). The lowest expected inventory would be 99 (the safety stock).

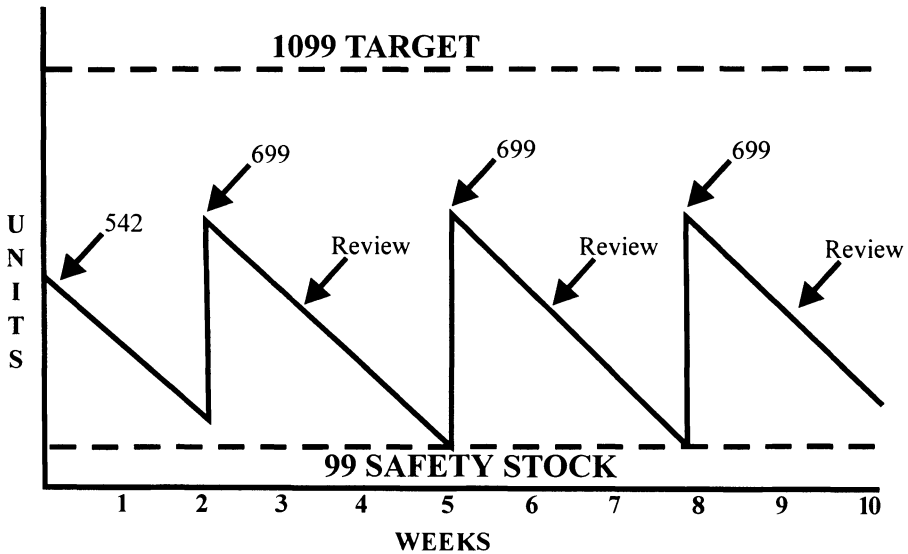


Figure 6-2. Periodic Review Model

VISUAL REVIEW SYSTEMS

A visual review inventory control system is utilized when perpetual records are not maintained. This may include the entire product line, such as a small retail operation, or selected items from a much larger item data base, such as hardware items in a manufacturing or assembly operation. In a visual review system, the visual results may be compared to an order point or, when using a periodic control system, to a target level.

The two-bin system is an example of visual review using reorder point logic. The material is stored in two bins. When the first bin is emptied, a replacement order is issued. The second, or controlling bin, must hold sufficient parts to at least cover the demand during the lead time as well as the desired safety stock. With this simplified system, the lead time must be short, as open order records are usually not maintained. Another example of visual reorder control is the wall or floor markings in a shipping department which signals supervision to order additional packaging material. The visual control approach is best applied to maintenance supplies, office material, and inexpensive manufacturing hardware. As with conventional reordering systems, the lot size is fixed.

Using visual controls in a periodic review system calls for ordering to the predetermined target based on the subtraction of the cycle count from the

target. The supply lead time must be less than the review period to avoid open order control.

In just-in-time manufacturing environments, inventories are often controlled by visual signals such as bins, cards, and floor markings. The determination of the number of cards, bins, kanban squares etc. is based on reorder point logic. The demand is the cycle time of need, the lead time is the sum of setup, run, and move times, and the safety or buffer stock is calculated to allow for fluctuations. The manufacturing lot size is often controlled by conventional EOQ logic, but with reduced setup times.

REPLENISHMENT VARIATIONS

Variations of the reorder and periodic systems are the:

- Double Order Point
- Periodic Review/ Reorder Point Combination
- Min-Max

The double order point system is a technique in which ROP (1) is the trigger calling for a replacement order and is based on the conventional calculation of usage during delivery lead time. ROP (2) is based on not only delivery lead time from the supplying center (the factory) but also includes the manufacturing lead time of the item. If the lead time from the factory to the customer is 3 weeks and the manufacturing lead time is 10 weeks, the ROP (2) will be based on a total lead time of 13 weeks. The “customer” in this situation is often a distribution warehouse. When the on hand and on order for an item is below ROP (2), it is a warning notice for production planning but not an authorization to ship. Shipment will not be called for until on hand and on order is below ROP (1). Figure 6-3 illustrates the inventory graph of a double order point system.

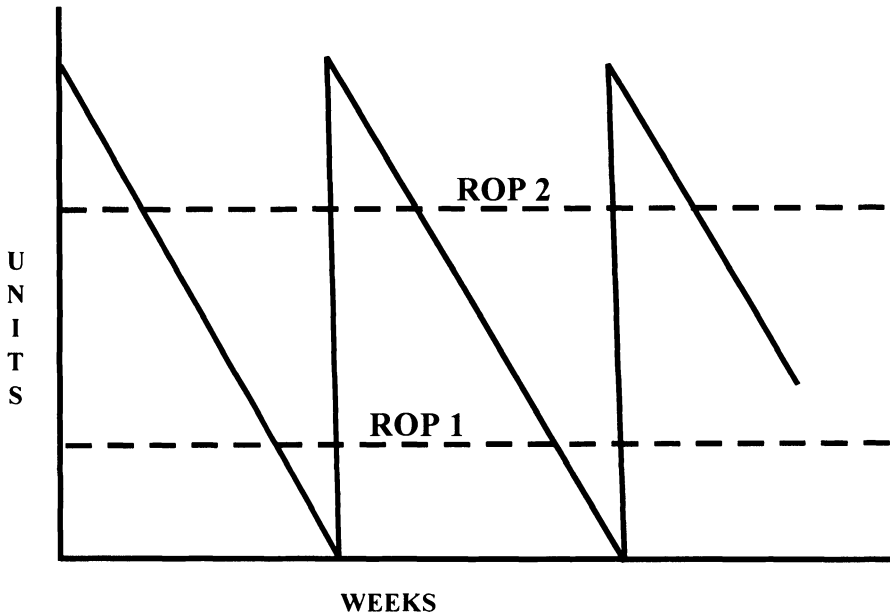
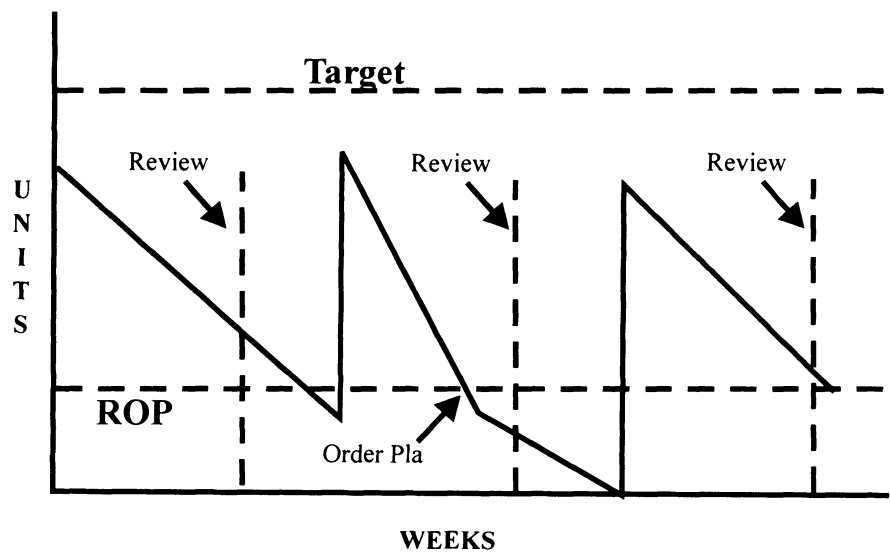


Figure 6-3. Double Order Point Model

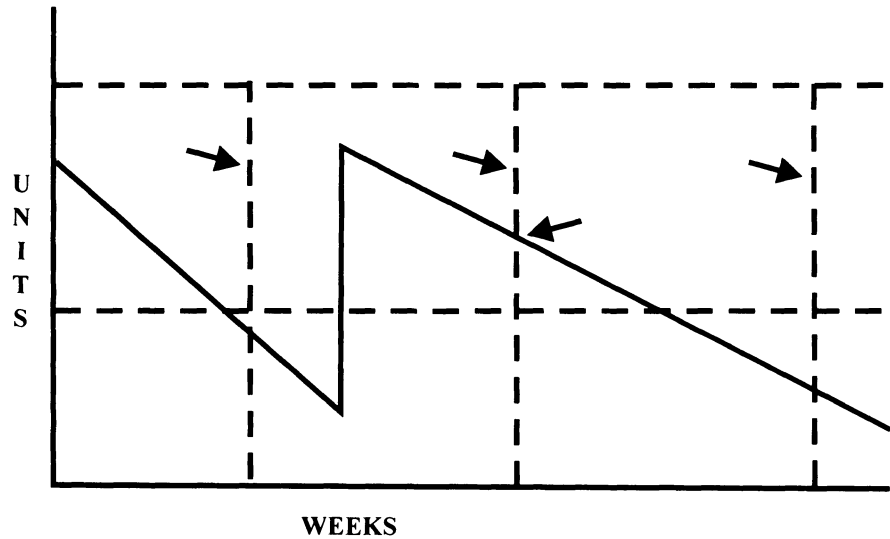
The periodic review/reorder point combination system is based on the periodic review placing of orders to a target level, but with a safeguard in the form of a reorder point that will call for order placement prior to the review period if on hand and on order have dropped below a reorder point. The reorder point is calculated in the conventional manner, with the safety stock based on demand during supply lead time. This compares to the periodic review safety stock calculation, which must add review time demand to the supply time demand. This combination system requires the maintenance of a perpetual inventory, while a simple periodic review system can be controlled by either a cycle count or a perpetual inventory. The combination technique works well when periodic review is called for, but there may be a high degree of demand variation.

The min-max system is based on a periodic review where an order will only be placed if the item is below a predetermined reorder point. This approach prevents the ordering of small quantities of specific products. The minimum (min) quantity is the order point and the maximum (max) quantity is the target level that is “ordered up to”. This system is also called an optional replenishment system. Unlike the periodic review/reorder point combination system, it can be controlled by either cycle count (visual) or a perpetual record. Both the min-max and the periodic review/reorder point combination systems are hybrid systems in that they consider period reviews and reorder points. Figures 6-4 and 6-5 compare the two.



Order placed before scheduled review as stock goes below order point

Figure 6-4. Periodic Review/ Reorder Point Combination Mode



Order is not placed. Stock level is above the reorder point

Figure 6-5. Min-Max Replenishment System

JOINT REPLENISHMENT SYSTEMS

The advantages of joint replenishment can be cost reductions in ordering, setups, quantity discounts, and transportation. The challenge is matching reasonable lot sizing with order releasing. Joint order releasing is useful when purchasing from single source suppliers, controlling warehouse inventories, and scheduling product family groups in the factory. A periodic review system ordering up to a target level is the most orderly approach, but some environments require reorder point control. Two reorder point joint replenishment techniques are:

1. Linking individual reorder points
2. Establishing a group reorder point

The first step in linking individual reorder points is the identification of specific ordering groups. The grouping may be based on such things as common suppliers, similar manufacturing families, or warehouse requirements. The second step is the establishing of joint order criterion such as ordering up to a total target based on total dollars, units, or truckload quantities. When the first item in the group reaches reorder point, all items in the group are then considered for replenishment. The replenishment quantity may be based on how far each item is from reorder point or the ratio of on hand and on order from reorder point. The individual quantities will then be prorated to meet the joint order criterion.

The following is an example of a four item group, where the ordering criterion is the determination of the ratio of each item's quantity on hand and on order, to the reorder point. Each item's individual EOQ is then divided by the ratio of the item. The purpose of this particular criterion would be to bring the inventory of all of the items in line with each other.

ITEM	EOQ	ROP	ON HAND AND ON ORDER	RATIO <u>ON HAND & ORDER</u> ROP	<u>EOQ</u> RATIO
A	200	85	80	.94	213
B	350	100	130	1.30	269
C	175	70	90	1.28	137
D	<u>280</u>	<u>65</u>	<u>200</u>	3.08	<u>91</u>
TOTAL	1005	320	500		710

The group quantity equals 710. If a group order quantity of 500 was desired, each item's quantity could be prorated by a factor of $500/710 = 70.4\%$.

ITEM	ORIGINAL QUANTITY	PRORATED QUANTITY
A	213	150
B	269	189
C	137	97
D	<u>91</u>	<u>64</u>
TOTAL	710	500

The calculation of a group reorder point is accomplished by summing up the individual reorder points and comparing this group reorder point with the sum of all on hand and on order quantities within the group. Individual order quantities can be determined in a manner similar to the individual item approach shown above. In the above example, the group reorder point would be 320 units. The example also illustrates the potential problem with this approach. Due to the large quantity on hand of item "D", the total on hand and on order quantity (500) for the group is not close to reorder although item "A" is relatively low. Some sort of a warning mechanism would be required to alert and prevent this situation.

CASE STUDY SMITH GAS GRILL COMPANY

By the end of 1988, sales for the Smith Gas Grill Company had increased from \$168,000 in 1986 to \$597,000 in 1988. The repair and replacement part business had increased at an annual rate of 22% but the major contributor to growth had been the addition of a patio furniture line which by year end had accounted for 53% of sales. In November, 1988 a line of gas grills was added to go along with both patio furniture sales and the grill repair business. Plans were underway to manufacture grills in the near future. In line with the growth of the existing business and future growth plans, a new facility in the suburbs was acquired that consisted of a showroom, warehouse, and planned manufacturing space. With the diversification of both products and function, the name of the company was changed to Smith Industries Inc.

Two problems in inventory management called for attention. In the past two years the sales had increased over three times, but inventory investment had increased five times. The cost of managing the inventory was increasing at an alarming rate both with respect to money as well as the time required

by critical employees. On the positive side, customer service goals were being met and inventory accuracy problems of the past had been eliminated through transaction auditing and cycle counting. The number of parts in the system had increased to over 1000 but this did not create a problem. The nonsignificant part numbering system allowed adding another digit for future part identification.

CASE STUDY - SUGGESTED SOLUTION

The inventory control system at this point was doing what it was programmed to do. The perpetual records, through a great deal of effort, were accurate. The lot sizes, based on EOQ calculations, were reasonable. Replenishment orders were based on the standard reorder point formula and were being delivered on time. For ease of analysis, all items were classified by broad family groupings. The family groups were:

Group 1	Gas grill A class parts
Group 2	Gas grill B class parts
Group 3	Gas grill C class parts
Group 4	Patio Furniture
Group 5	Gas Grills

The group by group analysis revealed the following:

Groups 1 and 2 consisted of approximately 400 items. They were valued at \$9000 and were in line with customer service, inventory turnover, and dollar growth. These two groups represented 22 % of the total inventory and 90 % of gas grill parts' inventory.

Group 3 consisted of approximately 500 items valued at \$1000, which was in line with respect to customer service and planned investment. This investment represented 10% of grill parts' inventory and less than 3% of total inventory. Additional analysis indicated that this group required over half of the inventory management effort in perpetual record control and replenishment activities. Based on this analysis, it was decided to simplify the system by eliminating the perpetual records of Group 3 items and replenish by one of the following systems:

- a) Control and replenish hardware items with a two-bin system
- b) Parts purchased from a single source are to be replenished with a _____ periodic review system based on visual review (cycle count)
- c) Remaining C class parts will be scheduled for cycle counts and compared to predetermined reorder points

Group 4 analysis indicated the opposite of Group 3 in that it represented relatively few items but a major part of the total inventory investment. Patio

furniture accounted for 53% of sales but 60% of the total inventory. The following actions were required to bring this group into line.

- a) Patio furniture replenishment had been based on a conventional reorder point system which assumes a steady demand rate. Patio furniture is seasonal with strong spring sales, moderate summer sales, a pick up toward the end of summer, and weak or almost non-existent sales in the fall and winter. A manually controlled time-phased order point system was initiated for better control.
- b) As the level of business increased, the patio furniture manufacturer was requested to supply some inventory on consignment to prepare for the busy season. This was agreed upon.

Group 5 investment was 10% of the total inventory while representing only 4% of sales. It was understood that this was a “start up” product and that increased demand would bring the inventory into line. The time-phased order point control system to be used on patio furniture will also control the gas grill inventory. It was understood that as the business grows, manual TPOP control will not be practical and additional software will be required.

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Chapter 7

REPLENISHING DEPENDENT DEMAND

DEPENDENT DEMAND CHARACTERISTICS

Dependent demand differs from independent demand in that it is related to the demand of another item, or items, rather than to the independent demand of the marketplace. Items causing the demand are called parents of the dependent demand items (or components). A bicycle can be the independent demand (the parent) of the frame (the component). The frame, in turn, is considered the parent of the aluminum tubing which is a component of the frame. The demand of the frame is dependent on the bicycle and the demand of the aluminum tubing is dependent on the frame. If the bicycle is assembled in lots of 100 every 2 weeks, the demand for the frame is 100 every 2 weeks. If the frame is fabricated in lots of 250 every 5 weeks, the demand for the tubing will be the quantity of tubing required to make 250 frames every 5 weeks. The above relationship are as follows:

- One (1) bicycle - Independent demand = 10/ day
- Assembly = 100/ 2 weeks
- One (1) frame/ bicycle - Dependent demand = 100/ 2 weeks
- Fabrication/ 250/ 5 weeks
- 10 feet tubing/ frame - Dependent demand = 2,500 feet/ 5 weeks
- Purchasing lot = 10,000 feet/ 20 weeks

Figure 7-1 illustrates the demand patterns of the bicycle, frame and aluminum tubing.

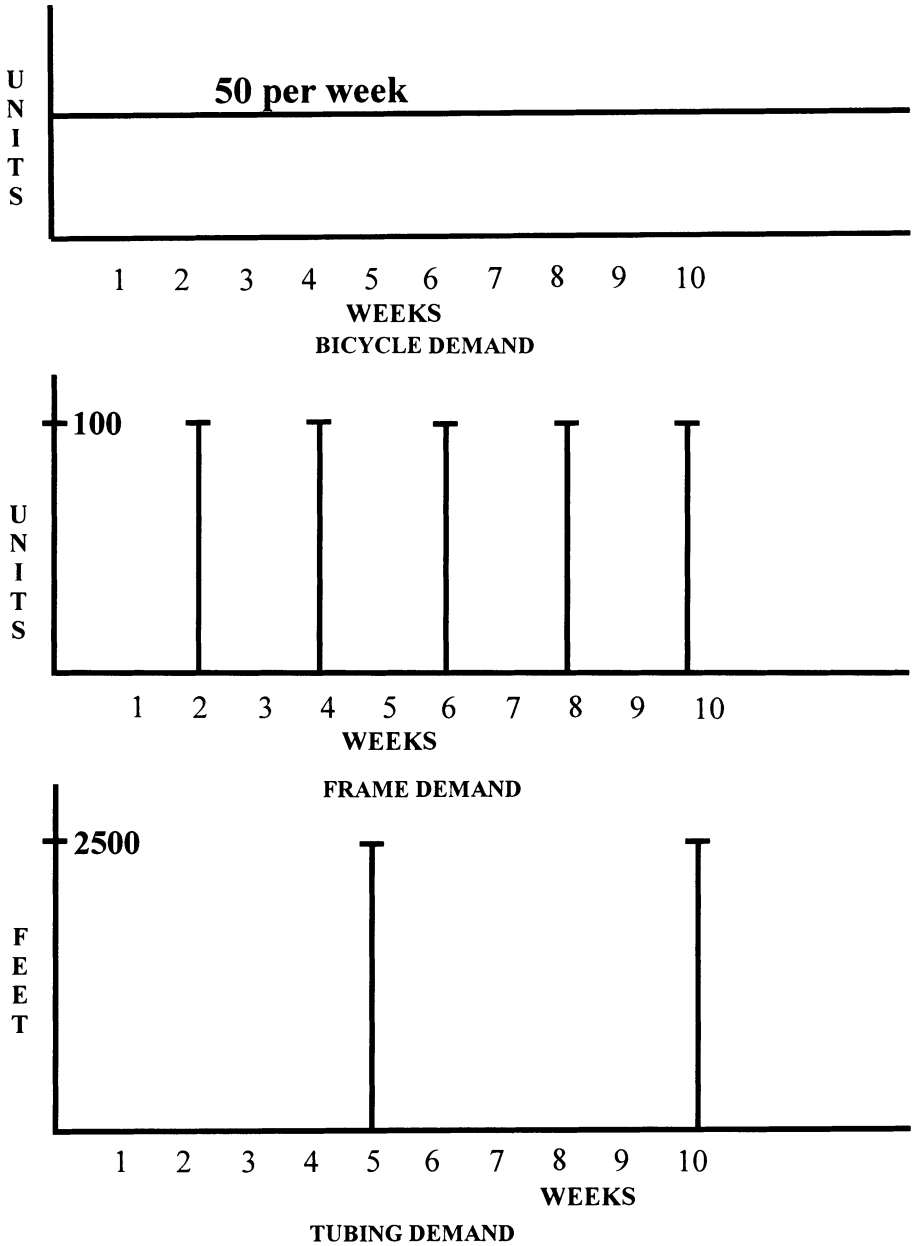


FIGURE 7-1. DEMAND PATTERNS

Figure 7-1 shows that while independent demand may be continuous, the demand of the components of the independent demand item can be discontinuous (lumpy). This is due to the fact that dependent demand is a function of the lot size of the parent, not the parent's demand pattern. It also tells us that dependent demand can be calculated. The relationship chain of parent to component is defined by the total product structure which is called the bill of material. Inventory control of dependent demand is best managed by material requirements planning (MRP).

THE BILL OF MATERIAL

With the bill of material, the finished product is defined in detail listing all items and structure, level by level in order to show the parent-component relationship. Each item in the bill of material must be specifically identified. The parent-component relationship must be stated in a manner that will satisfy purchasing, fabricating, and assembly requirements. A single-level bill of material will list the parent, the component(s) and the quantity directly used to make the parent. Therefore a single-level bill of material will consist of two item levels. Examples of a single-level bill of material is a bicycle (the parent) consisting of the component frame, seat, handle bar, pedal assembly, and wheel assemblies. Another example of a single-level bill of material is the above frame (as the parent) consisting of the component aluminum tubing.

A multilevel bill of material will list all components and the quantities required for the final assembly and is structured level by level, indicating all important dependent relationships of the components to the parents. A component, such as a hardware item, may be listed on more than one level of the bill of material. A multilevel bill of material can be summarized to list all items and their required quantities, but it does not list the parent-component relationship.

A product bill of material can be restructured for manufacturing purposes. Restructuring will not change the product itself. Planning and controlling at a modular (major subassembly or options) level is an example of restructuring. The requirements for a bill of material should be the following:

1. Ease of Product Forecasting. If a product consists of four major modules with three variations of each module, the combination of the various modules would be 81 final products ($3 \times 3 \times 3 \times 3$). Forecasting at the modular level would call for 12 items ($3 + 3 + 3 + 3$) to be forecasted rather than 81. The less items forecasted, the higher the degree of accuracy.

- 2. Ease of Master Scheduling. As with forecasting, the less items to control , the more workable the plan.
- 3. Order Entry, Costing, and Final Assembly Scheduling. Even though the forecasting and master scheduling may be done at the modular level, a bill of material defining the finished product will be required for these functions.

An additional advantage of a modular planning structure can be the minimizing of inventory investment in common components.

Figure 7-2 is an example of a multilevel bill of material.

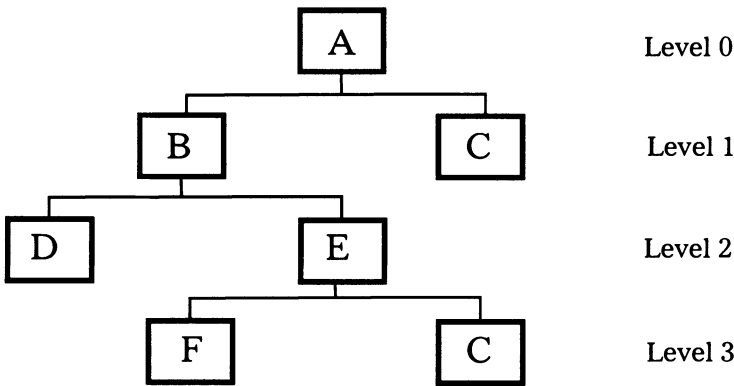


Figure 7-2. Multilevel Bill Of Material - Product A

Note that item C is listed at both levels 1 and 3. In a product structure the topmost item is, by convention, considered level 0. Figure 7-3 illustrates the multilevel bill of material for subassembly B which, following the convention, is now listed as level 0

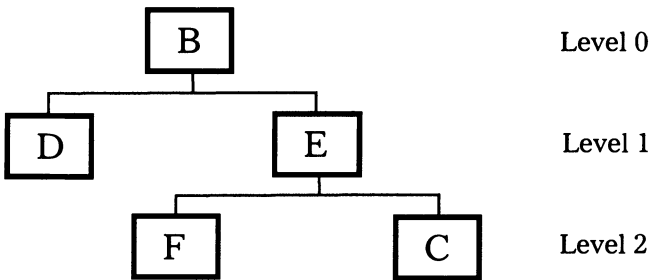


Figure 7-3. Multilevel Bill Of Material - Subassembly B

MATERIAL REQUIREMENTS PLANNING (MRP) LOGIC

Material requirements planning (MRP) is a system used in the inventory management of dependent demand components in manufacturing operations. All items listed in a bill of material (purchased, fabricated, or subassemblies) can be controlled through the MRP system. Notice the use of the word *can*. Some items such as hardware or packaging may be more easily controlled through alternative methods such as two-bin or reorder point systems, but would still be listed in the bill of material for purposes of product costing and item pulling. MRP plans component fabrication or purchasing and will recommend action to release or reschedule orders at the appropriate time.

A reorder system only addresses a required quantity need at one point in time. Dependent demand items, which most often do not meet the reorder point criteria of uniform demand, require time phasing — the stating of anticipated future demand and inventory planning by time periods. Time phasing addresses both quantity and timing. The time periods in most MRP systems are in weekly time buckets in which all data are accumulated in weekly periods.

An MRP system is capacity insensitive in that it will list component requirements to meet a master schedule (the anticipated build plan) without regard to capacity. If there is a capacity problem, it must be addressed through adjustments to the master schedule. The master schedule plans and controls end items or modules depending on the structure of the bills of material. MRP systems determine requirements based on the explosion of all master scheduled items through all levels in the bills of material and is based on parent-component relationships. The system combines the requirements of items that are common to more than one parent, and it will also combine requirements of items that occur at more than one level in the bills.

The time-phased inventory status is the heart of the MRP calculation. Table 7-1 represents an 8-week period of projected activity. The gross requirement of 100 per week is the anticipated need in each time period. The scheduled receipt of 300 due by the beginning of week 2 is based on an open purchase order or shop order. The projected available for a period is the projected available of the previous period minus the gross requirements plus the scheduled receipts plus the planned receipts. The projected available at the end of week 2 is

$$0 - 100 + 300 = 200$$

The projected available at the end of week 7 is

$$100 - 100 = 0$$

A planned order receipt is called for when the projected available becomes negative. The negative quantity is the net requirement. The planned order receipt is calculated to cover the net requirement with the order quantity based on the item's lot size rule (in table 7-1, the lot size = 300). The net requirement at the end of week 8 is

$0 - 100 = -100$

and therefore calls for a planned order receipt of 300.

Planned order releases are determined by offsetting the planned order receipt by the item's lead time. The planned order receipt due in week 8, offset by the 2 week lead time, is planned for release in week 6. Planned orders are not normally released until they reach week 1. The planned order release date is most critical in the linking of the MAP records (parent-component relationship).

**Table 7-1. Projected Activity; Lot Size = 300,
Lead Time = 2 Weeks
On Hand = 100**

Week	1	2	3	4	5	6	7	8
Gross Requirements	100	100	100	100	100	100	100	100
Scheduled Receipts		300						
Projected Available	0	200	100	0	200	100	0	200
Net Requirements					100			100
Planned Order Receipt					300			300
Planned Order Release			300			300		

The requirements explosion is the linkage of parent to component relationships through all levels of the bill of material. Level 0 orders in the master schedule drive the gross requirements of those level 1 components required for the parent. The gross requirements of the component must cover the planned order release of the parent. The planned order release of level 1 is calculated in the same manner as shown in table 7-1. This planned order release, in turn, creates the gross requirements of level 2 items. This logic follows through all levels of the bill of material.

Based on the following bill of material for Product A, the results of an MRP explosion are shown in table 7-2. Note that after consideration for lead time offset and lot sizing, the planned order release for a parent in a given period causes a gross requirement of the component in that period. To start to produce an item, the component(s) must be there.

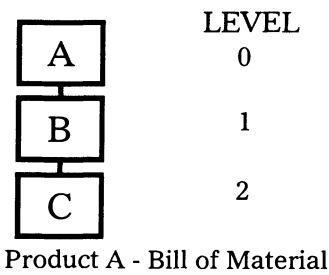


Table 7-2. MRP Planning Grid

Part	Lot Size	Lead Time	Time Periods						
			0	1	2	3	4	5	6
A		2							
Master Schedule						10		10	10
B	12	1							
Gross Requirements				10		10	10		
Scheduled Receipts									
Projected Available			12	2	2	4	6	6	6
Net Requirements						8	6		
Planned Order Receipt						12	12		
Planned Order Release					12	12			
C	5	1							
Gross Requirements					12	12			
Scheduled Receipts					5				
Projected Available			0	0	3	1			
Net Requirements					7				

INPUT TO MRP

The primary input to the MRP system is the master production schedule (MPS) or “driver of the system. The manufacturing environment will determine the planning level of the products to be master scheduled. End items, major subassemblies, components, or raw materials can be products of the MPS. The minimum length of the master schedule horizon for MRP control is the longest critical path of the master scheduled items. Adjusting the master schedule is often required in order to reconcile capacity problems. The master production schedule is detailed at length in Chapter 8.

The input defining the parent-component relationships required for MRP is the product structure which is detailed in the bill of material file. The bills of material must be compatible with the items in the master production schedule, that is, product and/or planning (restructured) bills. The bills must reflect all levels (multilevel) in order to plan all components. The explosion of all MPS items through all levels in the bills of material will determine the requirements based on parent-component relationships. The system will combine the requirements of items that are common to more than one parent, and it will also combine requirements of items that occur at more than one level in the bills.

Inventory status data for all items are maintained in the item master or parts master file. The data are either planning factors which are static and are user maintained or inventory quantities which are considered dynamic and are transaction driven. Examples of planning factors required for MRP systems are as follows:

1. Lot Size Order Policy Rule. There are a variety of lot size rules that would be applicable to different items within the system.
2. Safety Stock. Planned safety stocks may be based on quantity or safety lead time.
3. Manufactured or purchased.
4. MRP, MPS, or non-MRP controlled..
5. Planning group or family.
6. Unit of measure.
7. Low-Level Code. This is the lowest level which the component is listed in any bills of material. This code is useful in the calculation of requirements for multilevel items.
8. Planned Lead Time. This is the estimated overall lead time for both manufactured and purchased items. It is used for lead time offset in the MRP calculation. It is an estimate and may not exactly match the sum of the calculated operational lead times when scheduling the shop order, but they must be reasonably close.

Inventory data in the item master file are both quantity on-hand and on-order. On-order information is based on either open shop or purchase orders. A record of allocated (reserved) stock, which is planned for released shop orders but not taken from stock, is also maintained. Since it is not available for other planning, the allocated quantity must be subtracted from the on-hand quantity. When the material is withdrawn from stock, both the on-hand and allocated quantities must be reduced.

MRP OUTPUT

A planned order is based on the net requirement of an item adjusted for lot size and with a release date based on lead time offset from the required due date. Planned order due dates extend the planning horizon of the MRP system. Planned orders are calculated within the system and will be adjusted or cancelled when the system is rerun (regenerated). A release date in the current week, the action week, is a recommendation to initiate the purchase or manufacturing order of the item. The term manufacturing order is used interchangeably with shop or work order.

When a planned order is released, the system will show the order as a scheduled receipt and the planned order is no longer listed. While the MRP system will adjust or cancel planned orders, it will not change a scheduled receipt. The system will allocate the material or components required for a manufacturing order at the time of order release.

In addition to the recommendation to release current planned orders, the system will make recommendations to expedite (move up), de-expedite (move back), or cancel existing orders (scheduled receipts). With each generation of the MRP system, recommendations may be made based on forecast changes, inventory adjustments, scrap and rework, unplanned shipments, and so forth.

Although the system is sensitive to change, at times it may be too sensitive and create a nervous system which results in planned shop or purchase orders being “jerked around” needlessly. The system can be stabilized through the use of “firm planned orders” which is a technique used to stabilize the quantity and timing of planned orders. It overrides the logic of MRP and by firming the planned order of a parent, will stabilize all lower level components. The greatest degree of stabilization is achieved by firming orders at the master production schedule (MPS) level.

When it is realized that an item is not going to meet a calculated need date, an understanding of that item’s relationship to all affected materials is required. If the item is an end item with independent demand, all lower-level components may be affected because their previously required due dates may no longer be valid. Dependent demands may have either vertical and/or horizontal interdependencies. When a dependent demand has missed or is predicted to miss the due date, one or both types of dependencies may come into the plan.

Figure 7-4 is a simple illustration of vertical dependency. Item A is dependent on the availability of item B, which in turn, is dependent on the availability of item C.

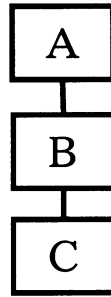


Figure 7-4. Vertical Interdependency

Figure 7-5 is an illustration of both vertical and horizontal interdependencies. Item B's dependency on item C, and item D's dependency on item E are both considered vertical dependencies. However item B's and D's relationship to each other is a horizontal interdependency. When a material availability problem arises, analysis of all interdependencies is required.

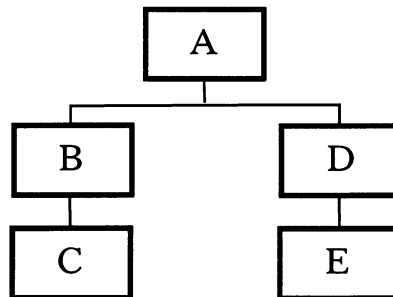


Figure 7-5. Vertical and Horizontal Interdependencies

Planned orders within the system with release dates in the future, project requirements for the next level down. An example would be a planned order to produce a subassembly with a planned release date in 6 weeks. The gross requirements for the subassembly's components will be listed in week 6. Future planned orders also serve as inputs to capacity planning systems in order to calculate future work-load profiles. Capacity planning systems are explained in Chapter 8. An additional use of planned orders, covering the planning horizon, is in the calculation of future planned raw material, component, subassembly, and work in process inventory investment.

REGENERATION AND NET CHANGE MRP

There are two methods used in the approach to the replanning cycle of MRP. They differ in the timing and the data utilized in the process, but the logic and the output remain the same. The regenerative system is time-driven and normally scheduled to run weekly. It calls for a total explosion of all bills of material for master scheduled items. All planned orders from the previous explosion are recalculated. Although there may be a comfort level in the disciplined approach to a weekly time cycle, there are disadvantages of which to be aware, such as deterioration of the plan as the week progresses and a very heavy load of output with the weekly explosion.

The net change system calls for a partial explosion and will relate only to those items affected by a change since the last explosion. The system is transaction-driven rather than time-driven and is often processed daily or in some situations on a real-time, on-line basis. With net change, the planned orders and their associated requirements are not erased but will be rebalanced if a transaction has affected the inventory, bills of material, or requirements. Net change systems have the advantage of being more responsive to change, being continually up to date, and evening out the work load due to less output per run. Care must be taken in that a responsive system may become a nervous system, causing never-ending replanning and rescheduling of requirements. Partial control of nervous output can be achieved by “firming” planned orders as mentioned earlier. If the activity levels of finished goods and service parts are such that almost all items are affected daily, the net change system will call for large computer resources and planning activities. It will be similar to a regenerative system that generates daily.

The decision to operate in a regeneration or net change mode will be dependent on the nature of the manufacturing environment. It should be remembered that MRP is for planning and that timely execution might best be controlled by an off-line technique that would be compatible with the MRP plan.

MANUFACTURING RESOURCE PLANNING (MRP II)

After the introduction and implementation of MRP, it was realized that a system was needed not only to calculate requirements, but also to determine if there was available capacity to produce those requirements. To meet this need a system called “closed-loop MRP” evolved. It is defined by APICS as a system built around material requirements planning that includes the additional planning functions of sales and operations. Once the planning

phase is complete and the plans have been accepted as realistic and attainable, the execution functions come into play. These include the manufacturing control functions of capacity measurement, detailed scheduling, and dispatching. The term “closed loop” implies that not only is each element included in the system but also that feedback is provided by the execution functions so that planning can be kept valid at all times. Material Resource Planning (MRP II) evolved from the closed loop system.

The term MRP has evolved to mean not only “material requirements planning” (MRP), but also “manufacturing resource planning” (MRP II). Material requirements planning calculates what is needed to meet the independent demand of finished goods and replacement parts. It assumes infinite capacity, in that it states what is needed and when, in order to meet the master schedule.

Manufacturing resource planning (MRP II) is a system for the effective planning of necessary resources such as plant capacity, manpower, and finances. The process is the linkage of business planning, production planning, master production scheduling, material requirements planning, and execution support systems. Through simulation, the output data are used to perform what-if evaluations of alternative plans so as to determine a realistic operation plan. MRP II is an outgrowth of material requirements planning.

CASE STUDY SMITH INDUSTRIES INC.

In 1989 the first assembly operations of the new product line of three models of Smith Grills were underway on a project basis. Marketing efforts started to show favorable effects, and sales started to increase at a good rate. Planning of the grills was based on the same manual time-phased order point technique used for patio furniture. Bills of material defining the three models were established. Since all parts at this time were purchased and assembled with an informal bench/line approach, the bills were single level. Some parts were unique to the assembled grills while others were common to the existing A, B, and C class repair and replacement parts. All parts’ replenishments were based on reorder point control.

The grill assembly operation initially grew at a steady, continuing rate and the component usage was based on lot-for-lot requirements, with a lot usually of one (1) assembly unit. The reorder points for the unique parts were based on the forecasted demand of the grills. The reorder point calculation for the common parts (grill assembly, repair, and replacement) were increased to reflect the added anticipated assembly demand.

In the early stages of production, there were quality and assembly cost problems to overcome, but parts’ availability was not a problem. Fairly

accurate forecasting of demand and a relatively steady usage rate allowed the reorder point system to work.

To gain greater quality and cost control, the bench/line system was replaced with an assembly line that would be paced and controlled with a conveyor belt. A grill base was to be placed on the belt and components added as the unit progressed through complete assembly and packaging. In order to make the operation flow in an efficient manner, the following changes were made:

1. Only one model would be scheduled at a time. To reduce line changes, it was decided that the minimum model run would be one week.
2. Some components required welding operations which did not fit into the assembly line operation. The weldments were produced off line and stored for use when required. The bills of materials were changed to reflect the weldments as subassemblies which added an additional level to the bill. The same routine added other subassemblies in order to increase the flow rate of the final assembly line.

Initially the new assembly line seemed to meet all expectations especially with respect to labor costs. However, as time passed, problems started to arise with respect to material control. Part shortages were causing line shutdowns. The subassembly operations were also suffering from part shortages.

Steps taken to solve these shortages did not seem to work. In an effort to know which parts would be short, assembly lots were pulled one week early. It was thought that this information would assist in getting a head start on expediting. When this action did not seem to help, the assembly lots were pulled two weeks early, which made matters worse.

A review of demand history indicated that the forecasts of the end item gas grills remained accurate, but the demand for component parts, both unique and common, was increasing at an unanticipated rate. As soon as a shortage became known, expediting action was taken in the form of going back to the suppliers with requests to bring in open orders early or to deliver products in less than stated lead times. Safety stocks were also increased which added additional orders to the already overloaded suppliers. The safety stock increase was for all components because the inventory personnel were not comfortable in knowing which part would cause the next shortage. This action not only added to the suppliers' capacity problems, but it increased inventories of some items that were not in trouble.

Inventory accuracy, controlled through transaction procedures and cycle counts, remained at acceptable levels. Formal operating procedures for material control, which had been written the previous year, were being

followed in every detail. It was most frustrating to be doing the right things but getting the wrong results.

CASE STUDY - SUGGESTED SOLUTION

In an effort to better understand the causes of the part shortages, two samples were chosen for review. The first was a subassembly that was unique to one of the assembled gas grills, and the second was a replacement part common to the assembled grill as well as a service part used in the outside grill repair business. The grill was assembled in lots of 60 every 4 weeks. The analysis indicated the following:

1. The subassembly was a valve assembly consisting of a valve and knob. The parent gas grill had a forecasted demand of 15/week. Therefore using the existing reorder point system, the forecasted demands of the subassembly, the valve, and the knob were also 15/week.
 - A) The valve assembly's lead time = 1 week, safety stock = 1 week, and the reorder point = $15 \times (1 + 1) = 30$ units. The lot size = 15 units. The actual demand of the subassembly was 60 every 4 weeks, while under the reorder point system the maximum units in stock would be 45.
 - B) The valve's lead time = 2 weeks, safety stock = 1 week, and the reorder point = $15 \times (2 + 1) = 45$ units. The lot size = 50. The actual demand to meet the subassembly requirements of 60 every 4 weeks was also 60 every 4 weeks. When all valves were consumed, the lot size of 50 would meet the reorder point but not the next requirement of 60.
 - C) The knob's lead time = 1 week, safety stock = 1 week, and the reorder point = $15 \times (1 + 1) = 30$. The lot size = 100. The actual demand was the same as the valve's, 60 every 4 weeks. When all knobs were consumed, the lot size of 100 would cover the next requirement of 60 but would leave 40 in stock, meeting the reorder point but not the next requirement of 60.

2. The replacement part, a venturi tube, had service requirements forecasted at 5/week. The reorder point was based on a lead time of 2 weeks, a safety stock of 1 week and a combined demand $(5 + 15) = 20$. The reorder point $= 20 \times (2 + 1) = 60$ and the lot size $= 50$. The anticipated demand pattern would be
- Week 1 = 5
 - Week 2 = 5
 - Week 3 = 5
 - Week 4 = 65

The inventory could be 61 to 64 going into week 4 and not meet the anticipated requirement of 65. If going into week 3, the inventory dropped to 60 or less, the replacement order would not be received in time to meet the week 4 requirement.

Based on the above analysis, it was decided that the reorder point system was not adequate for the dependent demand of assembly components. An MRP software program was purchased and installed over the next two years. The parts master file listed all inventoried items, coding the manufactured grills as master scheduled items (MPS), and dependent components as material requirements planning items (MRP). An exception was C class parts which were coded as "non-MRP" because, due to the larger lot sizes, visual reorder control was simpler and would work. Repair parts with no dependent demand were also coded for reorder point control.

Repair parts, with independent demand combined with dependent assembly demand, created a control problem. The decision was made to add the forecasted independent repair requirements to the gross requirements of the components. Repair parts were found to be quite difficult to forecast and, in an effort to add some stability as well as customer service, recommended repair parts' lists were published and supplied with new grills. About 40 % of the customers ordered the recommended repair parts and this assisted in the forecasting effort.

The routine of pulling orders early in order to get a jump on expediting, was discontinued. It was realized that, even when a system was working as planned, pulling ahead of time would create false shortages. If the assembly requirement was in week 9, an MRP system would call for the components to be available in that week. Unless safety lead time was planned, a part would not be available for an early pull in week 7. If stock were available in week 7, it may have been there for another requirement, such as anticipated repair. An early pull would make the part unavailable for the repair order.

When the MRP system became operational, early expediting became a reality, in that the system would give action messages stating that pulling up an order would be necessary to meet a future requirement. It would also give

a message that an order was scheduled earlier than required and could be de-expedited if desired.

The MRP system also allowed a reduction in safety stock. The dependent demand of components was calculated based on the forecasted demand of the end items and therefore safety stock to cover forecast error would be maintained at the end item (MPS) level. Some component safety stock would still be needed if there were repair part forecasts at the component level. Safety stock should also be considered when there is unreliable supply due to quality problems or late delivery.

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Chapter 8

MASTER PRODUCTION SCHEDULING

MASTER SCHEDULING

The master schedule is a time-phased planning chart that presents planned demand of designated master planning items. These designated, or assigned items, can be finished goods, such as a television set, a planned module, such as a transmission, or an option, such as a sun roof. Although the terms “master schedule” and “master production schedule” are commonly used synonymously, there is a distinction between the two terms. While the master schedule is a planning chart, the master production schedule is the anticipated build schedule driving material requirements planning.

In the development of a master schedule, various demands must be considered. In a make-to-stock environment, the forecast of future sales over the horizon is critical. The forecast demand must be in time periods or buckets consistent with master production schedule (MPS) and material requirements planning (MRP) programs. The sales forecast must include not only finished products, but also replacement parts for service or testing.

In a make-to-order environment, production is not initiated until the order is received, but a sales forecast may be required extending to the critical path in order to have raw material or purchased parts available at the time of order receipt. In an assemble-to-order environment, the sales forecast is required in order to have components or subassemblies available at the time of order receipt.

The customer order is the major demand source in make-to-order manufacturing and is also the demand source in the in-close periods of assemble-to-order situations. In make-to-stock or “off-the-shelf” operations, the customer order demand may be indirectly considered by comparing

actual demand with the forecast. The relationship of customer orders and forecasts are controlled by predetermined time fences built into the system.

Forecasted sales demand from distribution centers must be considered and care taken to understand if this demand is part of the total forecast. If the distribution demand is forecasted by time period and is reported through an organized distribution requirements system (DRP), an adjustment to the total sales forecast may be required. DRP systems will be covered in Chapter 10.

Other demands to be considered are desired safety stocks, planned work-in-process levels, and allowances for product shrinkage. Again, the source data must be understood. DRP requirements transmitted to the manufacturing facility should have already allowed for safety stock and inventory adjustments.

In that the MPS is an anticipated build plan or a detailed plan of production, simply scheduling anticipated demand by time period is not realistic. Production lot sizes must be considered. The production demand may be 50 units per week, but if the smallest practical lot size is 150 units, the MPS must reflect requirements of 150 units with a frequency of 150 units every 3 weeks.

A painful adjustment of the MPS demand is when the system says that there is not sufficient capacity. Only after retesting, considering outsourcing, overtime, and so forth, should there be an adjustment to the MPS. This information must be understood and communicated to all within the organization. A less painful adjustment of demand may be for the purpose of load leveling. An overload in one period may be adjusted by shifting to an underloaded period or the total load may be adjusted for the purpose of smooth, continuous flow through the manufacturing and supply chain operations. The demand-frequency adjustment due to lot size can be automatically handled through the MPS system logic, but load leveling and capacity adjustments require management intervention.

MPS CALCULATIONS

Table 8-1 shows an 8-week horizon with a forecasted increasing sales rate (100 to 150 units in week 4), production lot sizes of 300, a beginning on-hand balance of 120, and projected on-hand inventories for each period. Note that the projected on-hand balances at the end of weeks 6 and 8 are negative, indicating the need for a plan adjustment. The original plan calling for MPS lots of 300 every 3 weeks was established prior to the forecasted increased rate in week 4.

Table 8-1. MPS Plan for Eight-Week Horizon; Lot Size 300, On-Hand 120.

Week	1	2	3	4	5	6	7	8
Forecast	100	100	100	150	150	150	150	150
Projected on Hand	320	220	120	270	120	-30	120	-30
MPS	300			300			300	

Table 8-2 represents an MPS plan that includes customer orders. Note that in week 1, the customer orders, rather than the forecast, were considered in the projected on hand balance calculation. This is based on a management decision that the first demand week time fence is frozen and that only the customer order quantities will be considered. Beyond the one week time fence, a management decision is to calculate the projected on-hand balance by using the larger of either the forecast or customer orders.

Table 8-2. MPS Plan Including Orders; Lot Size 100, On-Hand 40

Week	1	2	3	4	5	6	7	8
Forecast	25	25	25	25	25	25	25	25
Orders	23	27	17	8				
Projected on Hand	17	90	65	40	15	90	65	40
MPS		100				100		

Although the time-phasing calculation is straightforward and the same as MRP logic, it is recommended that the computer system should not control the maintenance of the MPS. Management control is continuously required to maintain a relatively stable and realistic plan. “Firming” MPS orders is a technique that will not allow the computer system to change the quantity or timing of the planned MPS order.

Implementing policy decisions relative to control of operating procedures over differing time periods is accomplished with time fences. The up-close period of the first week or two may be frozen with no changes allowed. The intermediate period going out to the total cumulative lead time for parts availability would have less stringent controls, and the period beyond the cumulative lead time would be unrestricted.

The actual time fence decisions are dependent on the manufacturing environment. In a make-to-stock environment, the firm or frozen time period would include customer order processing, whereas the assembly and component lead time would be somewhat flexible. In the assemble-to-order

environment, the firm period would include customer order lead time and the assembly lead time with component lead time flexible. The make-to-order firm period would include component lead time as well as assembly lead time. Common raw material procurement lead time will be within the somewhat flexible time period. The term “slushy” is used to define somewhat flexible.

The firm time period is defined as being within the demand time fence, whereas the limited flexibility is beyond the demand time fence but within the planning time fence. Beyond the planning fence, the period is considered free and completely flexible and is primarily used for capacity planning.

The available-to-promise (ATP) quantity is the uncommitted quantity of projected on-hand inventory in each period when an MPS order receipt is planned. These quantities are useful in customer order promising. The ATP quantity calculation is shown in Table 8-3. Note that the ATP is calculated for each period of time covered by the MPS order and is not cumulative. This is based on the assumption that although there are unsold units of 17 in week 1 and 48 unsold projected units in weeks 2 through 5, these will be sold by week 6 and, therefore, only the MPS order of 100 will be available at that time.

Table 8-3. Available-To-Promise Quantity; Lot size 100, On-Hand 40.

Weeks	1	2	3	4	5	6	7	8
Forecast	25	25	25	25	25	25	25	25
Orders	23	27	17	8				
Projected on Hand	17	90	65	40	15	90	65	40
ATP	17	48				100		
MPS		100				100		

UTILIZING PLANNING BILLS

In the determination of bill of material structuring strategy for master scheduling, both the nature of the product and the manufacturing environment must be considered. An uncomplicated product with relatively few components and minimal bill levels will be maintained at only the product level. An extreme example of an uncomplicated product bill would be a washer stamped out of sheet metal. For more complicated products, the product structure to be utilized for master scheduling is dependent on the manufacturing environment. Three manufacturing environments are considered.

1. Make-to-stock and sold “off-the-shelf”.

2. Assemble-to-order using purchased and manufactured components that have been purchased and/or made-to-stock.
3. Make-to-order products that may be produced from a combination of standard items and customer designed items made-to-order.

Make-to-stock products would normally have a limited number of finished goods' items. The number of components and raw materials would be dependent on the product. The above mentioned washer would consist of one component—the sheet steel—or up to three components if packaging is included. A product line of VCRs might consist of six finished machines utilizing a total of 600 purchased parts and subassemblies. The assemble-to-order product line will have a large number of finished goods that are assembled from a much lesser number of components and subassemblies. In this environment, the major subassemblies are called modules that are defined in modular bills of material. Although the modules are fewer in number, they may consist of a much larger number of components. An example of assembling-to-order might be an automobile manufacturer who assembles to dealer orders from modular planned engines, transmissions, and so on. The make-to-order product may have a simple bill (again the washer) or an expanded finished goods line coming from a lesser number of components and raw materials. An example of the later would be custom-made furniture.

In the make-to-stock environment, the master production schedule is based on the finished product and, therefore, utilizes the product bill of material. The final assembly or finished product schedule will be at the same level and based on the same product (or end item). Bill of material master scheduling in an assemble-to-order environment is at the modular or subassembly level. The product structure utilized in this situation calls for planning bills such as modular and common parts bills. Whereas the MPS utilizes planning bills, the final assembly schedule will be based on product bills. The make-to-order environment will call for MPS planning at the component/raw material level. Again, the final assembly or finished product schedule is based on the product bill of material.

The modular bill of material is artificially arranged according to product modules or options. The common parts bill, or kit, groups common components for a product, or family of products, into one bill of material or one section of the bill of material.

A basic rule to follow is that the MPS level should correspond to the desired planning and stocking level. Figure 8-1 illustrates the environmental, MPS, and final assembly relationships.

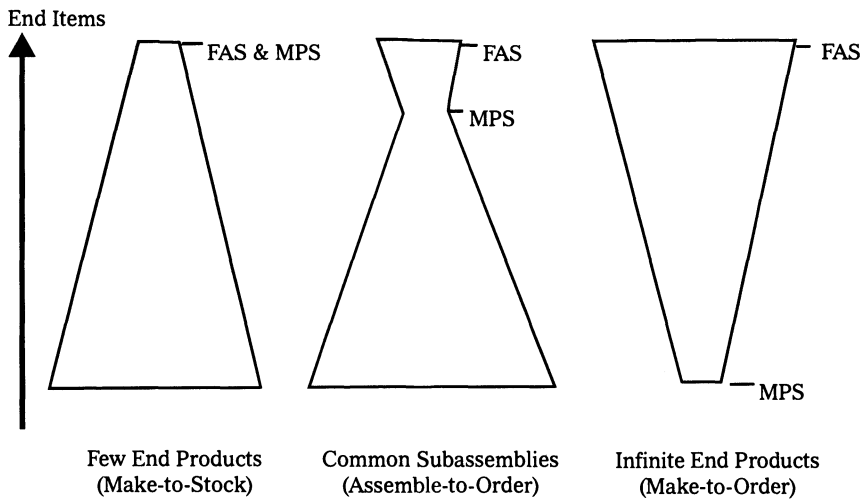


Figure 8-1. Environmental, MPS, and final assembly relationships.

A two-level master production schedule is an approach in which a planning bill of material is used to master schedule an end product or family, along with selected options and/or accessories. Figure 8-2 is an example of the product structure for two-level master scheduling of a bicycle with an optional gas motor. There are three frame, two tire sizes, and a choice of racing or touring safety features.

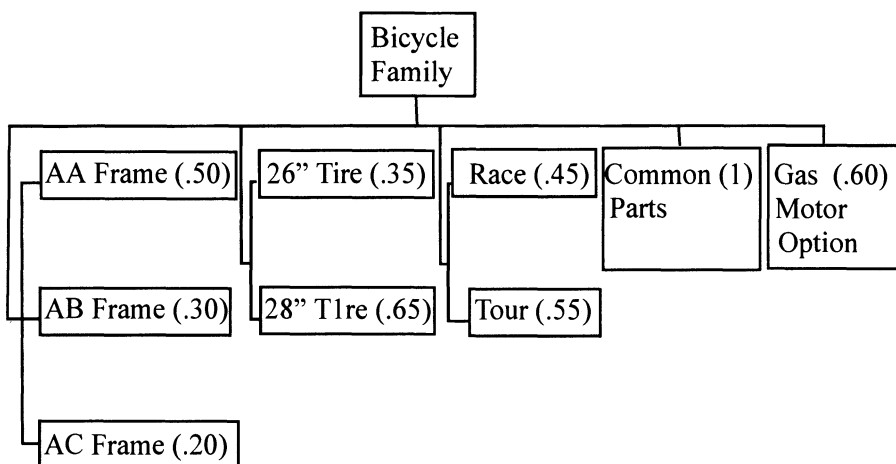


Figure 8-2. Two- Level Master Schedule

The bicycle family forecast will drive the production of the modules but the forecast of the option will be based on the calculated master production schedule of the modules (rather than the family forecast).

MANAGING THE MPS

The responsibility for the MPS includes the entire organization: marketing will input the forecast; engineering will structure the bills; finance will be responsible for approval of the required assets; and manufacturing will develop and execute the plan. The day-to-day development and maintenance of the MPS is the responsibility of the master scheduler.

Assuming that the product structure for the MPS has been established, control variables such as time fences and safety stocks determined, and an approved forecast in place, the initial capacity tests must be taken. Once satisfied that the plan is doable, the MPS orders must be firmed. Continual review of the MPS is required to assure the following:

1. The forecast is being consumed, or used up, as planned.
2. The MPS orders are being delivered as scheduled.
3. The capacity load remains realistic.

Whereas the MPS is an anticipated build or final product plan, the final assembly schedule (or finished product schedule) is the actual execution of the plan. It may be based on customer orders or stock replacement requirements. If the MPS bill of material structure is at the finished product level, the final assembly schedule (FAS) is compared easily with the MPS. If the MPS is based on planning bills utilizing modules, common parts bills, and/or components, the FAS must be coordinated with the MPS items. The FAS requirements must be compatible with the requirements generated from the MPS. An overstated FAS will create item shortages, whereas an understated FAS will cause readjusting the MPS and ultimately the MRP requirements.

Although the MPS may be based on planning bills, the FAS will require a single-level product bill for the purpose of component and subassembly order picking as well as product costing. The lead time of the FAS should be as short as possible and expressed in lesser periods, such as shifts or days. Final assembly products may be radically different, such as a four-door sedan and convertible and still be produced on the same assembly line. Translating the output of the order entry system to the FAS product bill of material is often a challenge.

CAPACITY PLANNING

The successful execution of a material requirements plan is dependent on a complete understanding of the required capacity for the plan. This method is the manufacturing resource planning (MRP II) approach. Capacity analysis is initiated at the strategic planning level and may conclude at the work center or manufacturing cell operation level. The highest level of capacity planning is based on the long-range business plan that extends out as much as 5 years. This time period is necessary for planning cash requirements, additional plants, capital equipment, and in some cases a work force requiring specialized skills. This level of planning will be based on the analysis of total planned sales or broadly defined product groups.

The next level of capacity planning would be the analysis and validation of the intermediate 2-year production plan. Initial analysis would be based on product families or groups and the prorating of critical resources. The analysis of the intermediate production plan is accomplished by the utilization of a bill of resources — a listing of the key resources needed to manufacture one unit of a product family. The definition of what resources to consider key, or critical, is up to the discretion of the user. The product group production plan will be exploded in a manner similar to the MRP explosion, but based on the bill of resources rather than a bill of material.

The next capacity planning level is rough-cut capacity planning (RCCP) and it is the technique used to validate the master schedule. This planning step is most critical since the MPS drives the material requirements plan which is capacity insensitive. MRP will only be effective if driven by a realistic master production schedule. Rough-cut capacity planning requires the following:

1. The bill of resources must be based on master scheduled items or groups of very similar master production scheduled (MPS) items.
2. If lot sizing is lot-for-lot, the resource profile time periods should be the same as the MPS — weekly.
3. If production lot sizes are large and not directly related to weekly requirements, the resource profile must be expressed in weeks or months and the MPS requirements grouped in similar time buckets. In this situation, the available capacity must be somewhat greater to allow for week-to-week demand variation.

Although rough-cut capacity planning at the MPS level gives more detailed information than resource planning at the production planning level, it does not project exact demand requirements. This is because existing inventory is not considered, time buckets may be larger, and time phasing is based on less detailed estimates than used in MRP.

The following example compares the results of resource planning at the production plan level with rough-cut capacity planning at the master schedule level.

A transmission rebuilding facility has an assembly-rebuild capacity of 80 hours per week and 320 hours for a 4 week month.

The family of transmissions is estimated to be 70% automatic and 30% manual.

Assembly-rebuild time for an automatic is 8 hours and 3 hours for a manual.

The key resource for the family is

$$8 \text{ hours(automatic)} \times 70\% = 5.6$$

$$3 \text{ hours (manual)} \times 30\% = \underline{.9}$$

6.5 hours

The 4- week production plan called for the assembly-rebuild of 47 of the family group. $47 \times 6.5 = 305.5$ hours, well within the 320 hours capacity.

The master schedule for the 4 weeks was:

Week	1	2	3	4
Automatic	8	10	10	7
Manual	<u>3</u>	<u>2</u>	<u>2</u>	<u>6</u>
Total	11	12	12	13

Note that the total master scheduled items were 48, 1 more than the production plan. The total mix was close to the 70%/30% prorated over the 4 week period but not on a weekly basis.

The rough-cut capacity calculation of the master schedule is:

Week	Automatic hours	Manual hours	Total hours
1	$8 \times 8 = 64$	$3 \times 3 = 9$	73
2	$10 \times 8 = 80$	$2 \times 3 = 6$	86
3	$10 \times 8 = 80$	$2 \times 3 = 6$	86
4	$7 \times 8 = 56$	$6 \times 3 = 18$	74

Weeks 2 and 3 are scheduled over capacity. Recommended action would be to increase capacity or adjust the schedule.

Capacity requirements planning (CRP) is the last level of capacity analysis. It is the planning and control of the resources needed to produce the requirements generated by the MRP system. Detailed available capacity must be determined and compared to the anticipated capacity required. The process involves each work center and covers the same horizon and time periods as the MRP. Both open (released) shop orders as well as planned shop orders are considered in the determination of the required capacity (the work load). Detailed schedules for all orders are calculated based on the routing files, lot sizes, and work center files. These schedules, released and planned, are required in order to place each work center's load in the proper time period. As rough-cut capacity planning was used to validate the master production schedule, capacity requirements planning will validate the material requirements planning's output.

Figure 8-3 is an example of a work center profile which was developed by listing both open order and planned order loads by work center and time periods and then comparing the loads to available capacity. Because MRP assumes infinite capacity, overloads and underloads can be expected. If the detailed work center loads are reasonable (i.e., doable), the MRP output is validated and the process of "closed loop MRP" is complete.

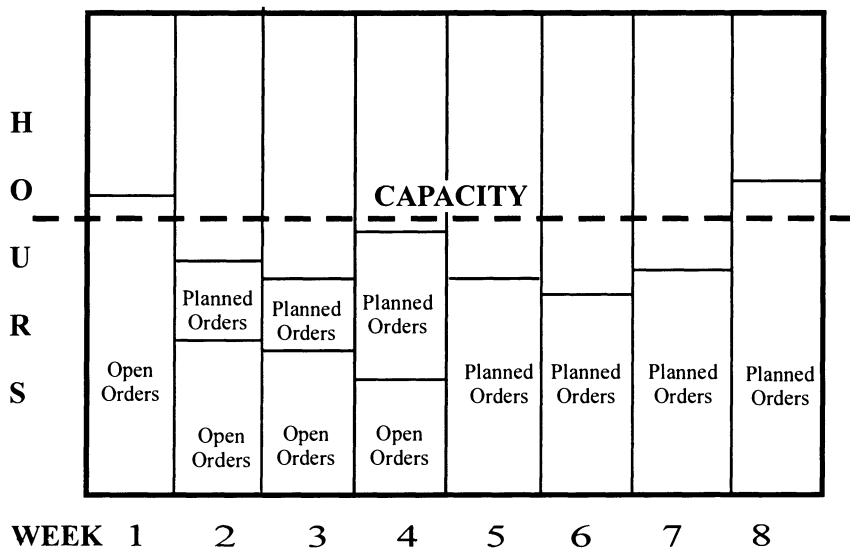


Figure 8-3. Work Center Load Profile

Controlling the work-in-process at a work center is accomplished by input-output monitoring. The actual input of work to a work center is compared to the planned input projected by the capacity requirements planning (CRP) system. The actual output is compared to the planned output. The input difference may be due to unplanned variations in arrival patterns due to previous operations being completed early or late against schedule. Output less than planned can be due to production problems such as machine breakdowns, quality considerations, absenteeism, or lack of available work. Output greater than planned is usually due to an effort to reduce the queue of available work.

An overloaded work center will cause late delivery and increased work in process, whereas a starved work center will create manufacturing inefficiencies. This input-output control measurement system is necessary to identify the previously described capacity problems. Input-output data can be maintained on a daily or weekly basis.

The releasing of work to the shop in the form of work orders will list operation control dates to meet the demands of the MRP system. Although capacity work-load analysis has indicated that the plan is reasonable, the resultant schedule is still based on infinite capacity, in that the accumulated load at each work center is not compared to the capacity of that work center. The success of infinite scheduling is dependent on the initial capacity requirements planning, the flow of orders, and shop-floor prioritizing at each work center.

CASE STUDY SMITH INDUSTRIES INC.

In the early 1990s the grill manufacturing business grew at a faster than anticipated rate. The product line increased from three models to 72. The line consisted of gas, electric, and charcoal grills in differing sizes, heating options, and stands. Of the 72 models, 60 were made-to-stock with a 2 day pack and ship lead time. The other 12 models were made-to-order and were quoted with a 5-week lead time.

Four assembly lines were now in place to meet the increased demand. A subassembly area which consisted of table assembly and welding operations, was set up to supply the assembly lines. The manufacturing operation was expanded to include parts' fabrication which consisted of saw, mill, drill, and turret lathe departments.

A number of operating problems emerged with the growth of the business. Analysis indicated that there were five basic problems which probably were interrelated. They were:

1. The service level of make-to-stock grills had decreased to 85%. The safety stock levels had been increased for the entire stock line but forecasts of demand were less and less accurate as the number of models increased.
2. Although service levels were down on make-to-stock grills, inventory levels continued to increase creating a strain on both cash flow and space in the warehouse. Forecast problems seemed to be the cause of overstock problems as well as the service problems listed above in problem No. 1. Some item demands were overstated while others were understated.
3. The 5- week lead time quoted for make-to-order items was not being met. Over 50% of the orders were shipping up to two weeks late. This problem was obviously not a forecast problem (the items were not forecasted).
4. The assembly operation was not meeting schedules for both make-to-stock and make-to-order grills. The major problem was parts' shortages, primarily fabricated parts and subassemblies. Subassembly shortages were due to fabricated parts' shortages.
5. An increasing number of shop orders for fabricated parts were going "past due" against the MRP scheduled due dates. The results of initial studies were quite confusing. A given delinquent part might have been completed three weeks late in one department, but it was unknown if that part arrived in that department on time or possibly three weeks late. The largest backup of work (or queue) was usually in the milling and drilling operations.

CASE STUDY - SUGGESTED SOLUTION

The problems of finished goods' service and inventory levels were analyzed and it was determined that the cause was the forecasting and management of the master production schedule. A monthly forecast for all 72 models was created quarterly by the Sales Department. Production Control would break the numbers into weekly increments and enter that data

into the MPS program which would generate MPS orders, which in turn would drive the MRP program. Sales personnel were well aware of the inaccuracies in the forecast, and continually communicated with the field for additional input. The final assembly schedule (FAS) was generated by Production Control, based on a reorder point system for make-to-stock items and on customer orders for make-to-order items. There was no organized comparison of the FAS to the MPS other than continued complaints about the "lousy" forecast.

The cause of late shipments of make-to-order grills and the parts' shortages at both subassembly and assembly was due to "past due" delivery of fabricated parts. Production Control blamed the manufacturing departments for not meeting the schedule. The manufacturing departments response was that the schedules were not realistic and/or the shop orders did not arrive in time from the previous operation in order to meet the schedule. Management realized that there was a bottleneck somewhere but it was difficult to specifically determine what department or operation was causing the problem.

The decision was made to name a Master Production Scheduler. The responsibility of this person would be to:

- 1) assist in generating the forecast by working with the sales department and continually comparing actual demand to forecast data and
- 2) generate a realistic master production schedule that was compatible with plant capacity.

Based on the past experience, it was determined that creating a relatively accurate forecast for the 72 grill models was all but impossible. A plan was devised to restructure the product line, utilizing modular planning bills to forecast and master schedule. The 72 grills were defined by the following modules:

3 Grill bases

12" x 24"

18" x 30"

24" x 36"

6 Heating units

Gas- line fed

Gas- propane tank fed

Infrared- propane tank fed

Electric

Charcoal

Charcoal with gas starter

4 Stands

- Ground post
- Wood table
- Metal table
- Metal table with convertible top

The advantage of the modular planning bill approach was:

1. Defining the 72 models with 13 modules required the forecasting and master scheduling of the 13 modules rather than the 72 models.
2. Since only the 13 modules were maintained in inventory, investment in both dollars and space was substantially reduced.
3. The 60 grills previously supplied in a make-to-stock environment with a 2 day delivery promise, were now produced on an assemble-to-order basis with a 1 week delivery promise. This was acceptable to the customers, especially with the much improved delivery performance.

The master scheduler instituted capacity planning through the use of rough-cut capacity planning (RCCP) procedures. A simple bill of resources was designed listing the milling and drilling operations as the key resources. The approximate capacity required to meet the production plan was then calculated. It was based on the key resources required to meet an average expected mix of the forecasted modules. The results indicated that the required milling hours were greater than capacity and that drilling capacity was adequate but not by too great a margin.

The master production schedule was then exploded against the same bill of resources and the resultant calculation confirmed the fact that not only was milling capacity inadequate, but also that the drilling requirements were at the maximum capacity of that department. Although it was realized that the MPS was overstated, an MRP run based on the MPS was exploded in order to calculate a detailed work load profile for both operations. Based on the week by week requirements of the milling department, it was obvious that milling was the bottleneck. The drilling department was not a bottleneck in itself, but due to being at near capacity, it could only meet schedule when the shop orders arrived in an even continuous flow. Due to the nature of order routings and release patterns, this even continuous flow was not about to happen.

Based on the above capacity studies, the following steps were taken:

1. Arrangements were made with an outside contractor to outsource milling overload requirements.
2. The queue time allowance in the lead time calculation of drilling operations was increased to allow for the fluctuations of timing of incoming orders.
3. Input-output reports were initiated for both departments in order to monitor actual results and to take corrective action when required.
4. The MPS was to be validated through RCCP planning procedures on a monthly basis or whenever there were major changes in the schedule.

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Chapter 9

DISTRIBUTION MANAGEMENT

DISTRIBUTION NETWORKS

Logistics is defined as the obtaining, producing, and distributing of goods in the proper order and the proper place. In the industrial world, the emphasis placed on logistics is the distribution function. The distribution channel is the route a product travels from raw material to the customer. Inventory must be managed from point of manufacturer to the final customer. This management may include several layers of inventory when the product is stocked at distribution centers, wholesalers, and retailers. The distribution network structure defines the channel and therefore the relationships between various levels of inventory.

The distribution structure will include the manufacturing site, or a central supply center if the network does not include a manufacturing concern. Regional and area (branch) warehouses, distributor outlets, and retail outlets may be part of the total network. The entire network may be controlled by a single entity such as a manufacturer, who not only manufactures the product, but also owns the network of warehouses and retail outlets. This arrangement is known as a functional channel. In an institutional channel, the structure consists of vertically aligned companies where the ownership of the product is transferred at each level. In many situations, the channel is a mixture of both functional and institutional. A manufacturer may market the product through company owned retail outlets and may also distribute through a network of separately owned distribution and retail outlets.

In the past, many major appliances such as refrigerators, washing machines, and television sets were distributed through a functional channel with the manufacturer controlling all inventory levels through company owned retail outlets. Sears, although not a manufacturer, was also an

example of a functional channel in that the appliance would be manufactured under the Sears' brand name and distributed through Sears' stores. In the past 10 to 15 years, functional channelling has given way to institutional channelling as it has become evident that the customer often prefers a choice of brand name products at one retail location. Some products, such as flashlight batteries, have always been distributed through institutional channelling.

The primary goals of the distribution network are to maximize the service to the customer while minimizing the cost of distribution. Customer service means timely delivery with availability of all products in the line. When delivery lead times are long, such as products produced in Boston and sold in Seattle, a Seattle warehouse will shorten the lead time to the customer. If the anticipated demand is uncertain, safety stock stored in the Seattle warehouse will increase the chances of product availability. Some products are now being marketed through the Internet, which may eliminate the retail outlet from the distribution network. The structure may still include regional and/or area warehouses which would ship directly to the customer.

The presence of a Seattle warehouse may allow for transportation cost efficiencies for products shipped from Boston. The transportation cost advantage must be balanced with the additional costs of maintaining the warehouse as well as the cost of carrying additional inventory.

There are a number of decisions required in the determination of a distribution network structure. They are:

- How many stocking levels will there be in the structure? The cost of regional warehouses may be justified by consolidated freight savings and reduced inventory requirements for branch warehouses.
- Where should the warehouses be located? Geographical locations of customer demand and freight consolidations must be considered.
- What stock should be stored at what location? Fast moving items may be stored at the branch warehouse, slower moving items at the regional warehouse, and other slow moving or questionable items at the central supply center. A decision as to where to store safety stock is also required.
- Are the stocking locations in the structure owned by the manufacturer, subcontracted to an independent company, or owned by the retail outlet? The nature of the product and the market are often the determining factor.

- How is the system to be managed? Proper inventory control and transportation decisions are required.

The determination of a distribution network requires a complete understanding of the product, the market, the customer needs, and the complicated costs of maintaining the distribution system.

COSTS OF DISTRIBUTION

The total cost of distribution must be determined on a level-by-level basis. Once there is an understanding of all incremental costs, a determination of the most cost effective system is possible. However the most cost effective distribution system may be in conflict with the best customer service. Same-day availability may be possible with many branch warehouses, but at a high cost. If this level of service is required, a cheaper solution might be the use of air transport. Air transport would most likely be practical for high-value, low-weight items. The optimum customer service level may be cost prohibitive. If this is the case, and it usually is, the solution is to rank and prioritize the trade-offs.

Distribution costs are best analyzed when based on an understanding of the three major cost segments. They are:

- Transportation costs.
- Storage costs.
- Inventory carrying costs.

Both inbound and outbound transportation costs must be considered. The most used mode of transportation is highway motor transport. It may be by over-the-road equipment or specialized short-haul equipment. The advantages of motor transport are flexibility, short-haul capability, and the ability to handle variable capacities. Rail transport can be less costly than motor, but large volumes are required and there is a loss of flexibility. Water carriers are cost effective, but are slow and limited by geographic location. Air transport is expensive, but is the fastest mode over medium to long distances. Pipeline transport, which has a high initial cost and low operating costs, is limited by application and geography.

Storage costs are those expenses required to operate a distribution center. Expenses to be considered are building and land costs, labor costs, insurance costs, and taxes. Building and land costs are relatively easy to determine. The cost of labor must consider those involved in material handling as well as those involved in the management of the inventory. Taxes may be based on both the value of the property and the value of the inventory. Insurance rates can also be based on both property and inventory.

The inventory carrying cost, described in Chapter 5, included the storage costs listed above as well as the opportunity cost of money and the cost of

obsolescence risk. For purposes of distribution analysis, the cost of carrying inventory considers opportunity and obsolescence costs relating directly to inventory but not storage costs, which are considered fixed. The amount of inventory carried is dependent on the lot size, the frequency of ordering and the planned safety stock.

SITE LOCATION PLANNING

The number of warehouse sites and their locations are dependent on both the product and customer requirements. If availability and timely delivery is uppermost with respect to customer service, retail outlets located close to as many customers as possible is the goal. These outlets may be owned by outside organizations, such as department stores, or company owned such as a general Motors owned dealership. Linear programming and simulation techniques can assist in the quantitative evaluation of site selection and transportation cost minimization. As mentioned above, customer service may then become the deciding factor. A grid system may be used that calls for a computer calculation of the various distances to customer sites to determine the desired warehouse location. A center-of-gravity system analyzes customers' locations and weighted product demands. The resultant center-of-gravity is the "best" warehouse location.

Area warehouses may be company owned or owned by an outside organization such as a wholesaler. In some situations the warehouse may be a public warehouse serving either the manufacturer or the wholesaler. The purpose of the area warehouse is to allow quick access to the retail outlet. Area distribution centers may order directly from the manufacturing plant or from the manufacturer's regional warehouse. A wholesaler will be ordering from a variety of manufacturers.

Regional distribution centers may cover the requirements of a major section of the country, such as the Midwest United States, or an overseas market such as western Europe. The overseas distribution center may be a "free-trade-zone" warehouse used by distributors engaged in international trade. Products stored in these warehouses are exempt or have reduced customs duty liability. Taxes and duties are not paid until the goods are actually sold and shipped. The term "bonded warehouse" is often used to describe a free-trade-zone warehouse. A bonded warehouse is also defined as a facility operated by U.S. Customs for storing imported merchandise. Regional distribution centers often allow transportation cost saving from point of manufacture.

The manufacturing location (also considered a central supply center) is the initial point of product inventory. In some manufacturing operations, there will be multiple manufacturing sites due to the nature of the product. A company manufacturing steel strap may have more than one manufacturing

facility with each one located near a steel mill in order to minimize incoming raw material freight costs. Automobile manufactures may have multiple assembly operations in order to minimize the finished product's (the cars) delivery cost. A multiple manufacturing facility may serve one or more regional distribution centers, or ship directly to an area warehouse, a retail outlet, or the end user.

Determination of the locations of the sites within the network are dependent on a number of factors. Transportation and storage costs described earlier in this chapter, are obvious considerations. Other factors for consideration are:

- The labor market. The skills required for an operation must be matched with labor availability in the area. An additional consideration would be the labor relations in a given area.
- Available transportation. Depending on the product, the required mode of transportation must be a consideration. Access to airports, railroads, or water transport may be an important requirement.
- Schools. In many situations, when the goal is to attract good employees, the quality of the school system can be a deciding factor.
- Recreational facilities. As with school systems, the availability of recreational outlets must be a consideration. The "quality of life" factor may make the difference in attracting desired employees.

MODES OF TRANSPORTATION

The mode of transport is dependent on both the product and the market location. As mentioned above, motor transport is the most utilized form. The advantages of motor transport are flexibility of both location and time and speed of delivery (especially with short-haul equipment). Long haul shipments will be by truckload when there is sufficient volume, while with less volume, LTL (less truckload) is used. Delivery will take longer with LTL due to the carrier's consolidation time. Motor transport equipment may be specialized such as automobile carriers, refrigerator trailers, and liquid tank trucks.

Railroad transport is used for moving large volumes of freight over long distances. Over the past years rail usage has declined as motor transport has taken over short haul business and water and pipeline carriers have taken bulk commodities freight. While rail transport offers cost advantages for high volume - long distance hauls, it has the disadvantages of fixed (non-flexible) time schedules and service from terminal to terminal rather than from stocking location to stocking location.

Water transport is utilized for large loads of low-value-per-unit goods, for example iron ore. The carriers are specialized for internal river and canal transport, such as barges, Great Lake lakers, and international deep sea

ships. The design of the vessels is specialized for various cargoes. A second design consideration is the water characteristics of the planned routes. The disadvantages of water transport is the slowness of travel and the lack of flexibility due to port to port delivery.

Air transport accounts for the smallest proportion of ton-mile traffic. The reason for the minimal amount of air traffic is the high cost of the service. With most airlines, freight transport is secondary to passenger service, although freight service companies such as UPS and Federal Express have planes dedicated to freight service only. Air carriers are primarily used for:

- 1) Emergency transport of critical items.
- 2) Speedy transportation of high-value, low-weight products.
- 3) Speedy transportation of perishable items.

DISTRIBUTION CENTER CONTROL

When the distribution network is in place, management decisions both at start-up and ongoing are required. Which products are going to be stored at what locations and in what quantities must be determined. Active retail items will be in inventory at each retail location, but will these items be stored at area and regional locations as well? This secondary decision may be dependent on the volume sold at the retail level and the transportation cost involved. Within the same organization, low volume retailers may be served by an area warehouse or a distributor while a high volume retailer could receive shipments direct from the central supply center. Inventory planning may dictate that inventory of slow moving items be maintained at the central supply or regional warehouses rather than at the retail level. Within the same organization, the network may differ when the product demand varies from area to area due to factors such as climate. The sales volume of heavy winter coats will be much greater in Minnesota than in Kentucky where the demand would be much less.

The planned quantity of product in inventory will be dependent on

- 1) the ordering frequency,
- 2) the lot size, and
- 3) the safety stock.

In warehouse management, a joint replenishment system is often called for in order to gain quantity discounts and transportation savings. With joint replenishment systems, a periodic review with a fixed ordering pattern, such as every 2 weeks, will often be in place. This system of review will call for ordering the quantity of each item up to a predetermined target level. With this approach, the order quantity will equal the demand during the past review period. When a reorder point system is used, the lot size is fixed and the frequency of reorder will be dependent on the demand rate of the

product. Each stocking location within the network may be controlled by that specific location's replenishment system.

Safety stock may be maintained at any or all levels of the network. If safety stock is maintained at the area level, less total safety stock is required than if it is maintained at each retail operation being served within the area. The ratio required for centralized safety stock compared to decentralized safety stock is expressed as

$$\text{Decentralized SS} / \text{Centralized SS} = \text{Number of Locations}$$

If the safety stock of 4 retail outlets equals 3600 units, the safety stock required if centralized in one location would be:

$$\text{Centralized SS} = 3600 / 4 = 3600 / 2 = 1800 \text{ units.}$$

The reduction of safety stock inventory due to centralization must be balanced with the possible additional freight cost of safety stock delivery to the customer.

When the product changes ownership in an institutional network, the manufacturer of the product may continue to maintain a degree of control. The control may be defined in a legal document, such as a licensing agreement. The manufacturer may also informally maintain some control by supplying advertising dollars which work to the advantage of both parties. The question of who has the control may depend on the clout or strength of the two parties. Retail operations, like Sears or Walmart, deal from a position of strength when dealing with their suppliers. The small Chevrolet dealer does not have this strength when dealing with General Motors. Manufacturers may choose to use a wholesaler who is placed between the manufacturer and the retailer. The wholesaler offers not only knowledge of the marketplace, but also assumes the inventory management responsibility that goes with product ownership. The disadvantage to the manufacturer may be loss of control of price and promotion.

Customers are placing orders on the Internet at an increasing rate. This mode, in some situations, may eliminate the retail level of the network, but the product must still be delivered in a timely manner and at a reasonable freight cost. The network may consist of just the manufacturer and the customer as is the distribution channel used by Dell Computer. The Internet may also be an ordering device used by a retailer like Barnes and Noble which not only markets books through their retail outlets, but also through barnesandnoble.com. An automobile purchaser may search the net for a specific car and then pick an available dealer with the most favorable price. Internet technology creates a new set of distribution possibilities and challenges.

FREIGHT CONTROL

The appropriate mode of transportation is dependent on traffic-related, shipper-related, and service-related factors. Traffic factors cover such things as the size of the shipment, the length of delivery, and fragility and perishability of the product. Shipper-related factors can include marketing strategies, financial considerations, and availability of different modes of transportation, such as rail sidings and airports. Service considerations include transit time, reliability, and customer relations. Some routings will call for multiple modes, as for example water transport to an overseas port where the product is transferred to rail or truck delivery. Containerization, where products are sealed in standard-sized containers, contributes to the efficiency of handling between ships, railcars, and trucks.

The routing and scheduling of deliveries can be most critical especially when freight requirements cover a wide variety and volume of products to be delivered to multiple locations. Planning the delivery of a single product to a single customer is not complex but the complexity increases as the number of products and delivery locations increase. In the past, every effort would be made to minimize freight costs through the planning of full truck loads. As inventory management efforts are now in the JIT approach of minimizing inventory investment, the full truck load is often in conflict with the customer requirement of small and more frequent deliveries. Joint replenishment control systems can sometimes offer the best of two worlds by the ordering of multiple items in sufficient quantities that call for full truckloads.

Freight consolidation is a technique that will allow reduced transportation costs without increasing inventory investment. This can be done by the grouping of products at a central point to be shipped to a specific location where the products are then distributed to the customers. The shipping vehicle may be a rail car or a truck. In either case, the vehicle can be considered a distribution center. Another approach to freight consolidation is when products are collected and consolidated to be delivered to a specific customer. The disadvantage of freight consolidation may be increased lead times and safety stock requirements.

A form of freight consolidation that services JIT process flow manufacturers is “milk run” routing. The milk run route will call for the pickup of mixed loads from multiple suppliers for delivery to the manufacturer. The scheduled delivery is repeatable and designed to meet the immediate (such as daily) requirements of the customer. Just-In-Time process controls are often used in conjunction with milk run routing. Part containers, full when delivered to the customer, will be returned empty to the supplier to be refilled and reshipped when called for. Just-In-Time philosophy calls for the elimination or at least reduction of non-value added

activities. Most transportation related activities like packaging, receiving and storing, do not add value to the product. Accordingly JIT freight movement planning attempts to minimize these activities.

Transportation services may be owned by the firm or subcontracted to outside transporters. Some companies may own their trailers or rail cars but subcontract the transport to independent haulers. Firms may purchase vans or customize small trucks for use in milk runs or short, flexible deliveries.

CASE STUDY SMITH INDUSTRIES INC.

Due to innovative designs, Smith Industries became the industry leader in infrared gas grills. Not only did they enjoy a large market share of this product, but the other grill and patio furniture businesses also fluoresced due to the reputation gained by the infrared grills. Sales of both grills and patio furniture continued to grow domestically while the grills also became quite popular in Europe. Domestic regions with the strongest markets were the Midwest, the Southeast, and the Southwest. The Northwest and Northeast regions, due to more moderate climates, had lower sales levels. In Europe, Germany was the leading country in gas grill sales followed by England and Spain.

Midwest sales were handled through company-owned retail outlets in Chicago, Cleveland, Detroit, and St Louis. All other domestic sales were marketed through independently owned retail stores. Nation-wide replacement parts were distributed directly from the manufacturing component parts department. European grill sales were through independent retailers, who like the independent domestic retailers, ordered directly through the US manufacturing facility. As the business grew, four distinct distribution problems arose .They were:

1. Patio furniture was sold through the company-owned stores and the independent retailers. All the furniture was manufactured by outside concerns and sold to Smith Industries for resale. The products were ordered and stocked, along with grills, at the manufacturing warehouse (the supply center). The furniture would be shipped to the retail centers at the time of sale. The secondary freight cost of the patio furniture was expensive and the customers expressed dissatisfaction with the delivery time. The furniture manufacturers were reluctant to direct ship to Smith's retailers stating that their responsibility was not to stock and distribute for Smith Industries.
2. Domestic grill distribution was similar to patio furniture distribution in that grills were shipped to retail outlets at time of sale. Unlike patio furniture, there was no secondary freight cost due to the fact that the grills were manufactured and stored at the manufacturing warehouse.

The customers expressed dissatisfaction with the delivery time. Due to the wide variety of grills in the product line, the retail outlets were reluctant to carry the finished goods stock.

3. Replacement parts sales, which shipped directly from the component stock at the plant, did not create a freight problem when the needed parts were in stock. If there was a stockout of a replacement part, the policy was to air freight the backorder. The increasing number of stockouts was starting to cause a high number of expensive air freight shipments. The stockouts were also creating part shortage problems in the manufacturing operation. The MRP system which controlled component inventory, had to assimilate both assembly and replacement part requirements.
4. The demand for grills in Europe brought about new distribution challenges. Ocean freight was too slow, especially for a seasonal product. Air freight was quite expensive for the heavy, bulky grills. The tariff charges(taxes charged by the receiving countries) were substantially reducing the profit margins.

CASE STUDY - SUGGESTED SOLUTION

Problems 1 & 2.

A distribution network was designed to cover domestic sales of patio furniture and grills. Regional warehouses were established to directly serve the retail outlets. A second distribution level (area warehouses) was considered as this would have brought the product even closer to the customer. A detailed cost analysis showed that this additional level would not be cost effective.

The planned regions were:

Southeast - Atlanta warehouse

Northeast - Boston warehouse

Midwest - The manufacturing central supply warehouse in Chicago

Southern - San Antonio

Southwest - Los Angeles

Northwest - Seattle

The Atlanta, San Antonio, and Los Angeles warehouses were company owned and managed, while the Boston and Seattle operations used public warehouse facilities. The northern regions had much less demand which did not justify the capital investment required for a company owned facility. It was decided that the northern regional sales managers could control replenishment operations while the public warehouses would be responsible for storage and material handling.

The regional warehouses were supplied from the Smith Industries' manufacturing supply center, while patio furniture was shipped directly from the patio manufacturers. The cost of the warehouse operations and

some additional inventory was balanced by freight savings and improved customer service.

Problem 3.

The replacement parts problem was not a distribution problem but a manufacturing problem. The size and weight of replacement parts were such that all retail outlets could be efficiently served directly from the manufacturing supply location - if the parts were available when needed. The system of adding the replacement parts' forecast to the gross requirements of MRP generated assembly requirements was not effective and created many conflicts between the replacement and assembly requirements. The replacement parts business had increased to a level that allowed it to be established as a separate profit center with a stand-alone inventory and inventory management system. The replacement parts operation would buy manufactured parts from the grill manufacturing operation and buy purchased parts directly from the suppliers. While this management approach caused some inventory duplication, this disadvantage was offset by more effective inventory management.

Problem 4.

The problem of product availability in Europe was initially addressed by the establishment of a free-trade-zone warehouse in Germany. The grills in stock were much closer to the customer and tariff was not charged until the products were shipped to the purchasers in the European area. This was a short-term solution as it required additional inventory investment and the high tariffs remained. The long range solution was to build a manufacturing facility in Germany. Raw materials and purchased components were readily available as was the needed labor force. In order to take advantage of quantity discounts, few purchased components were supplied from the United States. This solution eliminated the overseas freight cost as well as reducing the inventory. The tariff charges for sales in Germany, the largest European market, was eliminated. The grills manufactured for other European markets were stocked and distributed from the free-trade-zone warehouse.

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Chapter 10

DISTRIBUTION RESOURCE PLANNING

REORDER POINT PULL SYSTEMS

The purpose of a distribution system is to give maximum service to the customer. The structure of the distribution network is designed to achieve this end. If the management of the network is not properly executed, the end result can be poorer service than planned, costly transportation expenses, high levels of inventory, conflicts between network levels, or a combination of any of the above. Prior to implementation of the dependent demand concepts of MRP, many distribution operations were based on reorder point replenishment systems. Products would be 'pulled' from supplying centers when the inventory dropped to the reorder point. The reorder point system assumed that the material is available at the supplying center location. If the demand of a single stocking location calls for an even continuous rate, the reorder point system will work. However, if there are multiple stocking locations, each having even, continuous demand, the combination of demands will be lumpy requirements for the supplying facility.

Table 10-1 is an illustration of the time-phased combined demands of distribution centers, each with an even flow. The controlling factors at each distribution center (DC) are as follows:

	<u>Weekly Demand</u>	<u>Order Quantity</u>	<u>Order Frequency</u>
DC # 1	100	500	5 weeks
DC # 2	200	600	3 weeks
DC # 3	150	600	4 weeks

Table 10-1. Combined Demand

Week	DC # 1	DC # 2	DC # 3	Total
1	500			500
2		600		600
3			600	600
4				—
5		600		600
6	500			500
7			600	600
8		600		600
9				—
10				—
11	500	600	600	1700

Assuming that DC # 1 requires shipment in week 1, DC # 2 in week 2, and DC # 3 in week 3, the combined central supply replacement requirements will be as shown in the total column of Table 10- 1.

Lacking the visibility of the future, the central supply center, or the next level in the network, would not realize what was going to happen in weeks 9, 10, and 11. With visibility of future demands, proper steps could be taken at the planning level of the manufacturing (or supplying) system.

The double order point system, explained in Chapter 6 and illustrated in Figure 6-3, is an approach to forewarn the manufacturing center of orders that might be generated in the future. This technique can assist in manufacturing planning, but is not easily managed.

CENTRALIZED DRP SYSTEMS

Distribution resource planning (DRP), which is sometimes referred to as “distribution requirements planning”, was developed to handle the intermittent or lumpy demand pattern at the central supply center. This system communicates and combines the individual demands of each distribution center (DC) in a time-phased mode. The forecasted independent demand of each DC may be continuous or discontinuous, but in either case, the forecast is treated as a time-phased order point gross requirement similar to the gross requirement control of the master production schedule (MPS). As with MPS gross requirements, there will be the decision process required as how to treat customer orders in a forecasting environment. Just as with the MPS process, the control will be dependent on time fence policies and order quantity comparison to forecasted quantities.

Once the gross requirements are established at the DC level, the net requirements and planned orders are calculated using MRP time-phasing logic. The planned order release of the DC parent is then exploded down to the next level which may be an area distribution center, regional distribution center, or the central supply center. The level-to-level explosion, the parent to component relationship, and the dependent demand concepts are exactly the same with DRP as with MRP. However, because MRP deals with a manufacturing environment and DRP with a distribution environment, the data elements in the record files go by different names but react to the same logic. Table 10-2 lists the MRP elements and the equivalent DRP elements.

Table 10-2. Data Element comparisons

MRP	DRP
Gross requirement	Forecast
Scheduled receipt	In transit
Projected available balance	Projected available balance
Planned order receipt	Planned shipment receipt
Planned order release	Planned shipment release

Distribution resource planning is a planning system that covers the entire distribution network and can be integrated with the manufacturing planning system by being brought together by the master production schedule.

The control or execution of the DRP system may be centralized at a single control center or decentralized with each DC controlling its own replenishment orders. The centrally controlled system is sometimes referred to as a “push” system on the assumption that material will be shipped to the DC based on the anticipated use of the product. When the control of replenishment orders is in the field (the DC), the system is called a “pull” system. In reality, both systems will be replenished based on anticipated demand and the push/pull nomenclature is a misnomer. It can cause confusion especially in trying to compare to push or pull manufacturing control systems.

Those favoring centralized distribution management point out that with “push” system control, the responsibility for the total distribution inventory is with a single authority rather than split among the distribution centers.. This approach means that the central authority plans the distribution inventory level, and replenishes distribution inventories, rather than the distribution centers controlling their individual inventories. The decision for the locating of inventory reserves would optimize the investment for the entire distribution network.

With centralized control the distribution centers would be responsible for:

- Inventory record accuracy. This would involve transaction control and cycle counting.
- Forecasting. The distribution center could either submit forecasts or have the right to review and override forecasts submitted from central control.

The planned shipment release is determined by offsetting the planned shipment receipt by the lead time required for delivery to the DC. The DC lead time is an added time value to the critical path required for manufacturing the product. Therefore, the DRP planning horizon should be the sum of the MPS/MRP planning horizon and the DC lead time. An example of this concept is an item with a manufacturing critical path of 26 weeks and which is distributed overseas with a transportation time of 13 weeks. An overseas requirement at the end of September must be in stock at the central supply center by the end of June. To produce the item by the end of June, the initial action (probably placing a purchase order) would have had to have been placed at the beginning of the year. The 39-week DRP horizon is necessary to predict the end of June requirement to the MPS/MRP system, which in turn, must use its 26-week horizon to predict the initial purchasing requirements.

DRP USE OF MRP LOGIC

Each item stocked at a distribution center will be controlled by planning controls pertinent to the specific distribution center.

The lead time from the supply center to the distribution center is the sum of the following times:

- Supply center's order releasing..
- Supply center's picking and loading.
- In-transit.
- Distribution center's unloading and stocking.

The planning lot size of each item is based on the following considerations:

- The traditional balancing of the costs of ordering and the costs of carrying the inventory.
- The item's needs combined with other items in order to allow for economical truck or rail shipments.
- The pallet size required for the item's shipment.

If the policy is to carry safety stock at the DC, the quantity should be based on the error measurement as explained in Chapter 4, and should also be relative to the variations of demand at the individual DC. The anticipated usage rate at the DC (the gross requirement) will be the time-phased forecast of DC demand adjusted up close for open orders. In some DRP systems, the item's part number at the DC will be the corporate part number plus a suffix unique to the DC. This allows the combining of requirements at the supply center, and at the same time, allows for the identification of the individual requirements for each DC.

The DC replenishment needs (the planned shipment releases) are "exploded" down to the supply source and, with MRP logic, the gross requirements of the supply source are calculated. The DC requirements are the 'parents' and the supply source is the "component". In a DRP system the requirements of the distribution centers drive the MPS just as the MPS drives the MRP. Figure 10-1 illustrates the relationship of two DCs which are supplied directly from the central supply center which is the manufacturing facility. Note that the manufacturing operation must be in a JIT environment as there is "0" lead time to assemble Product A.

DRP	DC 1 Product A	DC 2 Product A
On Hand		
Balance — 20		0
Safety		
Stock — 0		0
Lead		
Time — 2 Weeks		2 Weeks
Lot Size — 2 Week Fixed Period		2 Week Fixed Period

Weeks	1	2	3	4	5	6
Forecast	20	20	20	20	20	20
In Transit		40				
Projected Available						
Balance	0	20	0	20	0	20
Planned Shipment						
Receipt				40		40
Planned Shipment						
Release		40		40		

1	2	3	4	5	6
30	30	30	40	40	40
60					
30	0	40	0	40	0
		70		80	
70		80			

MPS	Central Supply - Product A
	On Hand Balance — 0
	Safety Stock — 0
	Lead Time — 0
	Lot Size — 80

Weeks	1	2	3	4
Gross Requirements	70	40	80	40
Scheduled Receipts	80			
Projected Available Balance	10	50	50	10
Planned Order Receipt		80	80	
Planned Order Release		80	80	

Figure 10-1. DRP Driving the MPS

INTEGRATING DRP WITH MRP

The master schedule is the interface between DRP and MRP. In DRP, the distribution demands end at the master schedule. The total demands from the distribution system for each item appear in the MPS. In manufacturing, it all begins with the master schedule. The MPS is exploded and demands for components and raw material are created. In a DRP system, the MPS is the lowest level of the network structure while it is the highest level of the related bill of material.

Figure 10-1 illustrated the distribution demand for Product A. Figure 10-2 illustrates the MRP output for Product A based on the MPS generated by the distribution system. Product A consists of two components, B and C. Both components have “0” in stock and have no planned safety stock. B has a lead time of 1 week and lot-for-lot order quantities. B has a lead time of 2 weeks and an order quantity of 100.

Central Supply MPS - Product A				
Weeks	1	2	3	4
Gross Requirements	70	40	80	40
Scheduled Receipts	80			
Projected Available Balance	10	50	50	10
Planned Order Receipt		80	80	
Planned Order Release		80	80	

MRP	Component B				Component C			
	1	2	3	4	1	2	3	4
	Gross							
	Requirements		80	80		80	80	
	Scheduled							
	Receipts					100		
	Projected							
	Available							
	Balance	0	0	0	0	0	20	40
	Planned							
	Order							
	Receipt		80	80			100	
	Planned							
	Order							
	Release	80	80			100		

Figure 10-2. Integrating DRRP and MRP

If the distribution centers have separate data bases, a program must be written to read the planned shipment release requirements from all the centers, sum them, and post them to the MPS. Some software systems have DRP systems which are integrated with the MPS/MRP system.

MANAGING THE DRP SYSTEM

The DRP system will generate action messages to the DC to release shipment orders to its demand source (the regional or area warehouse, or the central supply center) when the release data coincides with the action bucket. It will also call for action when an in-transit order is scheduled too early or too late for requirements. The logic is the same as the action messages in MRP relating to scheduled orders. The difference is that a scheduled order may be more easily expedited or deexpedited, while an in-transit order's time is quite fixed. The DRP in-transit action message is, therefore, more useful as an informational tool.

Just as the DRP system generates action messages to the DC to release shipment orders to the central supply center, the MPS system will generate similar action messages to release MPS orders. Based on the DRP input, the MPS system may also recommend changing MPS order due dates. Although it may be impractical if not impossible to change the MPS, it communicates information that distribution requirements are in trouble and action is required.

Pegging is a tool that is useful when all the demands of an item cannot be met. The master scheduler or the distribution planner will use pegging routines with the DRP system to trace back detailed demand sources by date and quantity. Pegging will also be useful when adjustments to the MPS are called for in order to meet MPS goals. The routine of pegging up through the DRP levels is similar to pegging up through the MRP levels when tracing the source of a manufacturing demand.

The use of firming planned shipments is similar to firming planned orders in an MRP system in that this routine is for overriding the planning logic for DRP. The master scheduler may wish to override the system when using the MPS to allow for planned build-ups, temporary lot size reductions, planning to use safety stocks to meet demands, or adjusting demands to coincide with shipping schedules. The firming of planned shipments requires manual control and close communication between the central supply center and the affected distribution center.

Using the DRP system for stock build-ups calls for a complete understanding of the distribution network. The purpose of the build-up may be to solve distribution problems such as uneven demands due to

seasonality, promotions, network structure changes, or planned shutdowns. The stock build-up may be at the central supply center, the distribution centers, or both.

An example of DRP utilization is when a plant has scheduled a vacation shutdown and must plan a build-up. Table 10-3 shows the MPS planned build-up where weeks 1, 2, and 3 produce an extra 500 units each week to allow for the vacation shutdown in week 4. The build-up also allows for a reduced start-up rate of 500 units in week 5. The maximum space the plant (the central supply) can handle is 2100 units. The decision is made to move 400 units of the build-up stock to DC A. The DC A DRP display is shown prior to the planned extra 400 units of stock.

Table 10-3 Vacation Buildup

Master Schedule Display					
Safety Stock = 1000					
	Week				
	1	2	3	4	5
Distribution demands	1000	1000	1000	1000	1000
MPS receipt	1500	1500	1500		
Projected available balance	1500	2000	2500	1500	1000

Distribution Center A Display							
Lot Size = 400							
Lead Time = 2 weeks							
Safety Stock = 100							
Weeks	1	2	3	4	5	6	7
Forecast	200	200	200	200	200	200	200
Projected available balance	300	100	300	100	300	100	300
Planned shipping receipt			400		400		400
Planned shipping release	400		400		400		

It was determined that DC A’s receiving facilities could not receive more than 600 units per week. An extra shipment of the 400 units build-up was not a favorable option, so the decision was to increase the planned shipments in weeks 1 and 3 by 200 units each. These planned shipments were firmed and the resultant display is shown in Table 10-4. The adjusted master schedule display is also shown. Note that after week 5, the supply center stock level is back to normal with the 1000 units of safety stock.

Table 10-4. Firming Buildup Shipments

Distribution Center A							
Weeks	1	2	3	4	5	6	7
Forecast	200	200	200	200	200	200	200
Projected available balance	300	100	500	300	700	500	300
Planned shipping receipt			600		600		
Firm planned shipments	600		600				

Adjusted Master Schedule Display Safety Stock = 1000					
Week					
	1	2	3	4	5
Distribution demands	1200	1000	1200	1000	600
MPS receipt	1500	1500	1500		
Projected available balance	1300	1800	2100	1100	1000

An example of establishing a temporary stockpile location in order to handle a 2-month central supply build-up due to a plant renovation is shown in Table 10-5. The original master schedule reflects distribution demands of 2000 units per month for 7 months. The first 6 months' demand (12,000 units) are scheduled for production in the first 4 months to allow for the fifth and sixth month renovation shut down. The central supply center lacks storage capacity so a temporary stockpile location is established to accept same-day delivery from the central supply center at the rate of 1000/month. The stockpile location display reflects the 4-month build-up using firm planned shipments. It also shows the fifth and sixth month gross requirements when the location will act as a regional distribution center supplying the needs of the distribution system. With the addition of the temporary stockpile DC, the DRP demands will generate the adjusted MPS display which is shown.

Table 10-5. Temporary Stockpile Control

Original Master Schedule Display Safety Stock = 0							
	Month						
	1	2	3	4	5	6	7
Distribution demands	2000	2000	2000	2000	2000	2000	2000
MPS receipt	3000	3000	3000	3000	—	—	2000
Projected available balance	1000	2000	3000	4000	2000	—	—
Stockpile Location DRP Display							
Forecast					2000	2000	
Projected available balance	1000	2000	3000	4000	2000	—	—
Firm planned shipment	1000	1000	1000	1000			
Adjusted Master Schedule Display							
Distribution demands	3000	3000	3000	3000	—	—	2000
MPS receipt	3000	3000	3000	3000	—	—	2000
Projected available balance	—	—	—	—	—	—	—

CASE STUDY SMITH INDUSTRIES INC.

1. The DRP/MPS plan for the Atlanta distribution center's grill requirements to be received from the Chicago manufacturing plant are shown in Table 10- 6. Repairs to the Atlanta receiving dock are scheduled for week 5 and, therefore, no shipments can be received that week. The repairs are absolutely necessary and cannot be rescheduled. The Chicago plant has experienced major electrical problems and must be shut down week 4. The DRP/MPS plan must be adjusted to meet the two situations.

Table 10-6. DRP/MPS Plan for Atlanta DC

Atlanta DC							
Lot Size = 20, Lead Time = 2 Weeks, Safety Stock = 0							
Weeks	1	2	3	4	5	6	7
Forecast	10	10	10	10	10	10	10
In transit	20						
Projected available balance	10	0	10	0	10	0	10
Planned shipment receipt			20		20		20
Planned shipment release	20		20		20		

Chicago Plant					
Lot Size = LFL, Lead Time = 1 Week, Safety Stock = 10					
Weeks	1	2	3	4	5
Distribution demands	20		20		20
Scheduled receipts	20				
Projected available balance	10	10	10	10	10
Planned order receipt			20		20
Planned order release		20		20	

2. Gas grill demand was always low in the first quarter of the year, but business would always pick up in the second (spring) quarter. The decision was made to get a strong start in the spring by offering a favorable sales promotion for the month of April. Forecasted demand for the first quarter was 1000 units/month while April, due to the sales promotion, was forecasted to be 3000 units. May requirements were planned at 1800 units per month, the normal spring demand. Plant capacity for grill production was 2000 units/month. For that reason it was decided that there would have to be an inventory build-up to meet the April demand. The central supply center at the plant had space for an additional 600 grills. Because of both space and freight considerations, the San Antonio distribution center was picked to carry the additional grills in the build-up plan. Delivery to San Antonio was by rail and, therefore, the lead time was planned at 4 weeks. Table 10-7 shows the original master schedule and San Antonio distribution plan prior to both capacity and stock build-up considerations.

Table 10-7. Original Master Schedule and San Antonio DRP

Master Schedule Display Safety Stock = 0					
	Month				
	Jan.	Feb.	March	April	May
Distribution demands	1000	1000	3000	1800	1800
MPS receipt	1000	1000	3000	1800	1800
Projected available balance	0	0	0	0	0

San Antonio DRP Display Lot Size = 200 Lead Time = 4 weeks Safety Stock = 100					
Forecast	200	200	200	600	360
In transit	200				
Projected available balance	100	100	100	100	100
Planned shipping receipt		200	200	600	360
Planned shipping release	200	200	600	360	

CASE STUDY - SUGGESTED SOLUTION**Problem 1.**

Because of the receiving dock repairs, the planned receipt at Atlanta in week 5 must be moved forward to week 4. The planned shipment in week 3 must be moved to week 2 and “firmed”. The distribution demand at the Chicago plant is shifted to week 2.

The Chicago plant’s planned shut down can be controlled by moving the planned order release in week 4 forward to week 3. The planned order release in week 2 will be moved forward to week 1. The planned shipments to Atlanta in week 5 do not have to be rescheduled.

The revised plans are shown in Table 10-8.

Table 10-8. Revised DRP/MPS Plan for Atlanta DC

Atlanta DC							
Weeks	1	2	3	4	5	6	7
Forecast	10	10	10	10	10	10	10
In transit	20						
Projected available balance	10	0	10	20	10	0	10
Planned shipment receipt			20	20			20
Planned shipment release	20				20		
Firm planned shipment		20					

Chicago Plant					
Weeks	1	2	3	4	5
Distribution demands	20	20			20
Scheduled receipts	20				
Projected available balance	10	10	10	30	10
Planned order receipt		20		20	
Planned order release	20		20		

Problem 2.

The Chicago plant's distribution demand for March (to cover April sales) called for an MPS receipt of 3000 grills, 1000 beyond production capacity. The capacity problem is corrected by increasing February's MPS receipt by 1000 units and reducing March by that amount. The San Antonio DC had a planned shipping receipt of 600 grills in April. Moving and firming the April receipt to March (and therefore the release from March to February) reduces the Chicago plant build-up to 600 grills. Table 10-9 reflects these changes.

Table 10-9. Revised Master Schedule and San Antonio DRP

Master Schedule Display					
	Jan.	Feb.	Month March	April	May
Distribution demands	1000	1400	2600	1800	1800
MPS receipt	1000	2000	2000	1800	1800
Projected available balance	0	600	0	0	0

Table 10-9. continued

	San Antonio Display				
	Jan.	Feb.	Month March	April	May
Forecast	200	200	200	600	360
In transit	200				
Projected available balance	100	100	500	100	100
Planned shipping receipt		200	600	200	360
Planned shipping release	200		200	360	
Firm planned shipment		600			

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Chapter 11

PURCHASING MANAGEMENT

THE ROLE OF PURCHASING

The responsibility of the purchasing function is to ensure quality and economic supply of goods to the company's operation. The objective is to secure optimal supplier performance with respect to quality, timely delivery, and minimum cost of purchased items. To achieve these objectives, it is necessary to develop the satisfactory sources of supply and to maintain good relationships with these suppliers. In the past, the emphasis was to procure the product at minimum cost with less attention paid to quality and timing. Experience has shown that this was not the best course of action. The savings realized on minimum cost procurement has not been worth the cost of customer dissatisfaction due to quality problems. The cost and effectiveness of excessive safety stocks has not compensated for late or erratic delivery of material. At this time, quality, delivery and cost are quite properly treated with equal importance.

In the determination of a purchase, various influences will affect the final buying decision. The people responsible for the product design will have an interest in the quality and price of the product. The quality assurance people and the manufacturing engineers will also have quality interests. The sales or activity forecasters and production control will be concerned with timing, while material control and cost accounting will have an effect on the purchase quantity. The purchasing function, with primary responsibility, will influence all factors.

The purchasing function must also control the procurement process. The determination of the supplier, the placing and follow up of the order, and the closing out of the document are all part of the process. In some operations, purchasing will place a blanket order covering an overall quantity and period of time. A buyer/planner, who may or may not be a part of the

purchasing department, will be responsible for releasing requirements against the blanket order. This approach simplifies or eliminates the purchase requisition in the process. Purchasing is also responsible for co-ordination with both company and supplier departments, such as production control in the company and the traffic department of the supplier.

The purchasing function may be organized by a line, line and staff, or a functional organization. In the line organization, the buyer reports directly to the purchasing manager (director, purchasing vice president, etc.). In a purchasing department with a line and staff organization, the buyer is assisted by a specialized analyst such as a purchasing engineer. With a functional purchasing organization, the buyer reports directly to the plant or division manager, but indirectly (dotted line) to a centralized purchasing director or vice president.

Centralized control of the purchasing operation is practiced when the purchasing activity affects the entire operation, such as buying steel for steel strap manufacturing. Companies with a single plant will also have centralized purchasing. The advantages of centralized purchasing are greater control of dollar commitment, control of uniform procedures, and ease of training staff. When there are several buying groups reporting to plant or division managers, purchasing activity is considered decentralized. The advantage of decentralized control is that responsibility and authority are closer to the operation allowing for greater flexibility. Another advantage is the reduced reaction time in emergencies.

The first step in the purchasing process is the receiving and editing of the requisition which is the authority to purchase. It may be a written form, a travelling requisition for a repetitive item, or a computer generated action message such as one generated by an MAP system. The second step is the decision as to what supplier will be utilized. This decision will be dependent on the supplier's past history and the ability to supply a quality product with timely delivery at a reasonable cost. The next step is the issuance of the purchase order, which will be followed up through delivery of and payment for the product. In the process, change notices and expediting may be required. Required data for supplier performance measurement is collected. In present day business, the process is often managed by electronic data interchange (EDI). EDI is the utilization of computers to communicate and exchange documents between customers and suppliers. This paperless system includes purchase orders, releases, delivery notification, and invoices.

PURCHASING QUANTITIES

The standard economic order quantity (EOQ) formula can be applied to purchased items that can be economically stocked by the supplier and, as stated in Chapter 5, have a demand pattern that is level and continuous. MRO items, service parts, and standard manufacturing parts often meet this criteria. In utilizing the EOQ formula for purchased items, the ordering cost is the average cost of a purchase order. This average is calculated by dividing the operating cost of the purchasing function by the total number of purchase orders generated. This ordering cost is to the purchased item as the set-up cost is to the manufactured item. Other techniques based on balancing ordering and carrying costs, such as period order quantity (POQ) or least unit cost (LUC), can be used when the demand pattern is not level or continuous. As with the EOQ technique, these approaches are only valid for items that can be stocked by the supplier and are not unique to a specific customer.

When the purchased item is unique and manufactured specifically for the customer, such as a casting, the real EOQ is the supplier's economical manufacturing quantity (EMQ). The customer's EOQ may be calculated based on the following:

$$\begin{aligned}
 &\text{Purchase order cost} = \$40.00 \\
 &\text{Annual usage} = 2700 \text{ units} \\
 &\text{Standard cost} = \$10.00 \\
 &\text{Carrying cost} = 24\% \\
 &\text{EOQ} = \sqrt{\frac{(2)(2700)(40)}{(.24)(10)}} = \sqrt{\frac{216,000}{2.4}} = \sqrt{90,000} \\
 &\text{EOQ} = 300 \text{ units}
 \end{aligned}$$

However, in this situation, the supplier's economical manufacturing quantity might be calculated as follows:

$$\begin{aligned}
 &\text{Set-up cost} = \$200.00 \\
 &\text{Annual usage} = 2700 \text{ units} \\
 &\text{Standard cost} = \$7.10 \\
 &\text{Carrying cost} = 24\% \\
 &\text{EMQ} = \sqrt{\frac{(2)(2700)(200)}{(.24)(7)}} = \sqrt{\frac{1,080,000}{1.68}} = \sqrt{642,857} \\
 &\text{EMQ} = 802 \text{ units}
 \end{aligned}$$

Note that in this example, the customer's standard cost is based on the selling price (the purchase cost) of \$10.00, while the supplier's standard cost of \$7.10 is based on the manufacturing cost.

The above differences might be handled in a number of ways.

1. The customer might agree to place orders in quantities of 800 units.
2. The supplier might agree to accept orders in lots of 300 units but to produce in quantities of 600 or 900 units. The supplier would request a blanket order to insure eventual sale of the units being carried in the supplier's stock.
3. The supplier might agree to accept orders in lots of 300 unit and to produce in lots of 300. With this alternative, the supplier would probably increase the quoted selling price of \$10.00.
4. The supplier might give the customer an incentive to buy in larger lots through a quantity discount based on purchasing in lots of 800 units. The customer would have to evaluate the quantity discount based on the total annual cost of the alternatives.

The Total Cost = Carrying Cost + Ordering Cost + Annual Item Cost

If the lot size is 300 and the selling price is \$10.00, the total cost is:

$$\begin{aligned}\text{Total cost} &= (300/2)(\$10)(.24) + (2700/300)(\$40) + (2700)(\$10) \\ &= \$360 + \$360 + \$27,000 \\ &= \$27,720\end{aligned}$$

If a 3% discount is offered, based on a purchase lot size of 800 units, the total cost would be:

$$\begin{aligned}\text{Total cost} &= (800/2)(\$9.70)(.24) + (2700/800)(\$40) + (2700)(\$9.70) \\ &= \$931 + \$135 + \$26,190 \\ &= \$27,256\end{aligned}$$

Based on the above calculation, the customer should take the quantity discount.

5. The just-in-time approach to customer-supplier relationships would call for a mutual effort on the part of both parties to reduce the manufacturing set-up cost. If they could, through product design changes and set-up practice review, reduce the set cost to \$40.00, the ideal would be achieved.

EXTENSION OF THE MANUFACTURING FUNCTION

In manufacturing environments there is an increasing dependency on outsourcing for component supply. For this reason, the supplier is often considered an extension of the manufacturing operation. This relationship is more of a partnership than the treating of the supplier as an adversary. The results of the partnership approach has resulted in a greater number of single-source suppliers, longer term relationships, and greater co-ordination and contact between customers and suppliers.

There is a distinction between single-source and sole-source suppliers. The sole-source supplier is the only supplier capable of meeting the requirements of an item. The customer has no choice. The single-source supplier has been chosen by the customer to have 100% of the business, even though other suppliers are available. The advantages of a single-source, from the customer's viewpoint, are improved communications and the supplier's ability to focus on the manufacturing process. These features are similar to the understanding of the customer's own manufacturing operations.

Long-term relationships allow for a greater degree of understanding of the other party, improved sharing of information, and better long-range planning. The customer can release MAP or other planning output to the supplier. This information, while it is understood not to be a purchase order or release, will assist the supplier in planning capacity for anticipated future business. The supplier can also communicate back if there are possible future problems. With long-term relationships, the supplier can also play an active role in product design, often assisting in quality improving or cost saving suggestions.

When the supplier relationship is based on the concept of an extension of the manufacturing operation, there can be a greater degree of contact between the functioning bodies within both organizations. The production control groups within both organizations can work together in efforts to both reduce lead times and assure on-time delivery. The manufacturing group of the supplier can work with the customer's design engineers in order to have a better understanding of product specifications. This may lead to recommendations relative to specification changes that allow product cost reductions. The quality assurance personnel of the customer may work directly with the supplier's manufacturing people to assist in quality

problem solving, as well as to assist in product certification. Traffic departments may work jointly to assure a smooth flow of purchased products.

Some manufacturing operations are such that the decision may be one of “make or buy”. Conditions that may call for “make” (manufacturing in-house) decisions are:

1. You have a proprietary process.
2. Direct control over quality is required.
3. You can produce at less cost.
4. In-house manufacturing will absorb overhead.
5. You wish to protect your employment base.

Conditions that support the purchasing of items (an extension of your manufacturing) are:

1. It costs less to purchase.
2. Suppliers have unique processes or patents.
3. You lack the capital or expertise to produce the item.
4. Small volume does not justify in-house manufacture.

In the decision making process, a comparison of standard manufacturing costs with the costs to purchase may show a lower purchase price. A point to consider is that the standard cost includes fixed overhead, which will remain even if the product is purchased. This situation is addressed in condition # 4 (overhead absorption) in a manufacturing in-house decision. If the decision is to buy, there should be an understanding and plan relating to the excess capacity that has been created. Although this consideration is necessary, care is to be taken not to end up with inefficient manufacturing operations that do nothing more than absorb overhead.

SUPPLIER RELATIONSHIPS

The major responsibility of purchasing is selecting and maintaining reliable suppliers. In some situations, the task may include the developing of suppliers to meet the expectations of the customer. Evaluation

considerations in supplier source selection are quality, delivery, cost, and service.

In the quality evaluation, factors to review are:

- Is the supplier's record one of leadership and integrity?
- What quality control system is in place?
- Is the product consistently within specifications?

Delivery considerations for review are:

- Can the supplier ensure on-time delivery?
- Is the supplier flexible with regard to changing requirements?
- Can the supplier maintain a steady flow of material?

Cost factors to be determined are:

- Is the cost of the product reasonable and stable?
- Is the supplier's financial position stable?
- Is the supplier open to negotiations?

Service considerations are:

- Are there good lines of communication with the supplier?
- How does the supplier handle rejected material?
- Will the supplier assist in product development?
- Can the supplier provide training and education if needed?

The supplier selection process is most critical when the choice is going to be a single-source supplier. Some companies may consider their suppliers as single-source, but they still maintain backup suppliers.

Although the approach is one of a partnership between customers and suppliers rather than an adversarial one, the nature of the relationship may have some areas of stress and conflict. Sometimes the problem may be due to personalities of the buyer or salesperson. The buyer may give lip service

to the salesperson, but still deals in an adversarial mode in order to show his or her power or knowledge. The salesperson may only be interested in getting the order with little or no interest in supplying service to the customer. The only solution to these conflicts, assuming that the continuation of business is beneficial to both sides, may require intervention at the next level of the organisation(s).

Another area of conflict may be because both customer and buyer organizations have goals that are in conflict. The buyer's goal is to reduce inventory levels through ordering in smaller lot sizes, while the supplier wants to produce and ship in manufacturing economical lot sizes. The supplier may wish for a long-term contract while the customer does not want a long-term commitment. The customer wishes for short lead times while the supplier can more easily level the production schedule with the flexibility of longer delivery lead times. These conflicts are best resolved by an understanding of the other parties goals and working together for a solution that is agreeable to both. The lot size problem stated above might be resolved by both parties working together to reduce the supplier's set-up time.

The price of the product should be the deciding factor in a purchasing decision only when the product's quality and timely delivery factors have been determined to be at satisfactory levels. The price is subject to a number of conflicting factors other than quality and delivery. The buyer wants the lowest price; the supplier wishes to maximize profits. The buyer wishes to minimize inventory, while the supplier wants longer production runs. The supplier may get longer production runs by offering volume discounts. The buyer achieves the lower selling price at the expense of increased inventory while the supplier gets the longer production run at the expense of reduced revenue.

Some suppliers may base their selling price on their costs, but in a competitive environment, the price is usually based on market conditions. Lacking competition, the supplier may charge what the market will bear. When there are multiple, capable suppliers available, the price will usually be determined by the price of the low bidder. The low bid may be because the supplier has the most efficient operation, the supplier wishes to "get his foot in the door", or the supplier has no idea what his costs are.

An established price can be subject to change over time. Inflationary pressures may cause the price to increase while technical changes and/or the learning curve will allow a price decrease.

Pricing is often determined by a negotiation process that was the result of both buyer's and supplier's involvement. Both parties should go into negotiations having defined objectives, having a strategic plan, and being prepared with critical facts and details. Many offshore suppliers consider negotiations an important part of the process and seem to enjoy the exercise.

They may start the process with a higher selling price than they expect to get and expect the buyer to come in low. Negotiations may involve things other than price, such as packaging, traffic routes, and rejected products.

PERFORMANCE MEASUREMENTS

The three major measurements of a supplier performance, relate to quality, delivery, and cost. Quality measurements can be based on comparing rejected lots to total lots received. A rejected lot will not only score poorly in quality, but chances are it will also cause a late delivery. In many operations, there may be individual pieces rejected from an accepted lot. In this situation, the measurement will relate defective parts to parts received. The total quality performance measurement of a supplier should be a calculation based on the sum of the performance of all items received from that supplier.

Delivery performance must start with a definition of what is considered on-time. Just as quality specifications are based on tolerances such as three standard deviations, delivery tolerances are necessary for proper on-time measurements. Delivering two days ahead or one day after the specified due date might be considered within tolerance and considered on-time. Just-in-time deliveries may be measured by the hour rather than in daily increments. In some situations, the validity of the due date should be considered. The due date is obviously valid if it is based upon a mutually agreed upon lead time. Sometimes an order has a due date based on customer need, but not in line with the standard lead time. If the order is late, the question should be "did the supplier agree to the reduced lead time"? If not, there should be no penalty in the performance measurement. A decision will be required as to the treatment of a partial order that is delivered on-time.

A second delivery performance measurement may be based not on how many orders are late, but on how late they are. Safety stock or schedule adjustments may minimize the harm of an order that is four days late, but the order that is four weeks late, can cause many major problems. The measuring of late delivery duration may be more critical than instances of late delivery. In the calculation of delivery performance, the decision must be made to either relate late orders to total orders, or to relate late units to total units received.

Lead time reduction programs can be considered part of delivery performance measurement. The number of items that have shortened lead times can be measured and compared to total items purchased. A second lead time reduction measurement can be based on the percentage reduction in lead time.

The most utilized cost measurement is comparing the standard cost of an item to its' purchase (selling) price. The standard cost is normally

established at the beginning of the year and is based on what the expected selling price will be. As the year progresses, inflationary pressures may cause an increase in the selling price. The total cost variance is more important than the individual percent of unfavourable variances. A 2% variance on an item with \$200,000 annual usage is \$4000 and is more meaningful than a 8% variance on an item with \$10,000 usage and, therefore, with a variance of \$800.

Related cost measurements can be the comparison of actual cost savings compared to the goals of cost reduction programs. Similar measurement can be made by comparing freight cost savings with anticipated freight cost reductions.

Performance measurements should not be designed to punish the supplier, but to provide feedback to the supplier and to gauge the effectiveness of the purchasing operation. The measurements should be designed to meet the specific needs of the company.

CASE STUDY SMITH INDUSTRIES INC.

1. The Jones Electronic Company supplied three electronic modules to Smith Industries. In an effort to increase their manufacturing lot sizes, Jones offered a 2% quantity discount on all three items with the understanding that Smith could accept the discount on an item by item basis. The discount and relevant data on each module was as follows:

Module 4692

Annual usage	= 7200 units
Present lot size	= 900 units
Present selling price	= \$4.00
Proposed lot size	= 1200 units
Proposed selling price	= \$3.92

Module 5734

Annual usage	= 4000 units
Present lot size	= 500 units
Present selling price	= \$6.00
Proposed lot size	= 4000 units
Proposed selling price	= \$5.88

Module 6872

Annual usage	= 8000 units
Present lot size	= 700 units
Present selling price	= \$7.00
Proposed lot size	= 2600 units
Proposed selling price	= \$6.86

Smith Industries made the decision to evaluate each proposal based on an inventory carrying charge of 24% and a purchase order cost of \$50.00.

2. One of the more successful lines of patio furniture that Smith Industries marketed was a custom line manufactured by the Apex Speciality Furniture Company. The furniture was top of the line, quite expensive, and equally profitable for Smith Industries. The material for the cast aluminium framework was standard, but the fabric choice, which would be picked out by the customer, was extensive. Each furniture set was made to customer order. Every aspect of the product was well received by the public except for the availability date, which had to be quoted at four months - Apex Speciality's lead time. This lead time problem was thought to have limited the sales by about 50%.

Consideration was given to stocking the product, but due to the wide scope of fabrics, this was not considered a practical solution. Smith Industries would have to work with the supplier, Apex Speciality Furniture, to come up with a solution that would be beneficial to both parties.

CASE STUDY - SUGGESTED SOLUTION

1. The calculations of each module's 2% quantity discount was based on total cost and showed the following:

Total Cost = Carrying Cost + Ordering Cost + Annual Item Cost

Module 4692

$$\begin{aligned}
 \text{Existing cost} &= (900/2)(\$4.00)(.24) + (7200/900)(\$50) + (7200)(\$4.00) \\
 &= \$432 + \$400 + \$28,800 \\
 &= \$29,632
 \end{aligned}$$

With 2% discount

$$\begin{aligned}
 &= (1200/2)(\$3.92)(.24) + ((7200/1200)(\$50) + (7200)(\$3.92) \\
 &= \$564 + \$300 + \$28,224 \\
 &= \$29,088
 \end{aligned}$$

Based on the calculation, take the discount.

Module 5734

$$\begin{aligned}\text{Existing cost} &= (500/2)(\$6.00)(.24) + (4000/500)(\$50) + (4000)(\$6.00) \\ &= \$360 + \$400 + \$24,000 \\ &= \$24,760\end{aligned}$$

$$\begin{aligned}\text{With 2\% discount} &= (4000/2)(\$5.88)(.24) + (4000/4000)(\$50) + (4000)(\$5.88) \\ &= \$2,822 + \$50 + \$23,520 \\ &= \$26,392\end{aligned}$$

Based on this calculation, do not take the discount.

Module 6872

$$\begin{aligned}\text{Existing cost} &= (700/2)(\$7.00)(.24) + (8000/700)(\$50) + (8000)(\$7.00) \\ &= \$588 + \$571 + \$ 56,000 \\ &= \$57,159\end{aligned}$$

$$\begin{aligned}\text{With 2\% discount} &= (2600/2)(\$6.86)(.24) + (8000/2600)(\$50) + (8000)(\$6.86) \\ &= \$2,140 + \$154 + \$54,880 \\ &= \$57,174\end{aligned}$$

The two choices are a trade-off. It was decided to stay with the smaller lot size.

2. Smith Industries' personnel reviewed the four month lead time with Apex Speciality Furniture's operating people. The lead time was based on a critical path of 17 weeks. The detailed breakdown was as follows:

Order receipt and preparation	1 week
Placing order for fabric	1 week
Fabric delivery	11 weeks
Subassemble frame and sew fabric	1 week
Assemble furniture set	1 week
Pack, ship, and in-transit time to customer	2 weeks
Total lead time	17 weeks

The cast aluminium frame raw material was a stocked item at Apex Speciality Furniture.

An analysis of the 80 fabrics offered for customer choice, indicated that 14 were chosen 80 % of the time. If the fabric was a stocked item, like the cast aluminium, the leadtime could be reduced to the following:

Order receipt and preparation	1 week
Frame fabrication	1 week
Subassemble frame and sew fabric	1 week
Assemble furniture set	1 week
Pack, ship, and in-transit time to customer	2 weeks
Total lead time	6 weeks

After reviewing the fabric choice history, Apex Speciality agreed to stock the 14 most popular fabrics and to reduce the lead time on the affected furniture sets to 6 weeks. Smith Industries, in turn, agreed to accept responsibility for any fabric stock that would be adversely affected by the discontinuation of a furniture model. Furniture calling for the remaining 66 fabric choices continued to be quoted with four months' delivery. These choices, which had been 20% of the demand, dropped to less than 10% when the customers were given the choice of much faster delivery with the more popular items.

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Chapter 12

MANUFACTURING MANAGEMENT

JOB SHOP MANUFACTURING

A job shop is defined as a group of manufacturing operations where the productive resources are organized according to function and the work passes through in varying lots and routings. The manufactured end item is normally assembled from two or more components which have been fabricated and/or purchased. As reflected in the product structure, each assembly or subassembly is put together with fabricated or purchased components and each fabricated component is made from a purchased raw material. Job shop execution may also apply when the end items are single units rather than assembled. The execution of the manufacturing plan requires the successful operation of the assembly, fabrication, and purchasing functions.

The execution of fabrication operations in the job shop is normally based on recommended manufacturing orders (usually generated by an MRP system). In some situations, the fabrication requirements are generated by the actual rather than anticipated needs of the system. This is called the “pull” approach as compared to the “push” of the manufacturing (MRP) system and is a concept of Just-In-Time manufacturing. The goals of the scheduling system are:

1. Complete fabrication by due date with
2. Minimum lead time and
3. Maximum machine utilization.

Lead time and machine utilization goals conflict when, due to random fluctuations of work arriving at the work centers, favorable machine utilization is achieved through large queue allowances. The large queue

allowance increases the lead time, which in turn, increases work-in-process. With infinite loading systems, capacity has been addressed with a capacity requirements planning (CRP) review of the manufacturing plan, but this is no guarantee that the work load schedule for a given period will match the capacity of the machine or work center especially on a daily or hourly basis. Problems can result with too many jobs scheduled and available at the same time. Another problem can be when the scheduled work matches the capacity, but is not available due to problems with previous operations. The operation-by-operation schedule is based on the manufacturing order due date requirements, the planned setup and run times, and the queue, move, and wait allowances of the system. Backward scheduling calculates the start and due dates for each operation by starting with the order due date and computing backward. Forward scheduling starts with the order release date and computes each operation's start and due dates from the first to last operation.

Scheduling fabrication operations in a job shop with finite loading techniques differs from infinite loading, in that capacity is addressed and that the system will not allow the work load to exceed capacity. Real-time forward finite loading may not only consider the capacity of the work center but also the availability of the shop order, manpower and tooling. The system will monitor the data and then it will load based on predetermined priority rules. While infinite loading is compatible with MRP requirements, it may not be realistic. Finite loading may be realistic but it may not be realistic with MRP requirements. Another problem with finite loading to a given capacity, is the assumption that other actions such as overtime, added manpower, or alternate routings are not alternatives.

Operation sequencing is a simulation approach in which the initial calculation generates a short-term plan at each work center based on finite scheduling priorities. These plans are then projected to show completion times and simulated queues. The simulation continues by moving the job to the next work center and then the second day's run is simulated. Simulation can predict both potential overloaded and idle work centers and therefore assist the planner in making priority adjustments to short-term plans prior to the extension of the real-time schedule.

Whether employing finite or infinite loading techniques, rules of prioritizing orders must be established. Common priority rules are as follows:

1. Due date control is based on either earliest operation due date or start date. If all work is available as scheduled and there are no capacity problems at the work center, this is the rule of choice.

2. Schedule the job in order of least total slack time remaining. Slack time is determined by subtracting the remaining setup and run times from the time remaining to due date completion. Order A and Order B are both due in 8 days. Order A has 2 days of setup and run time remaining and, therefore, 6 days of slack time. Order B has 5 days of setup and run time remaining and only 3 days of slack time. Order B should be scheduled first.
3. Schedule the jobs with the shortest processing times first. This rule will cause lower work-in-process (WIP) but is only valid when all jobs are running late. It should not be used if it does not consider due dates.
4. Schedule the job with the lowest critical ratio. The critical ratio is the order time remaining to due date completion divided by the manufacturing lead time remaining to completion. Manufacturing lead time includes queue, wait, and move allowances. The job due in 6 days, but with only 4 scheduled days remaining, has a critical ratio of 1.5 and is running ahead of schedule. A job with 5 days remaining for both completion and scheduled time has a critical ratio of 1.0 and is on time. A job with 7 days of scheduled work, but is due in 5 days, has a critical ratio of 0.7 and is running late. The priority of the three jobs should be:
 1. Critical ratio 0.7
 2. Critical ratio 1.0
 3. Critical ratio 1.5

If all jobs to be scheduled have critical ratios of less than 1.0, the plant is in trouble.

Judgement is required in the execution of the priority system. There is no point in running a job first, no matter what the priority rule, if it is going to sit in queue for 2 weeks at the next operation. The only reason to run the job would be if there were no other jobs available to schedule.

PROCESS MANUFACTURING

Process manufacturing is best understood by defining the nature of the material routing and the related manufacturing activities. Where job shop manufacturing involves differing material flow routes through functional departments, process manufacturing has the characteristic of fixed routings. Both process and repetitive manufacturing have fixed routing characteristics, but they have other differences. Process manufacturing adds value to few materials and produces end items through mixing, forming, and separating operations, while repetitive manufacturing consists of fabrication and assembly operations. Examples of job shop, process, and repetitive manufacturing products are shown as follows:

1. Job shop products	Make-to-order machine tools Low volume generators
2. Processed products	Plastic strap Paint
3. Repetitive products	Automobiles Television sets

Process manufacturing is characterized by shallow bills of material as well as fixed routings. There are differing characteristics within process manufacturing in that some products will be made in a continuous flow, which in turn, will allow small work-in-process (WIP) inventories and short lead times. Other products will be produced in batches and may be subject to lot size considerations. Dependence on setup considerations for specific operations in the process routing may call for maintaining inventories at differing stages of the process and will result in larger WIP inventories while still being produced in a relatively short lead time.

Continuous process scheduling will be capacity driven with the only material consideration being raw material and with no shop floor or priority control required. Scheduling considerations for batch process manufacturing does require additional planning and control. Maintenance planning is especially important with continuous processing, as a breakdown will immediately shut down the entire line. The operation planning function may or may not be material requirements planning (MRP) or master production schedule (MPS) generated. Various scheduling approaches may be utilized in process manufacturing.

Continuous processing manufacturing with fixed routings, shallow bills of material, and short lead times, does not require the time-phased dependent demand logic of MRP for scheduling and WIP control. When material control is maintained with a separate system, the MPS is utilized for shop scheduling. With fixed routings there is little flexibility, especially with continuous-flow operations and, therefore, detailed capacity planning is necessary. The system can be controlled by a capacity-driven master production schedule. The MPS planning horizon may be dependent on raw material procurement lead times. It may be even greater if planning for seasonal finished goods. Often the demand during the high season of a product is greater than production capacity and, therefore, finished goods inventory buildups must be planned in the off season. With short manufacturing lead times, the firm part of the MPS is similar to the final assembly schedule in job shop manufacturing, in that the schedule is fixed. However, in process manufacturing, part shortages are not a problem.

Machine breakdowns and quality issues are process manufacturing's major problems. In make-to-order environments, MPS demand is order entry-driven and tends to be fixed based on delivery promises. In a make-to-stock situation, the MPS initial demand will be forecast-driven, but may call for continuous adjustments due to actual demand placed on the distribution system.

In continuous processing when MRP is not required (except for procurement of raw materials), the MPS will generate production orders, set priorities, and control a dispatch list. With relatively few products to be scheduled, these systems may be manual rather than computerized.

When there are finished goods calling for a high degree of raw material commonality, or raw material with long procurement lead times, MRP systems can be useful in purchasing management. When process manufacturing is in a batch mode with four or more bill of material levels, longer manufacturing lead times, routing variations or work center dependent lot sizes, planning and scheduling complications can be similar to those of job shop environments and then MRP logic is needed.

When an MRP system is used only for raw material control, it may be driven by a formal MPS system or a production plan. The production plan is less detailed than the MPS, but will supply adequate data for purchasing control. The more detailed information normally found in the MPS will be supplied through specific production orders when scheduled within the manufacturing lead times. The production orders will be based on customer orders or stocking requirements. The MRP system of raw material control will call for bill of material and inventory file data and be based on conventional time phased gross-to-net logic.

When the manufacturing process consists of multiple operations with the operations having different setup times and running speeds, batch control and WIP inventory levels are needed. For example, operation 1 might have a setup time of 4 hours and a running rate of 10,000 units per hour, while operation 2 has a setup time of 10 minutes and a running rate of 500 units per hour. The process, in this example, requires an additional bill of material level, increased WIP inventory, and a more complicated planning system (MRP). Although the process runs contrary to the concept of continuous flow, the nature of the manufacturing system makes it necessary for meeting customer requirements and machine utilization.

In continuous process manufacturing, the scheduling priorities are established at the production planning or MPS level with little, if any, shop floor control. The production order is released to the predetermined process line based on previous capacity and material availability checks. The scheduling considerations for both continuous or semicontinuous (batch) processes are as follows:

1. Prioritizing to meet customer order or MPS requirements.
2. Line balancing.
3. Operation efficiency.
4. Minimizing major setups through family groupings.
5. Time-critical products such as aging, fermentation, or baking reaction times.

In semicontinuous process scheduling, the priority considerations and goals are similar to continuous processing, but are more complicated and difficult to achieve. More detailed planning and shop floor control systems are required. There may be combination production lines with common processes rather than dedicated flow lines. One work center may feed a number of work centers, each with differing operations. Each work center or operation may require a specific schedule based on MRP planning and prioritized with finite scheduling procedures similar to those used in job shop environments.

Process flow scheduling (PFS) is an alternative to MRP. With PFS, the scheduling calculation is guided by the process structure rather than the bill of material. Greater emphasis is placed on process run rates and resources rather than the product structure and routing. The planning process is driven by a production plan rather than the MPS and can be applied to both continuous process manufacturing as well as semicontinuous (batch) manufacturing.

The continuous process system is based on scheduling the entire process as a single unit. Finite forward scheduling is utilized to meet the desired requirements of the production plan. Semicontinuous batch processing is managed with operation-by-operation scheduling. As with process scheduling, the system is production plan driven toward finished product inventory levels. The planning process may start with the desired inventory level, and then schedule each operation based on reverse flow or by forward flow starting with raw material. Each operation will be finite scheduled to meet planned inventory levels before moving onto the next (forward) operation. Lot sizes and run times will be based on the specific process technology. The planned inventory level may be based on lot sizes, curing times, or differing run rates. A bottleneck operation in the middle of the process may call for reverse flow scheduling to the bottleneck and forward flow scheduling after the bottleneck.

REPETITIVE MANUFACTURING

Repetitive manufacturing is the repeated production of the same discrete products or family of products. It embraces the Just-In-Time (JIT) philosophy of lean manufacturing with the goal of elimination of all waste through continuous improvement.

The basic strategy is to make the material flow in repetitive manufacturing operations as it flows in continuous process manufacturing. One of the challenges to achieving product flow is to convert job shop manufacturing into repetitive manufacturing or at least to adopt repetitive manufacturing features. The nature of some make-to-stock environments, such as television manufacturing, call for repetitive production, while make-to-order or assemble-to-order environments call for nonrepetitive production at least at the end item level. Examination of the product structure of nonrepetitive end items may indicate repetitive potential at the modular, subassembly, or option levels. Also to be considered, is the degree of commonality of components within the total product line. If the existing product structures show no repetitive features, efforts can be made to simplify existing products as well as considering repetitive demand potential in new product design. An additional consideration should be the grouping (families) of end items or components based on similarity of manufacturing processes. Family scheduling allows a higher degree of repetitive production.

To plan for process flow, an initial requirement is a level schedule at the production planning or MPS level. The level schedule is the first step in achieving balanced manufacturing for the entire operation. The level schedule, planned over a horizon of 6 months to a year, is implemented through a final assembly or end item schedule which is responding to actual demand. Although planning may be in weeks or months for raw material and component control, a flexible end item schedule should be controlled on a daily basis. Because customer orders do not arrive in even daily requirements, the system must allow for a level final assembly schedule to meet the demands of the marketplace which are not level. In a make-to-stock environment, an uneven customer demand can be met through the stocking of finished goods. In make or assemble-to-order environments, there are no finished goods inventories to compensate for unlevel demands. End item scheduling will be based on order backlogs rather than planned inventory levels. The larger the backlog, the more orders available to level the schedule with a favorable product mix. The negative feature of a large backlog is that the larger the backlog, the longer the lead time to the customer.

Design simplification is based on the assumption that a simple design is easier to produce because fewer the items to produce, the less complications

with which to deal. Modular designs not only assist in forecasting and master scheduling, but also in reducing manufacturing complexities through standardized process routing of the modules. Various combinations of modules will allow for a relatively large number of end products but with reduced total manufacturing processes. When the process has been simplified, the levels in the product structure can be reduced. Including the subassembly operation into the assembly operation will not only assist in process flow, but will eliminate an inventory level and the required transactions.

JIT philosophy does not accept setups as fixed and is based on setup reduction processes. Product flow requires small lot sizes and small lot sizes require small setup times. The formal setup reduction process is based on group or team involvement, with the team consisting of shop floor people with operators playing an important role. The first step is to analyze the existing process to determine if the setup is really required or if it can be eliminated through product grouping or process simplification. If the setup cannot be eliminated, the details of the machine, the tooling, the material, and the existing routines can be best captured by videotaping the entire operation.

The second step is to identify which setup activities are internal and which are external to the operation. An external activity is one which can be performed while the machine is running. An example of an external activity would be bringing the next tool or die to the workplace and preparing it in advance. An internal activity is one which can only be accomplished when the machine is stopped. Attaching a tool to a machine is an example of an internal activity. Once identified, the setup procedure should be reviewed to assure that the machine is running while external activities are taking place. The third step of the process is the reexamination of internal activities to assure that they were properly identified and to then attempt to convert them to an external activity. The preheating of the die for plastic molding is an example of an activity that might have been originally heated as an internal activity, but then converted to external by preheating. The final step is the improving of both internal and external activities of the setup. An example of this is the use of shims or blocks in die setting to standardize the height and eliminate adjustment time.

To achieve material flow in a manufacturing operation, attention must be paid to the physical aspects of production including plant layout, housekeeping, and visibility control features. Flow patterns consistent with JIT methods are accomplished with cellular manufacturing which produces parts or families of parts in a single line of machines. This approach is based on product flow rather than the functional groupings that are used in job shops. Cellular manufacturing requires the grouping of parts based not on their design but on process similarities, that is, routings that follow similar

paths. Other requirements for cellular manufacturing are short setup times, a level of volume that allows daily operation, and multifunctional workers and supervisors. The output of the work cell is based on the number of assigned operators rather than machines. If the planned output is reduced, there will be fewer operators who will be required to run more operations, thus the multifunctional requirement. The flow advantages of cellular manufacturing are reduced lead times due to small lot sizes and reduced (or no) queues between operations.

Material flow is achieved through synchronizing each operation to the next operation. Synchronizing of operations requires a level balanced repetitive work load and a facility that is organized for flow. The rate of flow is based on cycle time analysis. The cycle time is the time between two discrete units of production. For example, if an item is produced at the rate of 90 per hour, the cycle time of the item would be 40 seconds. The production cycle time of the feeding operation should relate to the cycle time of need of the next operation.

The pull system in a JIT repetitive environment has two functions which are:

1. Bringing the material to the using operation when it is called for and
2. Authorizing the replacement of the material.

There are a variety of systems used for controlling the material flow and replacement. When there are a number of work centers and moves required, a two-card system is used. The production card authorizes material replacement when it is removed from the container and replaced with a move card. After completing production (the replacement material), the production card will be attached to the new container. The move card authorizes a move when it has been removed from the container at the using location and replaces a production card at the supplying location. If the using location is adjacent to the supplying work center, a one-card system will work. An empty space in the designated outbound location is the authorization to replace an empty container with the required parts. The information normally found on the production card will be posted at the work center. The now full container will remain in the outbound location until moved via a move card generated by the inbound (using) work center.

Containers will serve as pull signals in less complicated flow operations. The container will be marked with a part number and specified quantity. When emptied by the using work center, it is returned for replacement at the supplying work center. Kanban squares will also serve as pull signals. There will be a designated space marked for specific materials. When that space is open, that is the authorization to replace the material. The two-bin system,

which is older than JIT, can also be considered a pull system. When the first bin is emptied, that is the signal to replace a given quantity.

SYSTEM REQUIREMENTS

There are three basic planning steps required for a manufacturing operation, no matter the size or nature of the process. The degree of formality and sophistication will depend on the details of the system requirements. The first step is the determination of a manufacturing plan. The manufacturing plan will be based on anticipated or actual customer demand and the required inventory to meet that demand. The second planning step is to ascertain the material and capacity requirements to meet the manufacturing plan. The third planning step will call for the purchasing of necessary material and execution of the manufacturing plan.

The determination of a manufacturing plan will require systems (or methods) to:

1. Forecast customer demand in a make-to-stock or an assemble-to-order environment. In a make-to-order environment, a forecast of raw material is often needed.
2. Establish an overall production plan which calculates the overall production level required to meet demand. If the number of end items is small and the process uncomplicated, the production plan will be the driving force for the second planning step. An example of the production plan driving the system would be a paint manufacturing process operation, where the plan would be based on the best color sequence.
3. Calculate and control a master production schedule. The MPS is required when there are a number of end items or modules to control. It must take into account the demand, the production plan, inventory levels, and production capacity. In job shop and repetitive manufacturing, the MPS will drive the MRP system. In some process manufacturing operations, the MPS may directly drive the execution system by the releasing of production orders.

Systems required for the second step, material and capacity planning, range from the detailed manufacturing resource planning (MRP II) systems to the simplicity of a two-bin system.

Job shop manufacturing with a large number of end items will require the MRP II to validate capacity and plan materials. The material will be controlled by the material requirements planning system (MRP) and capacity will be planned and measured with capacity requirements planning

(CRP). These systems require detailed item master records, inventory files, product bills of material, product routing and work center files.

Repetitive manufacturing requires planning systems similar to those used by job shops, with the exception of the feature of releasing orders. Output is planned by production rate rather than work order lot sizes. In a pure flow-through JIT operation, there will be no or very small lead time offsets. When manufacturing is lot-for-lot, gross to net calculations will not be needed. Both material and capacity planning are required just as they are in job shop manufacturing.

Continuous process manufacturing may bypass MRP systems and let the MPS or the production plan control the production schedule. When this approach is taken, raw material is planned and controlled through a simplified subsystem such as a reorder point or time-phased order point (TPOP) system. Semicontinuous process manufacturing, where batch WIP is maintained, will require the logic found in MRP systems. Process flow scheduling (PFS) is a system for planning usage and material requirements based on the process structure for scheduling calculations.

The third planning step calls for systems that will execute the plan. In job shop manufacturing, work orders are scheduled and controlled by the CRP system. Scheduling may be based on infinite or finite loading. Infinite scheduling assumes that the capacity is available at the work center. This assumption is based on a previously calculated work-load analysis. Finite scheduling is a technique that will not allow work to be loaded beyond the stated capacity of the work center. In both infinite and finite scheduling, the prioritizing of work is based on predetermined rules. Continuous monitoring of operations is accomplished with an input-output measuring and control system. The actual input of work is compared to the planned input projected by the CRP system and the actual output of work is compared to the planned output. The goal of input-output monitoring is to control the queue of work-in-process consistent with the plan. Purchased raw materials and components are managed through a purchasing subsystem. The goal of purchase order control is to maintain valid due dates through MRP system feedback and supplier communication.

The only operation scheduled in repetitive JIT manufacturing, is final assembly, with all other material requirements being pulled through the process by manual signal controls. The JIT goal is to simplify execution systems. There are a variety of manual systems such as cards, containers, or location spaces. The two functions of a pull system are to:

- Bring the material to the using operation when it is needed.
- Authorize the replacement of the material.

With continuous process manufacturing, the process will be scheduled with a single shop order. Shop floor data collection will be for quality and cost control purposes rather than WIP planning and control. In semicontinuous (batch) process scheduling, more detailed shop-floor control systems are required. Each work center or operation may require a specific schedule or dispatch list similar to those used in job shop environments. Lead time measurements for continuous processing will be in minutes or hours compared to days for batch operations.

CASE STUDY SMITH INDUSTRIES INC.

1. The most popular and growing line of patio furniture marketed by Smith Industries was manufactured by the Maplewood Furniture Company. In June, 1998, Maplewood reported to Smith Industries that they would have a capacity problem meeting Smith Industries' 1999 forecast of 3300 patio furniture sets, unless production could be spaced over a 12 month period. Their capacity was approximately 300 sets per month or 3600 sets per year. The problem was that Smith's requirements for 1999 delivery would not start until March, 1999, leaving a void in Maplewood's production schedule for the last four months of 1998. They requested an advanced order from Smith Industries that would allow for a level production schedule by planning a product build up. They would be willing to carry the stock build-up as long as Smith Industries would agree to take delivery during the selling season.

Smith Industries had to determine what would be a reasonable advanced order build-up commitment that would allow Maplewood furniture to produce at a level rate from September, 1998, through August, 1999. The forecasted selling rate for 1999 was:

March	300 sets
April	500 sets
May	700 sets
June	800 sets
July	700 sets
August	<u>300</u> sets
Total	3300 sets

2. By 1998, due to the growth of grill manufacturing operations, module availability at assembly had become a major problem. The grill bases and stands were not a problem, but the heating unit modules were often behind

schedule. The bases and stands did not consist of many components but the heating units had an average of 12 components per module. An analysis of the system indicated that master scheduling, material planning, and capacity planning all conformed to proper planning standards. It was decided that shop operations, in spite of input-output control, had grown too large and too complicated to control with existing systems. Subassembly of the six modules was plagued by component shortages. The six heating unit modules and their number of components were:

Module	Components
Gas line fed	12
Gas-propane tank fed	16
Infrared-propane tank fed	18
Electric	10
Charcoal	7
Charcoal with gas starter	11

The service level of individual module components was 98%, but with an average of 12 components per module, assembly orders would only be pulled complete 78% of the time (.98 to the 12th power).

CASE STUDY - SUGGESTED SOLUTION

1. Maplewood's annual capacity of 3600 (300/month) furniture sets was compared to the 1999 sales forecast of 3300 sets. Smith Industries calculated a possible production plan by forward scheduling a level monthly output of 275 sets per month starting in September, 1998. The results were as follows:

<u>Month</u>	<u>Production</u>	<u>Demand</u>	<u>Inventory</u>
September, 98	275	—	275
October	275	—	550
November	275	—	825
December	275	—	1100
January, 99	275	—	1375
February	275	—	1650
March	275	300	1625
April	275	500	1400
May	275	700	975
June	275	800	450
July	275	700	25
August	275	300	0

To minimize the build-up, which under the above plan would reach 1650 sets, Smith Industries adjusted the plan to reduce the build-up, while allowing additional capacity in June and July to allow for sales greater than forecast in those months. The adjusted plan, shown below, was accepted by Maplewood Furniture.

<u>Month</u>	<u>Production</u>	<u>Demand</u>	<u>Inventory</u>
September, 98	250	—	250
October	250	—	500
November	250	—	750
December	250	—	1000
January, 99	250	—	1250
February	300	—	1550
March	300	300	1550
April	300	500	1350
May	300	700	950
June	275	800	425
July	275	700	0
August	300	300	0

2. In order to improve production efficiency, the decision was made to eliminate the functional manufacturing departments and rearrange the plant layout to produce the heating units with cellular manufacturing processes. The heating modules which were controlled by the master production schedule, had relatively level and repetitive demands which were required for cellular manufacturing. Setup reduction programs had been underway for two years and consequently, reduced lot sizes, another cellular requirement, were already in place.

When detailed planning for the separate cells was underway, a major problem was encountered. The additional machine tools, required for the cells, were costly and the calculated utilization of these machine tools was very low. The problem was solved by grouping the modules, based on their commonality of components, and, thereby, reducing the number of cells from 6 to 3. The heating unit cells laid out by family groups were:

Cell A	Gas line fed and Gas-propane tank fed.
Cell B	Infrared-propane tank fed and electric.
Cell C	Charcoal and Charcoal with gas starter.

Repetitive flow manufacturing and schedule reliability was achieved with the new layout. Material to the cells was based on pull requirements,

using containers as the pull mechanisms. Material flow within the cells was based on visibility of movement. An extensive training program for the workers was undertaken to train them to be flexible, a requirement for product flow through the cells.

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Chapter 13

SUPPLY CHAIN MANAGEMENT

THE SUPPLY CHAIN

The supply chain is the processes from raw material to the ultimate consumption of the finished product linking across supplier-user companies. Production and inventory management must be synchronized from end to end across the entire supply chain. This synchronization will require engineered and controlled flow of information. The product will flow from raw material to the end use customer, but the information will flow from customer back to raw material. Examples of reverse information flow are inventory relief and customer demand.

The supply chain is defined by the distribution network structure which is described in chapter 9 (Distribution Management). The trading partner interactions within the supply chain are examined in chapters 10 (Distribution Resource Planning), 11 (Purchasing Management), and 12 (Manufacturing Management).

The simplest form of a direct supply chain would be a roadside Christmas tree stand. The seed that started the tree could be considered the raw material, the field would be the factory manufacturing the trees, and the stand would be the retail outlet supplying the trees to the end users. The advantages of this supply chain would be:

1. Low manufacturing and material costs.
2. Synchronized supply chain flow.
3. Little, if any, distribution costs.
4. Direct customer relationships.

The disadvantages of this supply chain would be:

1. Long cycle time (seed to sold tree).
2. High work in process and resultant large inventory investment.
3. Limited customer base.

Extending the above supply chain by marketing the trees through other retailers, such as grocery stores or gas stations, would increase tree sales. The selling price per tree to the manufacturer (the farmer) would be reduced and there would be increased freight costs.

An example of a more complex supply chain would be the manufacturing and marketing of an automobile. A large number of suppliers are required for the procurement of both the raw materials and components. The fabrication and assembly processes are extensive and complicated. The finished product (the automobile) is sold to an automobile dealer, who in turn sells it to the end user. Choices must be made from the beginning of the supply chain to the dealer's showroom. There must be make-or-buy (outsourcing) decisions for the sourcing of components. General Motors manufactures 70% of its components, Ford 50%, and Chrysler 30%. General Motors is in the process of reducing its share of component manufacturing by "spinning off" fabrication operations into separate companies. There are cost advantages to outsourcing, but there is also a loss of control. Automobile companies have multiple manufacturing locations in order to specialize in individual model assembly operations, to take advantage of available labor skills, and to reduce freight costs. An example is the Ford Taurus, which is manufactured in both Chicago and Atlanta.

Automobile procurement policies require choices of single, sole, or multi-source suppliers. The advantage of multiple suppliers is that the manufacturer is not dependent on one supplier. However, efforts to improve product flow through the supply chain are much more difficult with multiple suppliers.

Automobile sales are, for the most part, accomplished through independent dealerships. The advantage to the manufacturer is a much greater marketing scope as well as less finished goods to maintain. In the past 20 years there are more dealers carrying competing automotive products while at the same time there has been a substantial decrease in the number of dealerships. The remaining dealers tend to have much larger operations. The automobile manufacturers are well aware that their images are based on customer expectations of not only quality but also service. There is increased manufacturers' involvement in dealer/customer relations. Activities not only include advertising, but also such things as warranties and Internet customer assistance. Factory rebates are offered to stimulate sales and to assist in synchronized product flow.

A third example of a supply chain is that of a computer manufacturing operation which is based on purchasing all components, assembling the computers, and distributing them through independent retailers. The computers are produced to forecast and are stored in company owned warehouses in order to be available to the retail outlets. The retailers, in turn, will purchase the computers based on anticipated customer sales. The total cycle time of the product starts with the supplier lead times, is followed with assembly time, then the in-transit and warehouse times, and finally the time spent on the retailer's shelf. The cycle time is most critical for high tech products where the life cycle can be quite short due to technological changes. The life cycle of the supply chain is critical, not only due to the cost of the inventory investment, but also for the risk of product obsolescence.

The Dell Computer Corporation has reduced the supply chain cycle time by selling directly to the customer and eliminating the dollars and time invested in warehouses and retail outlets. The customer order pulls the product from assembly, which in turn pulls components from the suppliers. This approach is an example of applying Just-In-Time manufacturing techniques to the entire supply chain.

SUPPLY CHAIN GOALS

One of the goals of Just-In-Time manufacturing is the elimination of waste. Waste is defined as anything that does not add value to the product or service. The goal of creating an effective supply chain is the same as the Just-In-Time goal. The strategy for the elimination of waste is applicable to both the supply chain and to JIT. It is to "make the product flow". In a manufacturing plant, product flow is achieved by an assembly schedule that controls the flow through the plant using pull systems and synchronized scheduling techniques. Product flow in a supply chain is achieved by balancing the supply chain with customer demand. The techniques that assist in achieving JIT flow are the same that will be used in balancing the supply chain to customer demand. The use of these techniques is more complicated in supply chain management due to factors such as multiple trading partners, logistic requirements, and lengthy cycle times.

The supply chain of the Christmas tree product is easily understood, but not really controllable. The product flow has an extensive cycle time from seed to a mature tree. This lengthy supply chain is not easily balanced with customer demand. Because of the availability of improved artificial trees, the demand in 1995 could be substantially reduced by 2005, when a 10 year cycle is completed. The lack of supply chain balance with demand would result in over production and excess finished goods.

Reducing the cycle time of the supply chain will assist in achieving the goal of synchronized production flow. Lead time reduction in the manufacturing environment is accomplished through the reduction of queue, wait, and move times. The same approach will work in reducing the cycle time of the supply chain. The suppliers' lead times may be reduced through blanket order arrangements. The manufacturing lead times may be reduced through Just-In-Time techniques such as product simplification and cellular manufacturing. The distribution lead time may be reduced by minimizing or eliminating the number of levels in the distribution network.

The total cycle time is lengthy when the supply chain is global. A global supply chain is defined as when either the suppliers or manufacturing operations, or both, are in a country other than that of the end use customer. The cost advantages of global operations must be balanced with the additional cycle time and transportation costs as well as the possible loss of control. Cycle times of the supply chain can be reduced by moving to completely domestic operations. In the last 15 years, Japanese automobile manufacturers have transferred many of their operations to the United States to serve that market. General Motors and Ford have long had a presence in Europe with autonomous operations in that area.

The mode of transportation affects the cycle time of the supply chain. The shortest transport time will be air freight, the next shortest will be motor freight, followed by rail-motor combination, and the longest will be ocean freight. There are variations within the above modes such as full truckload and less than truckload (LTL) within the motor freight classification. The method of transport to be used is dependent on the product, freight rates, and the point of supply to the point of demand. When the alternatives are considered and the results are about equal, the shortest travel time should be the tie-breaker.

Inventory in the supply chain is based on three elements: lot size, buffer stock, and safety stock. This holds true whether the inventory is at the supplier, the manufacturer, the distribution center, or in-transit. The goal of perfect product flow requires making a little bit of everything, everyday. The production rate should equal the sales rate. This goal applies to the supply chain as well as the JIT plant. To make or stock a little bit of anything, requires a reduced lot size. The effort to reduce the manufacturing lot size requires setup reduction in the plant. Reducing the lot size of a purchased item, requires working closely with the supplier. The effort to control or reduce the lot size of in-transit stock, requires logistics analysis of factors such as freight rates, palletizing, carrier selection, and routing.

Both safety stock and buffer stock can be stored at any point in the chain. If the number of stocking locations can be reduced, the need for safety or buffer stock is also reduced. If the flow of product is directly from the plant to the customer, there will not be any safety stock required other than at the

manufacturing facility. Depending on the order lead time policy, there may not be any finished goods' safety stock required at all. Safety stock is required to compensate for forecast or supply error. The shorter the cycle time, the less amount of forecast error is expected and, consequently, less safety stock required. Buffer stock is maintained to cover uncertainty between operations. If the number of operations within the supply chain can be reduced and/or the transition, from one operation to the next made smoother, the buffer stock can be reduced.

A level, repetitive product flow through the supply chain is the goal. The synchronized process to meet customer demand is initiated with finished goods control. Customer demand is not always level and repetitive. A level final assembly (or last operation) schedule may be achieved by planned inventory of finished goods. A method of encouraging level customer demand is sales incentives such as automobile rebates that are offered toward the end of the model year. Small lot sizes are required for not only a repetitive final assembly schedule, but are also required for all planned activities within the supply chain.

An end item might have a customer demand of 20 units per day and be assembled at the level, repetitive rate of 20 per day. However, if the components are fabricated in lots of 2500 twice a year and the raw material is supplied in lots of 5000 annually, the supply chain is in no way synchronized nor level. If there was no safety stock required, the supply chain average inventory would be:

Finished goods	$20 \div 20 = 1 \div 2 = \frac{1}{2}$ day of supply
Components	$2500 \div 20 = 125 \div 2 = 62.5$ day of supply
Raw material*	$5000 - 2500 = 2500 \div 2 = 125 \div 2 = 62.5$ days of supply

* Assumes JIT delivery and immediate use of the first 2500 units

Level flow of a process may be hampered by a bottleneck within the process. The bottleneck may be a work center in the plant, a supplier delivering components, or a rail line transporting the product. The bottleneck, unless eliminated, will control the process flow of the supply chain. The first step is to identify the bottleneck and eliminate it, if possible. If it cannot be eliminated, it must be dealt with through a planning system that will optimize the utilization of the bottleneck. The bottleneck must be monitored and controlled to maximize output. Buffer stock should be planned ahead of the operation in order to insure continuous output. If the output is less than customer demand, all supply chain products can be sold in the marketplace. The activity level within the supply chain should be synchronized with the bottleneck.

The supply chain process can be simplified and streamlined through outsourcing and modularizing. An example of this strategy was the Compaq Computer Corporation which, in the 1980s purchased components from IBM suppliers and bundled them into IBM compatible personal computers. Chrysler Corporation has been successful in developing long-term relationships with their suppliers for the purpose of developing entire subsystems and sharing in the benefits. This approach has reduced the total time and cost to develop and launch a new vehicle. Toyota Motor Corporation, which has always outsourced extensively, developed its “lean production system” within a supply chain concentrated in the area of the Toyota City industrial complex. Toyota’s supply chain experiences in their North American operations have not been as successful and has forced them to make adjustments to their operations. Based on the experiences of many companies, knowing what to outsource is most critical for success.

REQUIRED CAPACITIES

The supply chain must be capable of balancing supply with demand. In other words, the process flow must be able to meet the demand rate of the marketplace. The capacity of each trading partner, as well as the capabilities of those involved in the physical distribution of the product, must be compatible with the requirements of the product flow through the supply chain.

The capacity of the manufacturing facility or facilities, is initially measured through resource planning, then rough-cut capacity planning, and finally through capacity requirements planning (CRP). CRP is required as it reviews each work center and if there is a bottleneck, it will be at the work center level. If there is to be product flow, the bottleneck must be dealt with. Large lot sizes can be compensated for with buffer stock, but insufficient capacity will limit the flow rate of the entire supply chain.

The capacity requirements of the manufacturing facility, also holds true for the suppliers of raw materials and components. It is best if the suppliers have the same controls over their capacities as the manufacturers. A working partnership arrangement between trading partners should bring to light any capacity problems. This approach is more favorable than finding out that a supplier is not capable of meeting requirements when the material is not available when promised. While a single source supplier is desirable when defining and controlling the supply chain, multiple sources may be the solution to a supplier’s capacity problem. A sole source supplier’s capacity problem may only be solved through design changes or additional investments.

The logistics of moving the material from one trading partner to the next are the links in the supply chain. Logistics are also a consideration within a

company when there is physical movement from one location to another, such as from the manufacturing facility to a warehouse. The art of moving and controlling material in a cost efficient and timely manner presents a challenge to both manufacturing and marketing operations. Due to its specialized features, the logistic functions are often turned over to logistics providers who can help in tightening the supply chain. They can assist in traffic management by hiring or leasing trucks and in distribution management by leasing and staffing warehouses. Because they handle a whole lot of goods, the logistics provider can achieve economies of scale when it comes to filling truckloads and warehouses.

The goal of the supply chain network is to minimize warehousing. One approach is to completely eliminate the distribution centers from the network, but this approach may be at the expense of customer service and may also cause high shipping costs. Inventory reduction programs can reduce required warehouse space, but again, the shipper may lose the cost advantage of truckload freight rates. Once the optimum distribution network is determined, the effort must be made at the warehouse level to assure an efficient operation, utilizing first-in, first-out rotation; product location control; and timely delivery. An analysis of planned inventory should be made in order to determine space requirements. An over-crowded warehouse will not allow the order and housekeeping necessary for an efficient operation.

SUPPLY CHAIN CONTROL SYSTEMS

Product flow in the supply chain is in a forward direction, from raw material to the end product delivered to the customer. An example of reverse product flow would be returned goods. The information flow that controls the supply chain will go in both directions. Examples of forward information flow would be manufacturing schedules and purchase orders, while examples of reverse information flow would be production reporting and purchased product receiving reports.

Trading partners within a network have access to various control systems that are applicable to their individual operations. The following are examples of these systems.

1. Reorder point control (ROP). This system will work for an uncomplicated operation producing or distributing a product that has independent, steady demand. If the demand is lumpy or discontinuous, a time-phased order point (TPOP) is used.
2. Manufacturing resource planning (MRP II). In larger manufacturing companies, MRP II systems are used for the planning of all

operations. It addresses material requirements (MRP) and capacity requirements (CRP). Output of MRP II can be integrated with other systems such as finance and purchasing.

3. Distribution resource planning (DRP). DRP is the system used to control the need for warehouse replenishment. It uses MRP logic with the explosion process and can be used for single level or multilevel distribution networks.
4. Electronic data interchange (EDI). EDI is the utilization of computers to communicate and exchange documents between trading partners. It is a communication link in the supply chain.
5. There are various systems used for the execution of operating plans. Examples include input-output systems used for job shop manufacturing, JIT pull systems for repetitive manufacturing, and vendor managed inventory (VMI) for purchased parts.

The above systems are all time tested and in most situations work well. The problem is when they work in isolation and do not interface with the trading partners. To synchronize the supply chain, visibility of the entire network is required. The supply side of the network is based on actual customer demand, while capacity requirements are based on the forecast of demand. The ideal system will broadcast this information over the entire network. It will continuously synchronize supply to demand at every point in the supply chain.

Enterprise Resource Planning (ERP) is the system that attempts to plan from supply and demand information taken across the entire network. It will attempt to rebalance supply and demand at each transaction point in the chain. The system will compare both actual throughput of the supply chain and capacity utilization against customer demand over an extended period of time. It involves company-to-company interfacing within the network. Integrated software applications to ERP software, called supply chain execution (SCE) systems, have been developed to address the needs of supply chain management execution.

A 1999 study of the seven leading vendors of ERP software determined that the average cost of ownership of an ERP system is \$15 million. The most expensive systems were the most complex. A complex system is required for the control of an extensive, complicated supply chain. The cost of the system should be an incentive to simplify the network as much as possible.

PERFORMANCE MEASUREMENTS

Supply chain performance measurements should reflect the strategy of making the product flow in the most efficient manner. Measurements of the chain will equal the sum of the parts of the chain. Measurement performance is fundamental to accountability and the purpose should be to stimulate improvements. Suggested specific measurements are:

1. Cycle time. The cycle time of the supply chain will be the longest supplier lead time + manufacturing lead time + the distribution network lead time + delivery to the customer. The lead times include order entry, order processing, transportation time, and order receipt time. This cycle time can be considered the critical path of the product. Lead times can be reduced by using air freight rather than motor freight, or manufacturing locally rather than in a third world country. The cost trade off must be the consideration for this type of decision.
2. Inventory investment. Inventory can be measured by the sum of total inventory dollars in the chain or by time (days of supply). Time measurement is easier to work with when working toward improvements. The advantage of dollar measurement is that it evaluates the specific investment. A 100 day supply of a \$10.00 raw material is less than a 20 day supply of a \$70.00 finished product. Inventories of safety stock can be reduced, but at the possible expense of customer service. Manufacturing lot sizes may be reduced, but at the expense of manufacturing efficiency. Purchased lot sizes may be reduced, but at the expense of losing a quantity discount. Total supply chain inventory investment is not easily calculated. The manufacturer will have data on its own inventory, but inventory investment of suppliers and independent distributors and retailers is not always available.
3. Customer service. This measurement can be based on units or orders shipped by promised date. If the demand is greater than the supply (non-synchronized flow), the customer service measurement will be the indicator of the problem. If the non-synchronized flow is due to supply being greater than demand, the increase in inventory investment measurement will highlight the problem. Customer service may be improved through increased safety stocks or additional distribution centers, but at the cost of additional inventory.

4. Simplification. The supply chain can be improved by reducing the number of suppliers, simplifying the product and process in manufacturing, and reducing or eliminating distribution warehouses. Reducing the number of suppliers may, in some situations, cause delivery problems which would have a negative effect on synchronized flow. Product simplification can cause problems in the market, if the simplification reduces customer choice. The elimination of distribution warehouses may cause higher transportation costs or timely delivery problems.
5. Financial data. Conventional financial measurements such as profit and loss, return on investment, and cash flow remain as important measurements. While some financial results may be late and not applicable to up-to-date decision making, the basic financial data is critical in supply chain management. The trade off decisions that involve inventory investment, manufacturing efficiency, and transportation costs, require accurate financial data.

The performance measurements should be tailored to the supply chain. The object is to understand if the measurement is capable of meeting predetermined goals, can provide timely indicators of actual performance, and provides the means to anticipate potential problems. If the system is synchronized, the inventory should remain stable and customer service goals should be met. If demand is at planned rates and the inventory is dropping, this is an indication of weakness in the supply chain that should be investigated. If demand is at planned rates and inventory is increasing, the supply chain is not synchronized with demand, and is over-producing.

CASE STUDY SMITH INDUSTRIES INC.

In 1997, Smith Industries purchased the Arlington Garden Specialties Company. Arlington Garden Specialties had been in business for 30 years but in the last few years, in spite of strong sales, deteriorating profits and cash flow problems had forced cutbacks in operations. The only remaining product was a line of garden hose reel stands. The reel stands were of a unique and patented design. They were manufactured in Chicago and sold nationally through hardware chains and discount stores. The product was considered by far the best in the market, but due to lower priced models offered by competition, it could sell for no more than \$45.00 per unit. The quality of the product, as well as the patent rights, were the reasons for the Smith Industries purchase. Annual sales of the reel stands was 60,000 units.

Financial analysis of the Arlington reel stand operation showed the following:

1. The average selling price of the reel stands to the retailers was \$30.00 per unit. Total sales were $60,000 \times \$30.00 = \$1,800,000$.
2. The total cost of manufacturing and selling the reel stands was \$31.00 per unit.
3. Direct material was \$10.00 and direct labor was \$3.00.
4. The \$18.00 balance of the total cost consisted of:

Manufacturing overhead	= \$9.00
Sales and Administrative	= \$4.00
Distribution (freight and warehouse)	= \$4.00
Inventory carrying cost *	= \$1.00

* based on a 9% cost of borrowing

Smith Industries reviewed the supply chain and came to the following conclusions:

1. The Chicago manufacturing facility was quite efficient. The product flow through the plant was based on JIT pull techniques. The work in process inventory averaged 9 days. The raw material inventory, which was primarily purchased components, was a 70 day supply. This did not include a 15 day supply that was in transit via ocean freight from overseas suppliers.
2. The supplier base was primarily located in China. Arlington Garden Specialities had made the procurement decisions based on selling prices that were below those of domestic suppliers. It was thought that the reduced selling prices would compensate for larger lot sizes and increased selling prices.
3. The marketing of the reel stands required more and more warehouse space across the country, because the retailers started to insist on Just-In-Time delivery. Although the Arlington manufacturing operation was manufacturing in a JIT mode, transportation costs dictated truckload shipments to regional and local warehouses. Warehouse

storage was required as the retailers (with the JIT approach) insisted on more frequent and smaller quantity shipments.

CASE STUDY - SUGGESTED SOLUTION

A procurement study was undertaken by the purchasing group to restudy the costs of using domestic suppliers rather than those located overseas. After all proposed selling prices were analyzed, it was determined that the unit direct cost of material would increase from \$10.00 to \$12.00. The advantages that would help offset the cost increases were:

1. Due to smaller lot sizes and reduced in-transit times, the average inventory would decrease from a 85 day supply to 15 days. Based on a cost of money of 9%, the savings would be \$0.25 per unit. This was a conservative calculation, in that the borrowing cost of money was used rather than the opportunity cost that is used in many EOQ calculations.
2. There would be a reduction in inbound freight costs of \$0.50 per unit.
3. With local suppliers, it was felt that communications and coordination would improve. This could be most important in the future when design improvements are planned.
4. Local suppliers would be able to resupply quickly and have greater flexibility with respect to sudden changes in requirements.

The decision was made to go to local suppliers and therefore reduce the chain at the supply end.

The major decision with respect to the supply chain was with product distribution. Smith Industries decided to take the same distribution approach taken by some of the technology companies. That approach was to eliminate the entire distribution network, including the independent retailers, and sell directly to the end user.

The marketing technique was to advertise the reel stand extensively in the media that would best reach the homeowner. The customer could order the product through either an 800 number, a fax number, or the internet. The cost of the stand would be \$38.00 plus freight. Shipment was promised within 2 weeks. Based on the existing sales rate of 60,000 units, the sales income increased from \$1,800,000 to \$2,280,000, an increase of \$480,000.

With the new marketing approach, the manufacturing operation remained the same, but due to shipping out individual units to the customers rather than the truckload shipments to the warehouses, there were extra packaging

and shipping requirements. This increased the direct labor \$1.00 per unit. Manufacturing overhead was unchanged.

The distribution cost of \$4.00 per unit which included warehouse and all inbound and outbound freight, was reduced to \$0.50. This remaining cost covered inbound materials from local suppliers. The inventory carrying cost was reduced from \$1.00 to \$0.50 per unit.

Sales and administrative costs were doubled due to the increased expenses in advertising and order entry under the new system. The following is a simplified profit and loss comparison:

	Old Supply Chain	New Supply Chain
Net Sales	\$ 1,800,000	\$ 2,280,000
Material	600,000	720,000
Labor	180,000	240,000
Manufacturing overhead	540,000	540,000
Sales and Administrative	240,000	480,000
Distribution	240,000	30,000
Inventory carrying cost	60,000	30,000
Profit (Loss)	\$ (60,000)	\$ 240,000

The 10.5% profit margin is not the final goal of the project. The plan is that future manufacturing improvements and increased sales will increase the profit margin.

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Chapter 14

INVENTORY MANAGEMENT ORGANIZATION

BASIC FUNCTIONS

My career in materials management started at the Textileather Division of the General Tire Company. I was assigned to the Production Control Department, the function of which was to schedule plant operations and control raw materials. My rather sarcastic boss described a scheduler as a person who was an expert in everything but scheduling. In a way, he was correct. The scheduler had to work with the sales people to understand the requirements of the customer. An understanding of manufacturing operations was necessary to schedule the various work centers. Scheduling sample orders through the facility required a close association with the research people. At the time of the dreaded annual physical inventory or when the dollar value of the inventory took an unexpected rise, an understanding of the basic accounting practices was an absolute necessity. The management of inventory at Textleather related to every function within the division, just as now, when it is understood that the supply chain is connected by the inventory control process.

In this chapter the word “function” is used, and perhaps overused, to describe the activities of a group rather than using a department or division name. Different companies use different names for essentially the same activities or functions. Examples are purchasing or procurement, production control or scheduling, stores or part department etc.

Production Control. The production control function is responsible for planning and regulating the movement of products through the manufacturing cycle from raw material requisitioning to the delivery of the finished product. Specific activities include planning, scheduling, analyzing inventory, and controlling raw material. Production control is responsible

for raw material, work in process, and, in some situations, finished goods inventory. Finished goods inventories are sometimes the responsibility of the marketing function.

Historically, production control reported to the operations (manufacturing) leadership such as the factory or plant manager. Relationships with other functions were and are as follows:

- **Marketing.** Planning activities requires that production control work with marketing to determine and understand the forecast of future requirements. Continuing communications is needed relative to promising and meeting customer orders.
- **Purchasing.** Production control requisitions materials stating quantity and delivery date. Purchasing picks the supplier, places the purchase order, and follows up the delivery.
- **Manufacturing.** Production control schedules each item at every operation, or in some facilities just the critical operations. The production departments are responsible for meeting the schedules in the most efficient manner.
- **Engineering.** Production control assists design engineering in the planning of new products and works with manufacturing engineers in the routing of products through the plant.
- **Finance.** Inventories are measured in dollars, and lot size calculations are determined by order and carrying costs. Production control must understand the mechanics of the cost accounting as well as the financial goals and cash flow requirements of the company.

Purchasing. The responsibility of purchasing is to select reliable suppliers and to negotiate the lowest reasonable purchase prices. Staying abreast of market conditions and latest technological changes are a requirement. Operating routines include issuing purchase orders, following up on the orders from issue to receipt, and expediting when necessary. The purchasing function often reported to the president or the general manager of the division. Relationships with other functions are:

- **Production control.** Purchasing works with production control toward achieving the goals of optimizing inventory levels and minimizing the need for order expediting. Systems that co-ordinate the activities of the two functions are most important.

- **Physical distribution.** When physical distribution is responsible for transportation, purchasing will work with them to minimize transportation costs. In some organizations, where there are no distribution operations, a traffic department or traffic function may be part of the purchasing department.
- **Receiving and stores.** Purchasing, through systems and communication, can assist in timely receiving, accurate counts, and effective inventory transactions.
- **Finance.** Purchasing will play an active role in procurement planning which will affect business plans and related budgeting and cash flow plan. There will also be continuing system relationships in the control of accounts payable.
- **Design engineering.** Design engineers depend on purchasing to keep them up to date with new available materials and products. Close co-operation is required when engineering changes are planned. The two functions will also work together in efforts to standardize materials and reduce part counts.
- **Industrial engineering.** Input from purchasing can assist industrial (manufacturing) engineers in the development of new manufacturing processes. The two groups can also work together to establish realistic material specifications.

Receiving, Shipping, and Stores. These three functions involve the physical handling of material in the operation with the goal of efficient flow and accurate inventories. They have often reported directly to plant management. Receiving handles incoming material and is responsible for accurately processing data relative to that material. On the other end of the operational flow of material, is the shipping function. The facility and equipment used in shipping is similar to that used in receiving, but the activity is that of shipping customer orders or transferring material to the next step in the supply chain network.

The stores function is that of physically storing raw material, components, or finished goods. The operating goals of the stores function are to control the material so it is secure, is easily located, and is properly recorded in the inventory records. The biggest operating problem in a manufacturing system has historically been inaccurate inventory records and, therefore, accurate inventory records must be the # 1 goal. The stores layout should maximize space utilization while optimizing operating costs.

Item locations may be fixed or random depending on the nature of the product. Functions relating to receiving, shipping and stores are:

- **Production control.** Production control is completely dependent on the data integrity of inventory records. The effectiveness of the receiving and stores functions has a major impact on the data integrity of the system.
- **Marketing.** The shipping operation can have a positive effect on customer service through handling orders in an on-time and accurate manner. In times of shipping overloads, the sales group can assist in prioritizing orders.
- **Manufacturing.** Operating efficiencies can be optimized by an uninterrupted flow of material, the responsibility of receiving and stores. Proper control and identification of material sent into the process is also most important. Just-in-time product flow philosophy calls for point-of-use storage. The proper control of material in point-of-use storage is the joint responsibility of manufacturing and stores.
- **Finance.** Receiving, shipping, and stores are important functions in the proper control of inventory assets in the balance sheet of the company. They also play an important role in the maintenance of accounts payable and accounts receivable records.

Physical Distribution. Physical distribution is the function covering the movement and storage of finished goods from manufacturing to the customer. It involves the activities of transportation, warehousing, order processing, and inventory control. When the responsibilities include inbound transportation, physical distribution will also have input to the purchasing function of the supply chain. The warehouses in the system may be public or private. The goal of physical distribution is to minimize distribution costs while maintaining customer service goals. In many companies, physical distribution is part of the marketing organization. Functions relating to physical distribution are as follows:

- **Purchasing.** Physical distribution can assist in improved inbound transportation by providing routing guides and preferred carriers.
- **Production control.** Production control is responsible for making the finished goods available for distribution. This activity must include lot sizes appropriate for both manufacturing and distribution. Physical distribution, by adjusting requirements, can assist in levelling demand due to seasonal fluctuations. The requirements of both manufacturing and

physical distribution are best handled with distribution requirements planning (DRP) systems.

- **Marketing.** Both marketing, through sales, and physical distribution, through shipments, have a direct relationship with the customer. An effective distribution system is required for good customer service. Feedback from the customer is an important element for both functions. Marketing's forecasts of finished goods demand can assist in both location of warehouses and product inventory requirements.
- **Finance.** Distribution's inventory management decisions are dependent on cost data from finance. At the same time, finance is dependent on accurate inventory records for cost accounting. Input from distribution, relative to future planning, is also required for the business plan of the company.

In listing the relationships of the four basic material control functions with other company functions, data processing (information systems) was not included. The relationship of data processing with the four functions is essentially the same. Data processing supplies the support to each group with respect to system analysis, software development, and computer operations required for the system needs of each function. Examples of the systems are material requirements planning (MRP), purchasing control systems, automatic storage and retrieval systems, and distribution requirements planning (DRP).

MATERIALS MANAGEMENT ORGANIZATION

The organization of a company is a means to an end rather than the end itself. The desired organizational structure is the one that will do the job best. The four basic material functions have often reported to different executives within the organization. With an increased understanding of the cost of materials and the importance of the supply chain, the materials functions have been brought together into a materials management group. A typical materials management organization is shown in Figure 14-1. Titles can be considered interchangeable depending on the nomenclature of individual companies. The following are some comparisons of titles.

Vice-President = Director = Manager

Manager = Administrator = Supervisor

Supervisor = Foreman

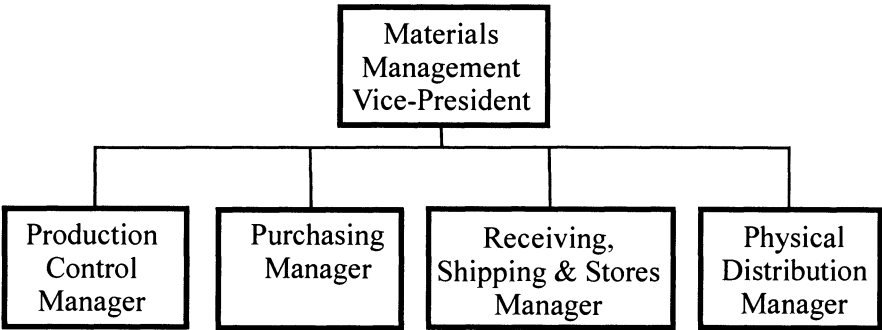


Figure 14-1. Materials Management Organization

A manufacturing operation that shipped finished goods directly to the customer might be organized without a physical distribution department but with shipping separated from receiving and stores. This arrangement is illustrated in Figure 14-2.

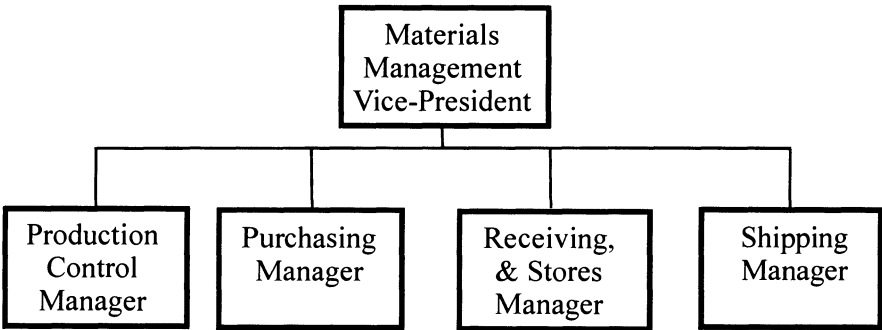


Figure 14-2. Materials Management Organization Without Physical Distribution

If the above company marketed purchased products, rather than manufacturing them, the production control function would be replaced by an inventory control function as illustrated in Figure 14-3.

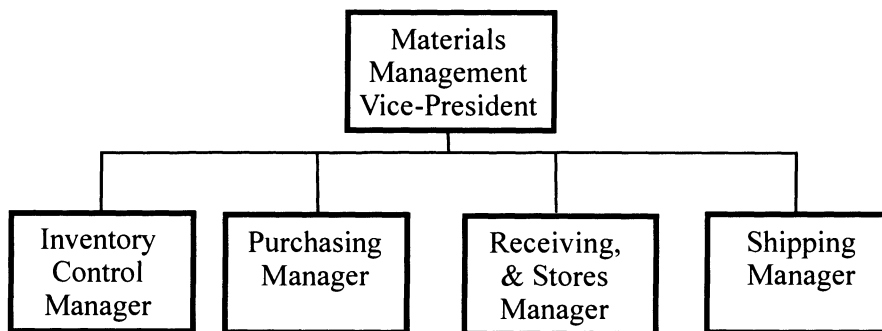


Figure 14-3. Materials Management Organization For NonManufacturing Operation

There are many other variations possible for organizing the materials organization. Basic responsibilities may be divided into one or more function. An example is shown in Figure 14-4.

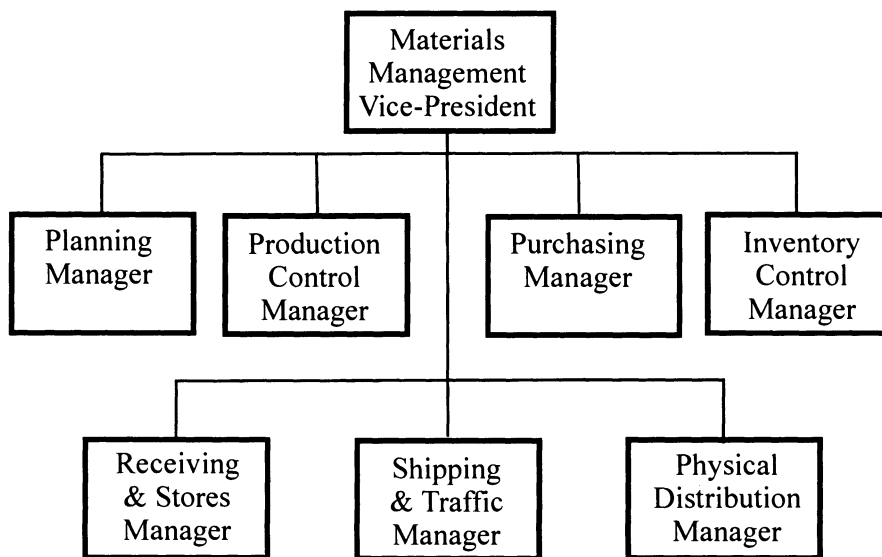


Figure 14-4. Materials Management Organization With Expanded Responsibilities

The materials management organization should be determined by the orientation of the company. A manufacturing concern selling directly to the customer, will not have to manage a distribution network, but must emphasize the traffic management function. A national hardware chain, that

purchases the finished goods to be distributed to licensed retail outlets, will require both strong purchasing and physical distribution operations. In this organization, production control will not be required, but an inventory management group may be needed to assist the purchasing group. A manufacturing operation that includes a distribution network, will require an extensive material management organization similar to the one shown above in Figure 14-4.

CENTRALIZED AND DECENTRALIZED MANAGEMENT

Centralized control is where all material management responsibility is at the top (corporate) level of the operation. In some organizations, the material management responsibility may be separated and moved from corporate control to local control. This usually is when there is more than one manufacturing plant or separate product divisions. This arrangement is an example of decentralized management. While organizational simplicity is desirable, the complex nature of a company may call for centralized control of some functions, but with local control of others.

The materials management vice-president at the corporate level might be responsible for production planning, purchasing, and distribution while the production control managers at the plants report to the plant managers. The materials management vice-president would have “dotted line” control over the production control managers. The production control managers, who report directly to the plant managers would be expected to follow material policy guidelines established at the corporate level. The materials management vice-president is said to have “staff” responsibility and the plant managers have “line” responsibility. This arrangement which is practical and workable, can at times put the production control manager in the middle.

When there are line and staff responsibilities, teamwork is essential and will work best when tasks, duties, and decision making are clearly defined. For example, the master production schedule (MPS) may be generated at the corporate level while the resultant material requirements planning (MRP) will be executed at the plant level.

Figure 14-5 is an example of both centralized and decentralized control. While purchasing and planning responsibility are at the corporate level, the plant manager is responsible for production control, receiving, and shipping. Plant A manager’s material responsibilities are shown. Plant B and C managers have similar responsibilities. The materials management vice-president has staff authority over the plant level materials functions. This authority is represented by dotted lines.

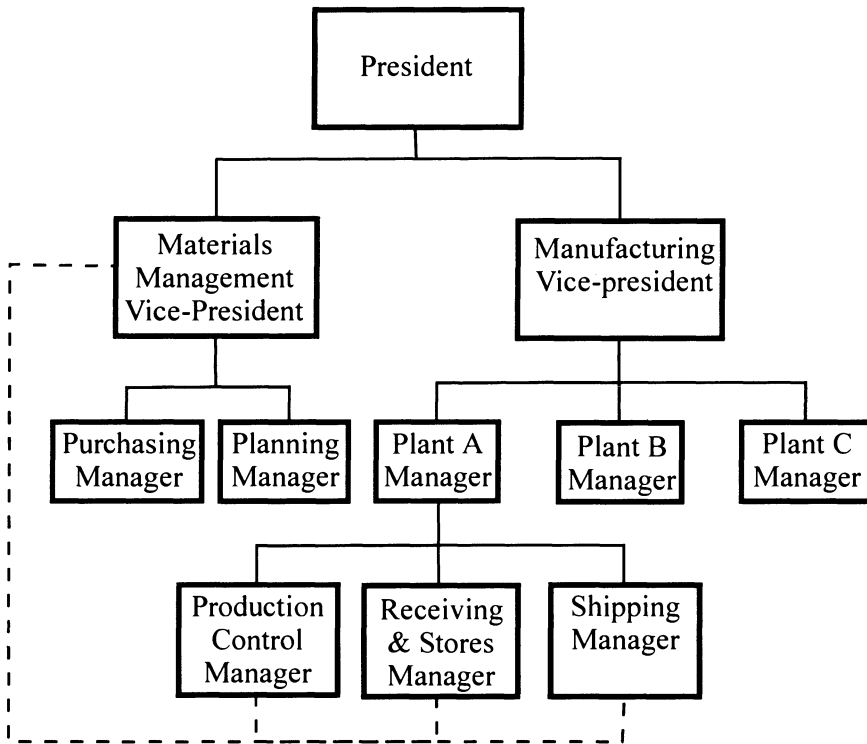


Figure 14-5. Materials Management Line And Staff Organization

A centralized organization is normal for smaller companies, but as a company grows, there probably will be a need to decentralize some functions. The advantages of decentralized functions include the following:

- Clear-cut accountability. The performance of a division or plant can be easily measured.
- Coordinated functions. All of the activities and expertise required to perform the function are grouped in one place under a single manager.
- Fast decisions and action. The speed of decision making is enhanced. Follow-up action can be directed at a local level.
- Job satisfaction. The personnel involved in the operation , being closer to the action, can better see and appreciate the results of their efforts.

Some of the disadvantages of decentralization are:

- **Narrow interests.** The interest of an individual division or plant may be placed ahead of the objectives and needs of the entire organization.
- **Duplication of efforts.** Often divisions or plants have staff members and specialists who perform all functions. This can lead to duplication of efforts at the expense of the overall operation. An example of this would be the separate development of similar material control systems.
- **Communication problems.** There can be a lack of information flow between plants, divisions and headquarters. Worse than no information flow, is misleading or misunderstood information.

Central (corporate) staff material groups can develop policies and procedures that relate to all materials and eliminate or reduce the disadvantages of decentralized operations. Some of the activities performed by central staffs include:

- **Systems development.** The staff can assist in the design and development of material control systems that are applicable to the operating facilities. This responsibility may include implementation and system debugging assistance.
- **Communication.** The central staff can provide a clearinghouse for pertinent information. This may take the form of directives, bulletins or informational papers.
- **Training.** Training can be performed by conducting seminars and meetings at centralized locations or individual operating units. The training can assist in having everyone “singing from the same hymnal”.

CASE STUDY SMITH INDUSTRIES INC.

With the purchase of the Arlington Garden Specialties Company, Smith Industries consisted of four product driven divisions. They were:

1. **Gas grills.** The grills were manufactured in Chicago and distributed through a warehouse distribution network.

2. Replacement parts. The parts were either purchased from both outside suppliers and the grill manufacturing plant. The parts were shipped directly from Chicago and not inventoried in the warehouse network.
3. Patio Furniture. The patio furniture was purchased from a number of outside suppliers and distributed through the same distribution network as the gas grills.
4. Hose reels. The hose reels were manufactured at the Arlington Specialities and sold directly to the customers.

Materials management was under the direction of a corporate group headed up by the materials management vice-president. The organization is reflected in Figure 14-6.

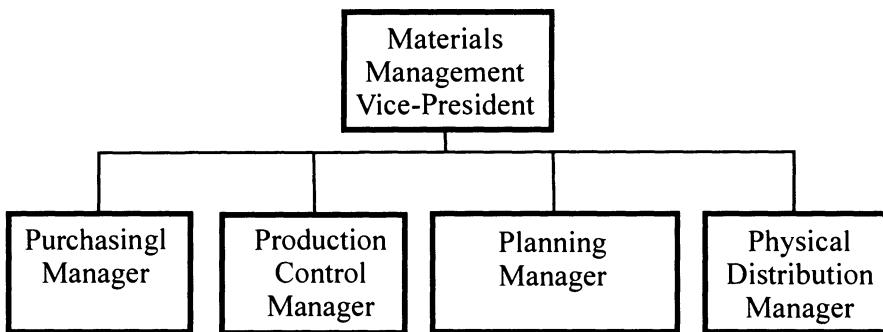


Figure 14-6. Smith Industries Corporate Materials Management Organization

Organizing by product line division for Smith Industries was, for the most part, working well. This organization recognized the differing manufacturing requirements for gas grills and hose reels and the differing purchasing requirements for patio furniture and gas grill parts. It also recognized that each line had a specific method of distribution. The problem was that the corporate materials management organization did not distinguish the differences. There were, at times, problems with acceptability and the time taken in the decision making process. It was decided that there should be a review of the materials management organization with the goal of getting the functions closer to the action, but without losing the expertise required for optimum performance.

CASE STUDY - SUGGESTED SOLUTION

The decision was made to reorganize the materials management group with a decentralized approach. Each operating division would have a materials management director, who would report directly to the division general manager and indirectly to the corporate materials management vice-president. The corporate materials management vice-president would be responsible for information systems, employee training, and performance measurement. The line and staff relationship is illustrated in Figure 14-7.

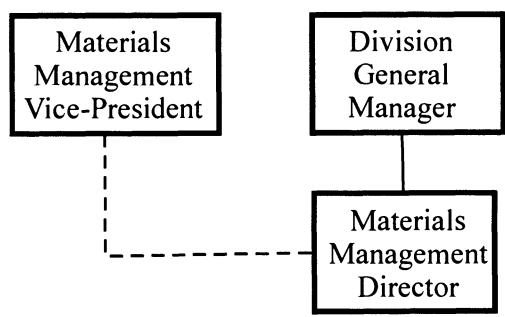


Figure 14-7. Materials Management Line And Staff Relationship

Figures 14-8, 14-9, 14-10, and 14-11 reflect the materials management organizations of the four operating divisions.

GAS GRILL DIVISION

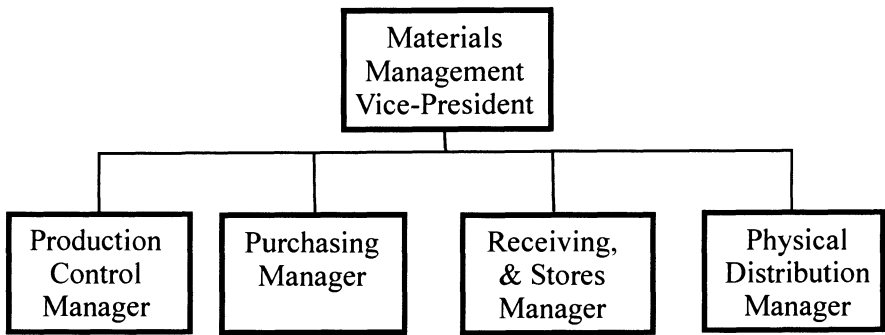


Figure 14-8. Gas Grill Materials Organization

REPLACEMENT PARTS DIVISION

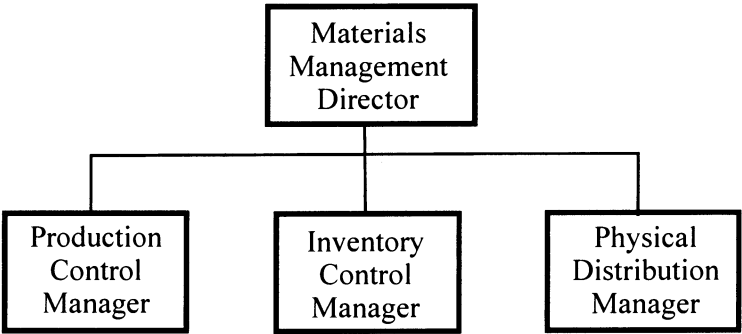


Figure 14-9. Replacement Parts Materials Organization

PATIO FURNITURE DIVISION

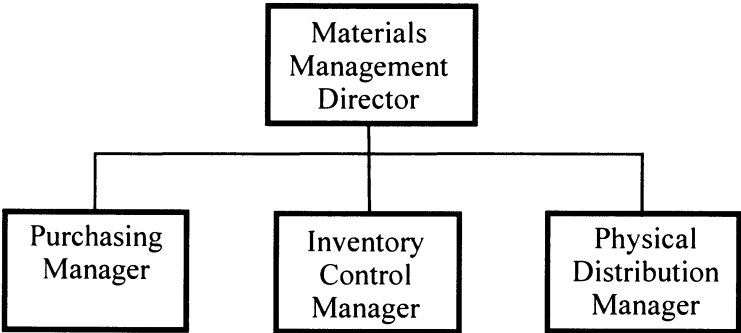


Figure 14- 10. Patio Furniture Materials Organization

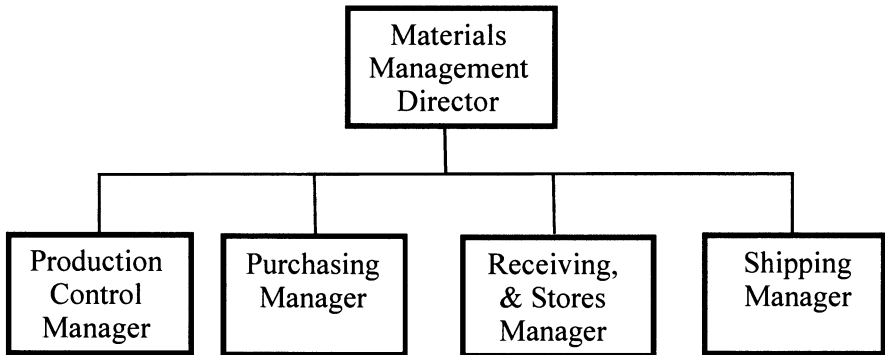
HOSE REEL DIVISION

Figure 14- 11. Hose Reel Materials Organization

The reorganization addressed the specific needs of each division.

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GLOSSARY

Many of the terms are adapted from the APICS Dictionary. It is reprinted with permission of APICS—The Educational Society for Resource Management, Alexandria, Virginia, 9th edition, APICS Dictionary, © 1998.

ABC. Activity-based costing.

Absorption Costing An approach to inventory valuation in which variable costs and a portion of fixed costs are assigned to each unit of production. The fixed costs are usually allocated to units of output on the basis of direct labor hours, machine hours, or material costs.

Activity-Based Costing A cost accounting system that accumulates costs based on activities performed and then uses cost drivers to allocate these costs to products or other bases, such as customers, markets or projects. It is an attempt to allocate overhead costs on a more realistic basis than direct labor or machine hours.

Allocated Item In an MRP system, an item for which a picking order has been released to the stockroom but not yet sent from the stockroom.

Assemble-To-Order A production environment where a good or service can be assembled after a receipt of a customer's order.

ATP. Available-to-promise.

Available-To-Promise The uncommitted portion of a company's inventory and planned production, maintained in the master schedule to support customer order promising.

Backward Scheduling A technique for calculating operation start dates and due dates. The schedule is started with the due date for the order and working backward to determine the start date and/or due dates for each operation.

Balance Sheet A financial statement showing the resources owned, the debts owed, and the owner's share of a company at a given point in time.

Bill Of Material A listing of all the subassemblies, intermediates, parts, and raw materials that go into a parent assembly showing the quantity of each required to make an assembly. It is used in conjunction with the master production schedule to determine the items for which purchase

requisitions and production orders must be released. The bill of material may also be called the formula, recipe, or ingredients list in certain process industries.

Bill Of Resources A listing of the required capacity and resources to manufacture one unit of a selected item or family. Rough-cut capacity planning uses these bills to calculate the approximate capacity requirements of the master schedule.

Buffer Stock Inventory used to protect the throughput of an operation or the schedule against the negative effects caused by statistical fluctuations.

Capacity Planning The process of determining the amount of capacity required to produce in the future. This process may be performed at an aggregate or product-line level, at the master scheduling level, and at the material requirements planning level.

Capacity Requirements Planning The function of establishing, measuring, and adjusting limits or levels of capacity. In this context, capacity requirements planning refers to the process of determining in detail the amount of labor and machine resources required to accomplish the tasks of production.

Carrying Cost The cost of holding inventory, usually defined as a percentage of the dollar value of inventory per unit of time. Carrying cost depends mainly on the cost of capital invested as well as such costs of maintaining the inventory as taxes and insurance, obsolescence, spoilage, and space occupied. Carrying cost is ultimately a policy variable reflecting the opportunity cost of alternative uses for funds invested in inventory.

Cellular Manufacturing A manufacturing process that produces families of parts within a single line or cell of machines controlled by operators who work only within the line or cell.

Common Parts Bill A type of planning bill that groups common components for a product or family of products into one bill of material, structured to a pseudoparent item number.

Component The raw material, part, or subassembly that goes into a higher level assembly, compound, or other item.

Cost Accounting The branch of accounting that is concerned with recording and reporting business operating costs. It includes the reporting of costs by departments, activities, and products.

CRP. Capacity requirements planning.

Cycle Counting An inventory accuracy audit technique where inventory is counted on a cyclic schedule rather than once a year. A cycle inventory count is usually taken on a regular defined basis, often more frequently for

high-value or fast-moving items and less frequently for low-value or slow-moving items.

Cycle Stock One of the two main conceptual components of any item inventory, the cycle stock is the most active component. The other conceptual component is the safety stock.

De-expedite The reprioritizing of jobs to a lower level of activity.

Demand Filter A standard that is set to monitor sales data for individual items in forecasting models. It is usually set to be tripped when the demand for a period differs from the forecast by more than some number of mean absolute deviations.

Demand Time Fence That point in time inside of which the forecast is no longer included in total demand and projected available inventory calculations; inside this point, only customer orders are considered.

Dependent Demand Demand that is directly related to or derived from the bill of material structure for other items or end products. Such demands are therefore calculated and need not and should not be forecast.

Direct Labor Labor that is specifically applied to the item being manufactured or used in the performance of the service.

Direct Material Material that becomes part of the final product in measurable quantities.

Discontinuous Usage A demand pattern that is characterized by large demands interrupted by periods of no demand as opposed to a continuous or steady demand.

Distribution Network Structure The planned channels of inventory disbursement from one or more sources to field warehouses and ultimately to the customer. There may be one or more levels in the disbursement system.

Distribution Requirements Planning The function of determining the need to replenish inventory at branch warehouses. A time-phased order point approach is used where the planned orders at the branch warehouse level are exploded via MRP logic to become gross requirements on the supplying source.

DRP. Distribution requirements planning.

Economic Order Quantity A type of fixed-order-quantity model that determines the amount of an item to be purchased or manufactured at one time. The intent is to minimize the combined costs of acquiring and carrying inventory.

End Item A product sold as a completed item or repair part; any item subject to a customer order or sales forecast.

Enterprise Resource Planning A method for the effective planning and control of all resources needed to take, make, ship, and account for customer orders in a manufacturing, distribution, or service company.

EOQ. Economic order quantity.

ERP. Enterprise resource planning.

Expedite To rush or chase production or purchase orders that are needed in less than the normal lead time; to take extraordinary action because of an increase in relative priority.

Exponential Smoothing A type of weighted moving forecast technique in which past observations are geometrically discounted according to their age. The heaviest weight is assigned to the most recent data. The smoothing is termed exponential because data points are weighed in accordance with an exponential function of their age.

Fabrication Manufacturing operations for making components, as opposed to assembly operations.

FAS. Final assembly schedule.

FIFO. First-in, first-out.

Final Assembly Schedule A schedule of end items to finish the product for specific customers' orders in a make-to-order or an assemble-to-order environment. It is also referred to as the finishing schedule because it may involve operations other than just final assembly such as final mixing or cutting.

Finished Goods A product sold as a completed item or repair part; any item subject to a customer order or a sales forecast.

Finite Loading Assigning no more work to a work center than the work center can be expected to execute in a given time period.

Firm Planned Order A planned order that can be frozen in quantity and time. This technique can aid planners working with MRP systems to respond to material and capacity problems by firming up selected planned orders. Firm planned orders are also the normal method of stating the master production schedule.

First-In, First-Out A method of inventory valuation for accounting purposes. The assumption is that the oldest inventory (first-in) is the first to be used (first-out), but there is no necessary relationship with the actual physical movement of specific items.

Fixed Order Quantity A lot-sizing technique in MRP or inventory management that will always cause planned or actual orders to be generated for a predetermined fixed quantity or multiples thereof.

Fixed Overhead All manufacturing costs, other than direct labor and direct materials, that continue even if products are not produced. Although fixed overhead is necessary to produce the product, it cannot be directly traced to the final product.

Fixed Period Quantity An MRP lot-sizing technique that sets the lot size equal to the net requirements for a given number of periods.

Focus Forecasting A system that allows the user to simulate the effectiveness of numerous forecasting techniques, enabling selection of the most effective one.

Forecast An estimate of future demand. A forecast can be determined by mathematical means using historical data, it can be created subjectively by using estimates from informal sources, or it can represent a combination of both techniques.

Freight Consolidation The grouping of shipments to obtain reduced costs or improved utilization of the transportation function.

Gross Requirement The total of dependent and independent demand for a component before the netting of on-hand inventory and scheduled receipts.

Horizontal Dependency The relationship between the components at the same level in the bill of material, in which all must be available at the same time and in sufficient quantity to manufacture the parent assembly.

Hybrid Inventory System An inventory system combining features of both the fixed order quantity model and the fixed reorder cycle inventory model. Features of both models can be combined in many different ways.

Independent Demand The demand for an item that is unrelated to the demand for other items. Demand for finished goods, parts required for destructive testing, and service parts requirements are examples of independent demand.

Indirect Costs Costs that are not directly incurred by a particular job or operation. Utility costs, such as plant heating, are often indirect. An indirect cost is typically distributed to the product through the overhead rates.

Infinite Loading Calculation of the capacity required at work centers in the time periods required regardless of the capacity available to perform this work.

Input/Output Control A technique for capacity control where planned and actual inputs and planned and actual outputs of a work center are monitored and compared in order to identify problems.

Inventory Those stocks or items used to support production (raw materials and work-in-process items), supporting activities (maintenance, repair, and operating supplies) and customer service (finished goods and spare parts). Demand for inventory may be dependent or independent.

Inventory Management The branch of business management concerned with the planning and controlling of inventories.

Inventory Valuation The value of the inventory at either its costs or its market value. Because inventory value can change with time, some recognition is taken of the age distribution of the inventory.

Item Master File A file containing all item master records for a product, product line, plant, or company.

JIT. Just-in-time.

Job Shop An organization in which similar equipment is organized by function. Each job follows a distinct routing through the shop. Production operations are designed to handle a wide range of product designs and are performed at fixed plant locations using general purpose equipment.

Joint Replenishment Coordinating the lot sizing and order release decision for related items and treating them as a family of items. The objective is to achieve lower costs because of setup, shipping and quantity discount economies.

Just-in-Time A philosophy of manufacturing based on the elimination of all waste and continuing improvement of productivity. The primary elements of just-in-time are to have only the required inventory when needed; to improve quality to zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; and to accomplish these activities at minimum cost.

Kanban A method of just-in-time production that uses standard containers or lot sizes with a single card attached to each. It is a pull system in which work centers signal with a card that they wish to withdraw parts from feeding operations or suppliers. The Japanese word *kanban*, loosely translated means card, billboard, or sign.

Kit The components of a parent item that have been pulled from stock and readied for movement to a production area.

Last-In, First-Out A method of inventory valuation for accounting purposes. The assumption is made that the most recently received (last in) is the first to be used or sold (first out) for costing purposes, but there is no necessary relationship with the actual physical movement of specific items.

Lead Time The span of time to perform a process or series of operations. Individual components of lead time can include order preparation time, queue time, processing time, move time, and receiving and inspection time.

Least Total Cost A dynamic lot-sizing technique that calculates the order quantity by comparing the setup (or ordering) costs and the carrying cost for various lot sizes and selects the lot size where these costs are most nearly equal.

Least Unit Cost A dynamic lot-sizing technique that adds ordering cost and inventory carrying cost for each trial lot size and divides by the number of units in the lot size, picking the lot with the lowest unit cost.

Less Than Truckload Either a small shipment that does not fill the truck or a shipment of not enough weight to qualify for a truckload quantity.

Level Of Service A measure (usually expressed as a percentage) of satisfying demand through inventory or by the current production schedule in time to satisfy the customers' requested delivery dates and quantities.

LIFO. Last-in, first-out.

Logistics The art and science of obtaining, producing, and distributing material and product in the proper place and proper quantities.

Lot for Lot A lot-sizing technique that generates planned orders in quantities equal to the net requirements in each period.

Low Level Code A number that identifies the lowest level in any bill of material at which a particular component appears. Net requirements for a given component are not calculated until all the gross requirements have been calculated down to that level.

LTL. Less than truckload.

Lumpy Demand A demand pattern that is characterized by large demands interrupted by periods with no demand, as opposed to continuous or steady demand.

Machine Utilization A measure of how intensively a machine is being used. Machine utilization compares the actual machine time (setup and run time) to available time.

MAD. Mean absolute deviation.

Make or Buy The act of deciding whether to produce an item internally or buy it from an outside supplier.

Make To Order A production environment where a good or service can be made after the receipt of a customer order. When options or accessories are stocked before the customer order arrives, the term *assemble-to-order* is frequently used.

Make To Stock A production environment where products can be and usually are finished before receipt of a customer order. Customer orders are typically filled from existing stocks, and production orders are used to replenish those stocks.

Master Production Schedule The anticipated build schedule for those items assigned to the master scheduler. This schedule represents what the company plans to produce expressed in specific configurations, quantities, and dates. It is the set of planning numbers that drives material requirements planning.

Material Requirements Planning A set of techniques that uses bill of material data, inventory data, and the master production schedule to calculate requirements for material. It makes recommendations to release replenishment orders for material. Because it is time-phased, it makes recommendations to reschedule open orders when due dates and need dates are not in phase. Time-phased MRP is accomplished by exploding the bill of material, adjusting for inventory quantities on hand or on order, and offsetting the net requirements by the appropriate lead times.

Milk Run A regular route for pickup of mixed loads from several suppliers. For example, instead of each of five suppliers sending a truckload per week to meet the weekly needs of the customer, one truck would visit each of the suppliers on a daily basis before delivering to the customer's plant.

Min-Max System A type of order point replenishment system where the minimum is the order point, and the maximum is the "order up to" inventory level. An order is recommended when the sum of the available and on-order inventory is at or below the minimum.

Modular Bill of Material A type of planning bill that is arranged in product modules or options. It is often used in assemble-to-order companies where the product has many optional features.

Move Card In a just-in-time context, a card or other signal indicating that a specific number of units of a particular item is to be taken from an outbound stockpoint and taken to a point of use.

Moving Average An arithmetic average of a certain number of the most recent observations. As each new observation is added, the oldest observation is dropped.

MPS. Master production schedule.

MRP. Material requirements planning.

Multilevel Bill of Material A display of all components directly or indirectly used in a parent, together with the quantities required for each component.

Net Change MRP An approach in which the materials requirement plan is continually retained in the computer. Whenever a change is needed in the requirements, open order inventory status, or bill of material, a partial explosion and netting is made for only those parts affected by the change.

Net Requirements In MRP, the net requirements for a part or an assembly are derived as a result of applying gross requirements and allocations against inventory on hand, scheduled receipts, and safety stock. Net requirements, lot-sized and offset for lead time, become planned orders.

On-Order Stock The total of all outstanding replenishment orders. The on-order balance increases when an order is released, and it decreases when material is received or when an order is canceled.

Operations Sequencing A technique for short-term planning of actual jobs to be run in each work center based on capacity and priorities. The result is a set of projected completion times for the operations and simulated queue levels for facilities.

Order Point A set inventory level where if the total stock on hand plus on order falls to or below that point, action is taken to replenish the stock.

Outsourcing The process of having suppliers provide goods and services that were previously provided internally. Outsourcing replaces internal capacity and production with that of the supplier.

Overhead The costs incurred in the operation of a business that cannot be directly related to the individual goods or services being produced. These costs such as light, heat, supervision, and maintenance, are grouped in pools and distributed to units of goods or services by a standard allocation method.

Parent Item The item produced from one or more components.

Performance Measurement System A system for collecting, measuring, and comparing a measure to a standard for a specific criterion for an operation, item, good, or service.

Period Order Quantity A lot-sizing technique under which the lot size is equal to the net requirements for a given number of periods into the future. The number of periods to order is variable, each order size equalizing the holding costs and the ordering costs for the interval.

Periodic Replenishment A method of aggregating requirements to place deliveries of varying quantities at evenly spaced time intervals, rather than variably spaced deliveries of equal quantities.

Perpetual Inventory An inventory recordkeeping system where each transaction in and out is recorded and a new balance is computed.

Phantom Bill of Material A bill-of-material structuring technique used primarily for nonstocked subassemblies. For the nonstocked item, the lead time is set to zero and the order quantity is lot-for-lot. This permits MRP logic to drive requirements straight through the phantom item to its components, but the MRP system retains its ability to net against any inventories of the item.

Planned Order A suggested order quantity, release date, and due date created by the planning system's logic when it encounters net requirements in processing MRP.

Planned Order Receipt The quantity planned to be received at a future date as a result of a planned order release.

Planned Order Release A row on an MRP table that is derived from planned order receipts by taking the planned order receipt quantity and offsetting to the left by the appropriate lead time.

Planning Bill of Material An artificial grouping of items or events in bill-of-material format used to facilitate master scheduling and material planning.

Priority Scheduling The process of calculating and communicating start and completion dates to manufacturing departments in order to execute a plan.

Process Flow Scheduling A generalized method for planning equipment usage and material requirements that uses the process structure to guide scheduling calculations.

Process Manufacturing Production that adds value by mixing, separating, forming, and/or performing chemical reactions.

Production Card In a just-in-time context, a card or other signal for indicating that items should be made for use or to replace some items removed from pipeline stock.

Production Plan The agreed-upon plan that comes from the production planning function, specifically the overall level of manufacturing output planned to be produced. The production plan is management's authorization for the master scheduler to convert it into a more detailed plan, the master schedule.

Projected Available Balance An inventory balance projected into the future. It is the running sum of on-hand inventory minus requirements plus scheduled receipts and planned orders.

Projected On Hand Projected available balance, excluding planned orders.

Pull System In production, the production of items only as demanded for use or to replace those taken for use. In distribution, a system for replenishing field warehouse inventories where replenishment decisions are made at the field warehouse itself.

Purchased Part An item sourced from a supplier.

Push System In production, the production of items at times required by a given schedule planned in advance. In distribution, a system for replenishing field warehouse inventories where replenishment decision making is centralized, usually at the manufacturing site or central supply facility.

Random Happenings Having no predictable pattern.

Raw Material Purchased items or extracted materials that are converted via the manufacturing process into components and products.

Regeneration MRP An MRP processing approach where the master production schedule is totally reexploded down through all bills of material, to maintain valid priorities. New requirements and planned orders are completely recalculated or “regenerated” at that time.

Reorder Point A set inventory level where, if the total stock on hand plus on order falls to or below that point, action is taken to replenish the stock.

Repetitive Manufacturing The repeated production of the same discrete products or families of products. Repetitive methodology minimizes setups, inventory, and manufacturing lead times by using production lines, assembly lines, or work cells.

Replacement Cost Systems A method of setting the value of inventories based on the cost of the next purchase.

Rough-Cut Capacity Planning The process of converting the master production schedule into requirements for key resources, often including labor, machinery, warehouse space, and in some cases, money. Comparison to available or demonstrated capacity is usually done for each key resource. The comparison assists in establishing a feasible master production schedule.

Safety Lead Time An element of time added to normal lead time to protect against fluctuations in lead time so that an order can be completed before its real need date.

Safety Stock A quantity of stock planned to be in inventory to protect against fluctuations in demand or supply. Overplanning can be used to create safety stock.

Sawtooth Curve A quantity versus time graphic representation of the order point/order quantity inventory system showing inventory being received and then used up and reordered.

Scheduled Receipt An open order (purchase or shop) that has an assigned due date.

Seasonal Inventory Inventory built up to smooth production in anticipation of a peak seasonal demand.

Setup The work required to change a specific machine, resource, work center, or line from making the last good piece of an item to making the first good piece of another item.

Single-Source Supplier A supplier that is selected to have 100% of the business of a part although alternate suppliers are available.

SKU. Stockkeeping unit.

Sole-Source Supplier The only supplier capable of meeting requirements for an item.

Standard Cost Accounting A cost accounting system that uses cost units determined before production for estimating the cost of an order or a product. For management control purposes, the standards are compared to actual costs, and variances are computed.

Standard Deviation A measure of dispersion of data or of a variable.

Stockkeeping Unit An item at a particular geographic location. For example, one product stocked at the plant and at six different warehouses would represent seven stockkeeping units.

Storage Costs A subset of inventory carrying costs, including the costs of warehouse utilities, material handling personnel, equipment maintenance, building maintenance, and security personnel.

Subassembly An assembly that is used at the next level of the bill of material to build another assembly.

Supplier Performance Measurement The act of measuring the supplier's performance to the contract. Measurements usually cover quality, delivery, and price.

Supply Chain The process from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies.

Supply Chain Management The planning, organizing, and controlling of supply chain activities.

Time Fence A policy or guideline established to note where various restrictions or changes in operating procedures take place. For example, changes to the master production schedule can be accomplished easily beyond the cumulative lead time, while changes inside the cumulative lead

time become increasingly more difficult to a point where changes should be resisted. Time fences can be used to define these points.

Time-Phased Order Point MRP-like time planning logic for independent demand items, where gross requirements come from a forecast, not via explosion. This technique can be used to plan distribution center inventories as well as to plan for service parts. Time-phased order point is an approach that uses time periods, thus allowing for discontinuous (lumpy) demand.

Time Phasing The technique for expressing future demand, supply, and inventories by time period. Time phasing is one of the key elements of material requirements planning.

Tracking Signal The ratio of the cumulative algebraic sum of the deviations between the forecasts and the actual values to the mean absolute deviation. Used to signal when the validity of the forecasting model might be in doubt.

Trend Forecasting Models Models for forecasting sales data when a definite upward or downward pattern exists.

Two-Bin System A type of fixed-order system in which inventory is carried in two bins. A replenishment quantity is ordered when the first bin (working) is empty. During the replenishment lead time, material is used from the second bin. When the material is received, the second bin is refilled and the excess goes into the working bin.

Two-Level Master Production Schedule A master scheduling approach in which a planning bill of material is used to master schedule an end product or family, along with selected key features (options and accessories).

Variable Overhead All manufacturing costs, other than direct labor and direct materials, that vary directly with production volume. Variable overhead is necessary to produce the product, but cannot be directly assigned to a specific product.

Variance The difference between the expected (budgeted or planned) costs and the actual costs.

Vertical Dependency The relationship between a parent item and a component in its bill of material that defines the need for the component based on producing the parent, without regard to the availability of other components at the same level in the bill of material.

Visual Review System A simple inventory control system where the inventory reordering is based on actually looking at the amount of inventory on hand. Usually used for low-value items, such as nuts and bolts.

Weighted Moving Average An averaging technique in which the data to be averaged are not uniformly weighted but are given values according to their importance.

WIP. Work in process.

Work Cell Dissimilar machines grouped together into a production unit to produce a family of parts having similar routings.

Work In Process A good or goods in various stages of completion throughout the plant, including all material from raw material that has been released for initial processing up to completely processed material awaiting final inspection and acceptance as finished goods inventory.

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