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A. Manufacturing Competitiveness/ MPC Framework

What does MPC stand for? It is the manufacturing planning and control, which is concerned with planning and controlling all aspects of manufacturing, including demand management, production planning, managing materials, scheduling of machines and people, and supplier and customer coordination. This lecture provides a framework for evaluating responses to changes because these activities change over time and respond differently to different markets and company strategies. The use of an effective manufacturing planning and control system is a key to the success of any manufacturing company. Any organization having a good MPC system can effectively coordinate with its suppliers as well as customers across the company boundaries. It must be realized that the MPC systems design is not a one-time effort; MPC systems need to continuously adapt and respond to changes in the company environment, strategy, customer requirements, particular problems, and new supply chain opportunities.

After the completion of this lecture, the students will be able to:

- *Define and identify market, economic, technological, and organizational elements that influence MPC Systems design*
- *Describe MPC Systems' components and match them with the needs of the firm*
- *Identify the forces that derive the change in the MPC system*

KEY AREAS OF INFLUENCE

Perhaps the most important aspect of the context for development and maintenance of a manufacturing planning and control system is the continual change in its competitive environment. Changes range from technological to political and strategic. Over the years, MPC system has been influenced by different factors: (1) International context for MPC, (2) the role of customer which has evolved over the years, and (3) the role of IT which has developed much more than it was in the 1970s or the 1980s. All these aspects have changed MPC accordingly.

International context for MPC

If we look at international context there is tremendous increase in breadth and depth of internationalization. In 60s and 70s the manufacturing used to take place where the market was. For example, an American company who is selling the product in the United States would produce the product in the United States. But now it has changed. The companies are moving towards the cheaper source of labor. If we look at an example of mobile phones, the popular phone brands are based in the US and Korea but most of their phones are produced in China and they are marketed around the world. These companies are designing the products but they are being produced in China with the components produced in another country.

These new arrangements have given rise to what is called "plug compatibility". Basically plug compatibility is something such as a gaming console that you have bought. You bring it at home plug it with your television set, turn it on and start playing the games. Next day probably your friends call you and ask you to come at their place where you all may play the gaming console together. All you have to do is to take the gaming console to your friends place, plug it with their television set and start playing the games. The gaming console is not specific to one region. The plug compatibility is a similar concept in manufacturing. In this concept the company on the basis of demand pattern outsources the production in Malaysia and as the demand pattern changes they may shift the production to China.

Now what does that mean? The company doesn't have to construct a facility in one area. They outsource the production to one region but if need arises they may switch to another location without investing any money in the new facility. For example in 2014's football world cup, the company which had the contract for providing footballs went to three countries: Pakistan, India, China. They found out that a Pakistani company was ready to produce the footballs more quickly than the other countries. It was a huge order of around six million footballs required in a very short time. The Pakistani company produced the footballs in only thirty three days. Now, according to the concept of plug compatibility they selected Pakistan for the production but they may shift to another country when they receive the contract again depending upon the availability of resources there. Therefore, the MPC has changed a lot because of the breadth and depth of internationalization.

The Role of customer

There has been a lot of influence because of the change in the customers' role in the MPC system. How has the customer's role changed? The demand of the customer has increased. When we say that the demand has increased it does not mean that only the quantity has increased but the customer are now asking for more variety of the same product. For example, in 1980s in the USA 2000 different food products were being sold in US. But within 10 years this number increased to 18000 different products. This means that in 10 years the customers' requirement changed tremendously and they wanted more choice and a large variety for selection. The companies seeing this have created new products at a faster rate. The customer demands more variety and not only they want more variety but they also require new products introduced in the market at a faster rate. For example, we see new models of mobile phones being introduced more quickly in the market. Each company introduces new model and because of competition and competitiveness they keep introducing new models regularly. This happens because of the customers' requirement. The customer also wants that the new models not only comes out without any delay but they also want that when they go to a retail shop the product is available and that they don't have to wait for it. The customers' requirements are changing and because of this the MPC system is coming under a lot of pressure and that has influenced MPC for changes in the system.

Because of the changes in customer's requirements, the companies are having problems developing operational capability. Therefore, in order to develop it further they have to bring a lot of the changes to the MPC system. On one hand the customer wants the price to be less but on the other hand he also wants it to be of high quality. Therefore, the inventory has to be less, the manufacturing processes have to be improved so that the quality of the product is high and there are no defects. Because of this the human resource has to be developed. The workers need to be multi skilled so that they know how to operate facilities more efficiently.

In order to be an effective competitor in today's marketplace, firms must have MPC systems with the ability to determine, transmit, revise, and coordinate requirements throughout a global supply chain system. Changing customer requirements and shifting consumer preferences make this an extraordinarily dynamic task.

The role of IT

Similarly the role of IT has also changed. The IT or information technology has developed a lot over the years and because MPC is integrated with it, the MPC come under a lot of pressure further development. For example if the enterprise resource planning (ERP) is installed in a company, MPC will be integrated with it. If we look at the development of ERP over the years, we see that in the late 1970s material requirements planning (MRP) module

was developed. It only handled the flow and planning of the materials throughout the manufacturing facility. Then some more modules were added to MRP and thus manufacturing resource planning (MRP2) was developed.

MRP2 was developed to handle the planning of all the company's manufacturing resources. Once MRP2 was developed successfully more modules were added to it and Enterprise Resource Planning (ERP) was developed, which now included the planning of all the resources of an enterprise. The ERP was further developed into Extended-ERP which includes areas like customer relations management, supplier relations management etc. Because of these types of development in IT, changes have been made in the MPC system so that it could be integrated effectively with ERP. Other developments are in the form of Electronic Data Interchange (EDI) and the internet. They are being used to coordinate and transfer data between firms, which have given rise to the concept of a "paper-less" enterprise. Through internet and EDI, effective coordination between firms is carried out and orders are placed with the suppliers and the customers more efficiently. Because of these new developments in IT there have been lot of changes to the MPC system and the MPC system of today is a lot different from the system of the 1970s and 1980s.

TECHNICAL SUPPORT ACTIVITY

Basically what MPC does is that it does not make the decision for the manager but it gives technical support for the decision making of the manager. This technical support is on three levels: Long term technical support, intermediate term technical support and short term technical support.

Long Term

The system is responsible for providing information to make decisions on:

- The location of the facility.
- The appropriate amount of capacity to meet the market demand of the future.

In long term technical support, the system provides information to the manager to make the decisions on the location of the facility. The role of the facility is two types: (1) Storage facility and (2) manufacturing facility. The location of the facility becomes very important. The top management has to answer the following questions: Where should the facility be located? What is the demand pattern? Should it be placed near the market place or the supply source? Should there be one facility that provides products to the entire world or should every market place have a facility? The data that is provided by MPC can help top management make the decisions regarding the location and the role of the facility.

Similarly, MPC helps provide information which will help make long term decisions about the capacity of the facility. The management could decide to have large storage capacity to cater for numerous markets or small storage facility could be used to handle a single market. For example, in Pakistan the storage facility could be located depending upon the requirement of the product. If the supply chain is cost efficient then there could be only one storage facility so the inventory cost and inbound transport cost could be reduced. But if it is a responsive supply chain then one would like to have the warehouses close to each market so that whenever there is a demand in the market, the products are easily accessible. In this the inventory cost and the inbound transportation cost will be more. It all depends on what information is being provided on which the manager is going to make a good decision.

These long term decisions are known as strategic decision. The company takes these decisions over several years. For example, how will the demand for the product be after four years? And how will it be handled? In long term decision, the human resource capabilities are

also taken into considerations. The management would like to know, what are the new technologies that are coming in the market? What technology should be used for manufacturing? To handle all these issues, MPC would provide information to the decision maker to make it easier for him to make good decisions.

Intermediate Term

The MPC system also provides information for management to make intermediate level decisions. In the intermediate term, the fundamental issues addressed by MPC is to match supply with demand in terms of both volume and product mix. Although this is also true in the long term, in the intermediate term, the focus is more on providing the exact material and production capacity needed to meet customer needs. This means planning for the right quantities of material to arrive at the right time and place to support product production and distribution. It also means maintaining an appropriate level of raw material, work in process, and finished goods inventories in the correct locations to meet market needs. MPC allows the management to handle decisions like these. For example in matching supply and demand, if the demand is the same as the supply and it takes less time to transport the material then the inventory cost will be reduced. Here we are talking about the complete supply chain from supplier of supplier to the customer of customer. In the whole of supply chain there is a billion of dollars' worth of inventory. If the correct information is provided at the right time then this inventory could be reduced. But if the information isn't provided correctly at the right time then a small change in customer demand will create a huge change on the supply side. This is called "bullwhip effect". If the demand fluctuates on a smaller scale at the customer level, the effect on the supplier level will be large. It refers to increasing swings in inventory in response to shifts in customer demand as you move further up the supply chain. To handle such a change large inventory is maintained. Also, right type of transportation plays an important role in mitigating this problem.

MPC system also provides information to the customer. For example there is a module called master production schedule. In it the production information, how much material is available to promise to the customer is provided to the sales force. The information given to the market includes the amount of the products left to produce, how much can be given for sales purposes and the time in which this order will be completed?

MPC also gives information for the planning of the capacity needs that includes planning on the intermediate level where overtime use is discussed and how can the capacity be increased. If the demand is more than the company's own capacity then it can outsource its production needs. This will increase the capacity. According to the customer demand, the capacity can be increased on an intermediate level with the effective use of MPC system.

Short Term

MPC system also provides information for short term decisions. Short term decisions include matters like the scheduling of the machines, resources, material requirements etc. This is also known as shop floor control. Shop floor is basically the factory floor. Factory floor includes the planning and scheduling of the production of the products by the manager. This is almost done on a daily basis. This includes human resource requirement and material requirement. This information is also provided by MPC to the manager to come up with very good solution. A machine can produce many types of products and it is very difficult to schedule all those products on one machine at the same time. For example if the manager makes a bad decision of the production schedule it may result in poor utilization of machines. But if they understand each product's processing time and handle the production through the

processing time then the utilization rate will be high. Obviously if the facility is capital intensive and more money is invested in it then the shareholders would like the utilization to be higher. Generally most of the time products spend in queues waiting to be processed or they are being transported between the work stations and the actual processing time is little as 15 to 20 percent. So if the time of the queues is reduced then the product will be produced quickly and will reach the market faster.

Performance Indicator

The important thing is not only scheduling but also tracking which resource is being used and what is being produced because if a production lot is found defective then the cause of the defect needs to be known to eradicate them. The MPC system also provides the management help in this aspect. The results that are coming out need to be monitored to see which products are being produced by which machine, the workers involved in the process to plan the production activity for the future. To find out the solution to problems like delay, cost and stability MPC provides on time information.

It is important that the MPC system have performance indicators for all the work it is performing. Performance indicators are needed to evaluate the types of performance by the MPC system. For example performance indicator will be the output result of all the processes that are being carried out. Are deliveries being done on time? Is the product being produced on time? Are targets that were set, being achieved? All of the output results indicate the performance made by the MPC system.

Another indicator is the equipment utilization. It is very important because the equipment which has a lot of investment made on should be utilized properly. If the utilization is not being handled properly then there is a problem with the system. Probably the forecast of the demand was not correct. There is demand module in the MPC system which provides the information on the demand forecast. Because of the incorrect information provided the utilization of the equipment will be poor and this would indicate the poor performance of the MPC system.

Customer satisfaction is another important aspect that the management has to deal with. It is also an important performance indicator. The company wants that the customer is satisfied and needs to know, how will the customer satisfaction be successfully achieved? Does the customer get the order on time? Product fill rate is one of the measures of customer satisfaction. It is a percentage of the order that gets delivered on time. An order may consist of a combination of different products. A customer would like to have whole of his order filled completely on time, else he will get frustrated. For example, if a customer orders a computer system to be delivered to his home. The computer consists of separate parts like the central processing unit, the monitor, the key board and the mouse. Now if all these four things do not reach the customer at the same time, he will get upset since the customer wants his order completely filled on time.

Costs are associated with products, labor, operating machine, project conditions and so on. These costs also indicate how the MPC system is performing. For example, if the per unit cost of the product is increasing it means that there is some problem in which the utilization of workers or machines is poor. Bad utilization of workers means that they are not working properly, sitting idle, machine is breaking down, or the material is not being received on time. Because of the bad utilization the cost of the products will increase, the departments cost will increase. To handle these costs, these indicators are very important to evaluate the performance of the MPC system.

Cost and Benefit of MPC Systems

The costs of an MPC system are substantial but so can be the rewards. Whenever a project is started its cost and benefit are analyzed. MPC system is a very costly system but its rewards are also numerous for example the inventory is reduced transportation is quicker to the market and customer will be satisfied. Because of these benefits, the costs of the MPC are offset.

It is common to see ERP system costs measured at 5-10% of cost of goods sold. It means that if an ERP system is implemented and the cost of production is not reduced by more than 5-10% of the cost of goods sold then there is no benefit in having an ERP system. Before implementing ERP system and MPC system, the cost and benefit of both the systems are evaluated to check the feasibility of implementing them.

MPC SYSTEM FRAMEWORK

It is most typical now to find the MPC system imbedded in an enterprise resource planning (ERP) system. Many essential activities that need to be performed in the MPC system have not changed. However, the details have evolved as changes in our knowledge, technology, and markets have occurred.

An MPC system has a number of modules which interact with one another. One module's output becomes an input for another module. And that is why all of these modules are integrated and the system works smoothly because of this integration. There are three levels of modules in an MPC system as shown in Figure A.1.

1. Front end modules
2. Engine modules
3. Back end modules

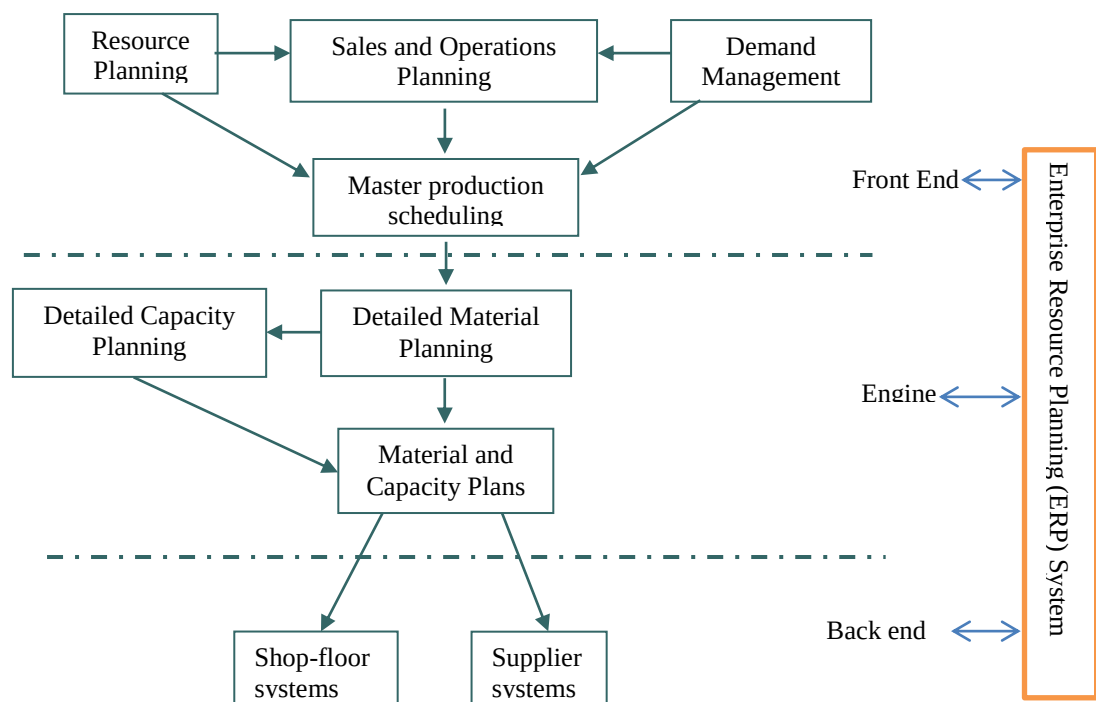


Figure A.1 Manufacturing Planning and Control System

Front End

One of the main modules of the front end is the sales and operations planning (SOP). It balances the sales/marketing plans with available production resources. It gets information

from the sales force through demand management module as well as from the resource planning module.

The plan developed in sales and operations planning module is done in aggregate term. Aggregate term means that although a product has a number of different models or stock keeping units (SKUs) but the plan is developed for a pseudo product and not for all the SKUs individually. For example, the plan will be developed for number of lamps to be produced in a year and not for the quantities of each individual models of the family of lamps to be produced. Similarly, the resources like human resources are not planned for a specific work center but the requirement of the whole facility to produce the desired quantity of the product would be determined.

The demand management module would provide the demand forecast in aggregate term of the product for each planning period in the next planning horizon. Resource planning module would provide the number resources available to meet this demand. The plan thus developed in the sales and operations plan module would become input for master production schedule (MPS). Demand management would provide disaggregate demand forecast to MPS. The forecast of the number of lamps would be broken down into SKU (model) level. The resource planning module also provides information to MPS module. It would provide information about the resources to determine if the resources are enough for production when the demand is disaggregated.

Forecasting for the product in aggregate terms is always easier than forecast at SKU level. Basically forecast is never accurate. It can be a good forecast or a bad forecast but never an accurate forecast because of the constant fluctuation in demand due to randomness. But aggregate forecast is more accurate than at the SKU level. For example, it is easier to forecast how many runs a cricket team will score in a match than to predict the number runs each player will score in the match. Similarly, demand management's aggregate forecast is easier for sales and operation plan and forecast for master production schedule at SKU level is difficult. Sales and operations planning, master production schedule, resource planning, and demand management combine to form the front end of an MPC system.

Engine

The engine in the diagram above encompasses the set of MPC system for detailed material and capacity planning. It takes input from the front end system and it has its own modules which set the directions for activities and overall system. The master production schedule's output is provided directly to the detail material planning module. The provided information is about how many units will be produced in each week. Usually in MPC detail material planning is also called material requirements planning (MRP). MPS gives us the plan for the production of end product whereas MRP develops production plan for subassemblies, components and raw materials required for the production of the end product. For example, let's say product A is required to be produced in the first week of April. On this basis the number of subassemblies, components, and other raw materials required to produce the desired number of end products are determined. For example, if product A is produced using two subassemblies (X and Y) then these subassemblies should be available before the first week of April so that the production of product A could be started on time.

Other than master producing schedule, input comes from the detailed capacity planning module. Detailed capacity planning is also known as rough cut capacity planning which provides the complete capacity information to detail material planning. From the material and capacity plans, the manager can determine which component should be produced on which machine and also if there is enough capacity available for its production. All these plans are

developed in the section called Engine. This section really drives the MPC system hence the name the engine. Material requirement planning was the first module that was actually developed in the enterprise resource planning system as discussed earlier.

Back End

MPC system has a third section called the back end. Why is it called the Back end section? This section is thus called because it coordinates with the suppliers and the shop floor to facilitate material requirements. The information that comes from the engine is used in the different modules in the back end system. There are two modules in the back end section.

Shop floor system

The term shop floor actually means the factory floor. The information in the production system is provided to the factory floor. The shop floor module deals more with the execution of the plan in real time. It is determined that which equipment will produce which products at what time? If we look at the production of a product, almost 80% of the production time is either spent waiting for the process to start or it is spent in travelling from work center to the other. And just 20% of the time is actually spent in operations being performed on it. One thing that needs to be understood is that production is done in lot sizes. That is, a lot only moves from one work center to the next only when all the units in that lot have been processed on the previous work center. Let's suppose that a product is produced in a lot of hundred and it takes one minute to process one unit in a work center. This means that to process the lot of 100 would require 100 minutes in the work center. But actually one minute is spent by a unit in the work center and rest of the time it would be waiting for other units to be processed. On the other hand it is possible that the management decides to implement just in time (JIT) system then the shop floor system will follow the JIT philosophy. All of the work will proceed according to the requirement of that system.

Supplier System

On the other hand many components and materials are outsourced. That means if suppliers are involved then the supplier system is used. The supplier system provides detailed information to the company suppliers. If the company is at arm's length relationship with supplier then the system will produce purchase orders that will be transmitted to the suppliers. Thereafter, the company MPC system will provide suppliers with updated priority information based on conditions in the company as well as in the suppliers' companies. In case of closer relationship with suppliers then the information can also include future plans, which would help the suppliers to understand the expected needs. This module is connected to the demand management module at the supplier's company.

MATCHING MPC SYSTEM WITH THE FIRM NEEDS

MPC system is not a generic system instead it is customized according to every firm's need. Generally there are three phases or levels but in all of the modules of every phase there are several options available which should be selected according to the business environment. And if the company's need changes then changes in MPC should also occur. For e.g. the MPC of a firm in 1980s would not be successful in this era, that is why changes and evolution in MPC should occur so it can cater to the business environment of today. Similarly we have seen that in 1980s there was not that much availability of online data but now days the IT is very advanced and in it we can find systems like EDI (Electronic Data Interchange), internet etc. Because of this we get real time data, which we could use in MPC. More changes like physical ones are also a cause for a change in MPC, for example, if first a company was using traditional manufacturing but now they have decided to use just in time

approach, which involves cellular manufacturing, then the MPC will also evolve as it would include these alterations. The firm will use the new MPC instead of the old one because if the old one is used then it would become a failure. Therefore we would have to make many improvements in the MPC system. Similarly, if the management decides to outsource manufacturing and only keep the core business in-house then again the MPC system would have to be modified. As many materials requirement would start moving through a supplier system while in the shop-floor system only core things will be produced. Another reason for a change in MPC might be because the company is now competing on speed of delivery, so obviously the execution of different decisions would have to be improved and again MPC will play an important role here and it would require major changes. This is because from cost cutting the firm has moved to delivery speed as their preferred strategy, therefore, accordingly the MPC system would be modified.

MPC classification schema

As it was stated earlier, the MPC is not a generic system instead it should be adapted according to the business environment. For example, there are different processes involved in manufacturing and they could be divided into five categories as shown in Figure A.2:

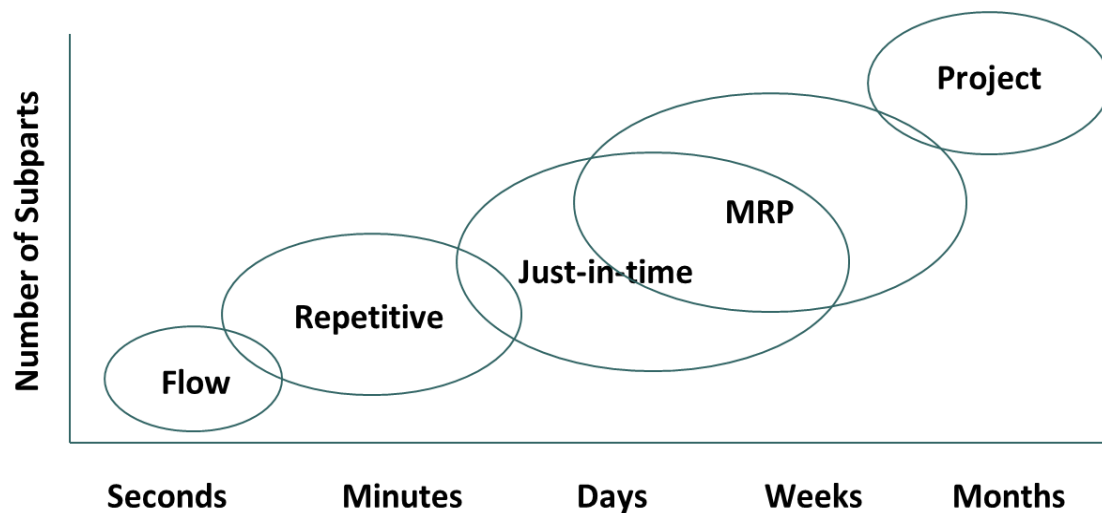


Figure A.2 Time between successive units

These classifications can help management decide, which option in which module to use and to make appropriate changes the MPC system. The processes are classified according to the number of subparts used in the production of the end product. If there are a large number of subparts then it will lie at one extreme of the schema, whereas if there are very few subparts then it will lie at the other extreme. Similarly, the time it takes in between the successive units that come off the production line also determines how we should classify the process. For e.g. the flow manufacturing process takes seconds and also its subparts are minimal and this can be seen in sugar mills, which has minimal number of subparts/raw material used in its production are almost negligible. Also, because sugar granules can be considered as units in this process, the time between successive units coming off the line is less than a second. With these processes, front-end concern of the MPC system is primarily the flow rate that becomes the master production schedule. Typically, these products have relatively few components parts, so the engine management is straight forward. Depending upon how components are purchased, back end may involve some complexity.

In a repetitive process, a product is repetitively produced, such as an assembly line (e.g., automobiles, watches, laptops, televisions etc.) This process involves an assembly line like method, so it takes minutes in between the successive units coming off the line and due to this its MPC would be different from the one used for the flow process. For such products, component parts management is necessary, but everything is coordinated with the flow or assembly rate for the end product.

Similarly there is just-in-time process which was basically developed by the Japanese automobile company and after 1974 oil embargo it became very popular. This was because during that period all the automobile companies incurred losses except for this Japanese company, which was using just-in-time system. Today companies are using lean manufacturing approaches, which are based on just-in-time concepts. JIT is shown as spanning a variety of products and processes. This MPC approach is increasingly being integrated with more traditional MRP-based systems. The goal is to achieve a better MPC system performance and to reduce costs of maintaining the MPC system.

Other than this we have MRP. This was basically developed in late 70's by American researchers and this was kind of a response to the just-in-time as both were targeting to reduce inventory but the MRP does its planning on a weekly basis. It is the platform for the ERP system and is the key to any MPC system involving management of a complicated parts situation. For many firms, successful use of MRP is an important step in evolving their approaches to MPC.

Lastly there is a project type of manufacturing process, which is very different from the other processes because in this type the product is stationery and the resources are moving around it whereas in the other processes the products are moving from one resource to another. For e.g. there is manufacturing of a jumbo jet, a ship etc. These are project type and obviously its whole setup is different so its MPC will also be very different from the other processes. Here the primary concern is time management. Related to time is money. Some firms have successfully integrated MRP approaches with the problems of project management.

B. Demand Management and Forecasting

In MPC's frame work, the demand management is part of the front end phase and it plays a very important role because if wrong information is provided through this module then the rest of the phases will fail. Demand management module basically falls on the boundary of MPC in between the market and production planning and it interacts with the sales force. Like I said earlier the output/information generated by demand management is being provided to the sales and operations planning as well as to MPS. A major activity of demand management is forecasting, which it develops based the information provided by the market mainly through the marketing department. These forecasts can be developed on the basis of time series or past historical data and any other information provided by the sales force regarding the market conditions. This is because any information related to a change in the market place will be known to us through the sales force as they interact more closely with the market place. For example, if a new product is launched in the market by competitors, the company's sales force would be the first one to know about it. This information can then be provided to demand management so that they could update their forecast accordingly.

After the completion of this lecture a student should be able to:

- *Appreciate the role of demand management in MPC systems*
- *Differentiate between independent and dependent demand*
- *Apply different techniques in forecasting short to medium term demand under different conditions*
- *Produce and evaluate detailed forecast and asses its quality using different metrics*

DEMAND MANAGEMENT IN MPC SYSTEM

Demand management is a gateway module in manufacturing planning and control, providing the link to the marketplace, sister plants, warehouses, and other important customers. Demand management is basically the function of recognizing and managing all demands for products. It occurs in the short, medium, and long term. In the long term, demand projections are needed for strategic business planning of such things as facilities. In the medium term, the purpose of demand management is to project aggregate demand for production planning. In the short run, demand management is needed for items and is associated with master production scheduling.

If material and capacity resources are to be planned effectively, all sources of demand must be identified. These include domestic and foreign customers, other plants in the same corporation, branch warehouses, service parts and requirements, promotions, distribution inventory, and consigned inventory in customers' locations.

The major activities of demand management are: (1) Forecasting; (2) Order promising; (3) Making delivery promises; and (4) Interfacing between manufacturing planning and control and the market place.

In each of these cases, production (supply) is being planned to react to anticipated demand as shown by the forecast. The position of demand management in the MPC system is shown in Figure B.1.

The double arrow in the figure between the demand management and the market place depicts the need to communicate with the market. It not only underscores the need to communicate with the customers but also to gather information from and about them. I have stated earlier that the output from demand management goes to the sales and operation planning (SOP) as well as to master production schedule (MPS). It was stated earlier in the last lecture that the demand management provides information on an aggregate level to the

sales and operation planning, whereas, it gives information in detail in disaggregate level to the MPS. The information provided to SOP is used to develop sales and operations plan covering a year or more at a fairly high level of aggregation. Both forecast and actual demand information is provided to MPS. Another thing that we should understand is that the short term, product specific manufacturing plans developed in MPS should be aligned with the decisions that have been taken in the sales and operation planning or the targets that have been set there.

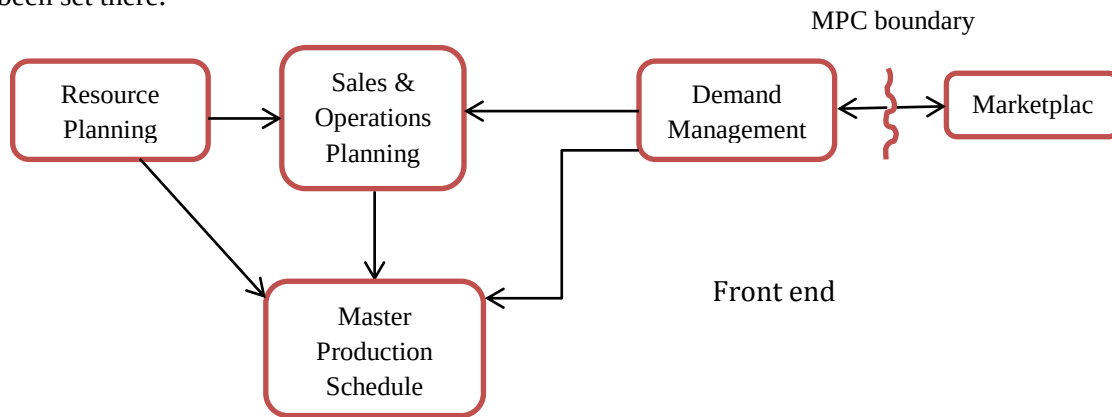


Figure B.1 Demand Management in MPC System

It shouldn't happen that the targets in the MPS are different from the targets in the sales and operation planning due to the fact that one is on an aggregate level, whereas, the other is on SKU level. Instead what should happen is that the aggregate targets which were set in the sales and operation planning should be taken forward to the MPS in a disaggregate form. The demand management provides information to both these modules so that they can effectively plan the production of different products in different periods.

Independent Demand versus Dependent Demand

In MPC the demand is divided into two categories; one is independent demand and the other is dependent demand. The independent demand is the demand of a product that is independent of the decisions of a firm. It means that the demand is generated by the customer or market and it is not related to the demand of any other product or service of the firm. For example, if a company makes wooden tables, the demand for the tables is independent. Master production schedule items are independent demand items.

The dependent demand items are those items whose demand is related to the demand of some other product. The components, subassemblies usually have dependent demand. The demand for the sides, ends, legs, and tops of the table depends on the demand for the tables, and these are dependent demand items. Since independent demand is not related to the demand for any other assemblies or products, it must be forecast. However, since dependent demand is directly related to the demand for higher-level assemblies or products, it can be calculated. Material requirements planning (MRP) is designed to do such a calculation.

An item can have both a dependent and an independent demand. A service or replacement part has both. The manufacturer of vacuum cleaners uses flexible hose in the assembly of the units. In the assembly of the vacuums, the hose is a dependent demand item. However, the hose has a nasty habit of breaking, and the manufacturer must have replacement hoses available. Demand for replacement hoses is independent since demand for them does not depend directly upon the number of vacuums manufactured.

Dependency can be horizontal or vertical. The dependency of a component on its parent is vertical. However, components also depend on each other (horizontal dependency). If one component is going to be a week late, then the final assembly is a week late. The other components are not needed until later. This is also a dependency and is called horizontal dependency. Planners are concerned with horizontal dependency when a part is delayed or there is a shortage, for then other parts will have to be rescheduled.

Also, it is important to understand that the independent demand although not related to the demand of any other product but it can be influenced. For example, the demand of an end product can be influenced by promotions or advertisement that the company offers but still it is the market or customer generated demand for the end product. Therefore, basically independent demand is handled by the demand management module in the MPC, which actually forecasts it and then sends that information to not only the sales and operation planning but also the MPS. While dependent demand is handled by the MRP module.

Forecasts and Plans

Like I have stated earlier that the independent demand is forecasted, whereas, the dependent demand is calculated. Forecast and plan are two different things. Forecast is done in the demand management module, whereas, we plan in the rest of the modules of an MPC system. We develop plans for the product we have to deliver to the customers and the plans are not only based on the forecasts but also on marketing quotas, promotions, special sales incentives etc. These amounts are based on inputs from many different sources not just quantitative forecasts.

On the one hand the demand is being created and its forecast is being made and on the other hand we have to decide how to meet this demand then that part is planning. The forecasts are never accurate. They may be good or bad but never accurate because there is always randomness involved in the demand pattern which makes it impossible to come up with an accurate forecast. Also a manufacturing manager's job is not to forecast demand. He is supposed to come up with a good plan which would help meet the demand. Therefore, a manager should not be blamed for the forecast because firstly it's not his job and secondly a forecast can be a good one but never accurate. On the other hand the manager can and should be held responsible for his plan because making plan is part of his job.

After developing a plan, the manager should provide the relevant information about the plan to everyone, even to the people at the lower level of management. Similarly if the environment changes or the requirement shifts then the plan should be changed accordingly. Therefore, a manager should develop a good plan, change it if required according to the changes that are occurring and then the new plan should be executed faithfully. Only then it would be successful otherwise even the MPC would not be able to help the manager.

MPC Environment

Demand management activities must conform to the strategy of the firm, the capabilities of manufacturing, and the needs of customers. Different strategies, capabilities, and customer need define different MPC environments within which the demand management activities are carried out. The MPC environments are classified into four categories:

1. Make to Stock (MTS) environment
2. Assemble to Order (ATO) environment
3. Make to Order (MTO) environment
4. Engineer to Order (ETO) environment

Make to Stock Environment

In make to stock environment, the end product is produced to stock. The demand in the market is met through inventory. The inventory acts as a buffer between the production facility and the market place so that the market pressures are absorbed by the inventory. This way the pressure on the production is relieved and the demand is met through the inventory. In this environment the decoupling point of the customers' orders is the finished goods inventory meaning the demand of the customer is fulfilled from the finished goods stocks.

In this environment the focus is on maintaining inventory. Also, the demand is tracked throughout the supply chain as a major activity. Different strategies are employed to reduce inventory and production costs while maintaining high customer satisfaction level. The key decisions are how, when, and how much stock to be replenished at different locations in the supply chain so that the total cost of meeting customers' demand is reduced and customer satisfaction level is enhanced. To meet the customers' demand, firms employ distribution centers, warehouses, and even vendor-managed inventory inside their customer's location. In this environment, managers require information on the inventory status in the various locations. The manager is more interested in good estimates of demand by location and by item or SKU level. It is also important for the manager to know about the relationships with the transport providers because that may make a difference to the responsiveness of a supply chain. Therefore, improvements can be made by having better knowledge of demand, of rapid transportation alternatives, speedier production, and more flexibility. Satisfying customers requires balancing the level of inventory against the level of service to the customers.

Assemble to Order Environment

In assemble to order environment the primary task of demand management is to define customer orders in terms of alternative components and options. Here the number of finished products is substantially more than the number of components that are combined to produce that product. That is why maintaining inventory of end products, as we do in MTS environment, is not feasible in ATO environment. Here the inventory of components and subassemblies is maintained. Therefore, in this environment when a customer's order arrives, the demand management defines it in terms of components and gives it to the production, who takes out those particular components from the inventories, assemble them into the end product and supply it to the customer. The process of combining the components and subassemblies as per customer order is known as configuration management. One of the important capabilities required in this environment is engineering design that enables as much flexibility as possible in combining components, options, and modules into the finished products. As discussed earlier the demand of end product generated from the customers/ market is an independent demand because this demand is not related to any other product but this demand is then converted to dependent demand of components and subassemblies because now it is related to the end product demand. So basically when the company decides how many end products to produce then the components or subassemblies that they require would become dependent on the company's decision. This tells us that in this environment the independent demand converts to dependent demand at the component and subassembly level. Therefore, the inventory that defines customer service is the inventory of components not finished products.

MTO (ETO) Environment

We usually consider manufacture to order and engineering to order as the same environment. The only difference between the two is that in manufacture to order we make the customer's product through raw materials as per customer's design. While, in engineering to order the company also develops engineering design on customer's specification. This tells us that there is only a little difference between the two, that is in one place the specifications and the engineering design are brought in by the customer and the company just produce the product, accordingly. While on the other end the engineering design is made by the company on the basis of the customer's specifications and then the product is produced. Here the decoupling point is at the raw materials or the suppliers' level and also in this environment the requirement of the information, regarding the components, is not as much in detail like it is in the ATO environment. Instead here the design is provided by the customer, then accordingly the components are produced or purchased and then the product is assembled and delivered to the customer. Here the important job of the demand management is the coordination between the customers' product needs and the engineering department. For example, in ETO environment the demand management communicates the customer's product needs to the engineering department, who then makes the design and provides it to the production people for the production of the end product. Therefore, the demand management's role is very important as they have to coordinate with the customer and the engineering department for efficient production of the product.

In this environment the customer decoupling point is moved to raw material or even suppliers, which reduces the scope of dependent demand information. Here the demand management instead of forecasting end product demands, it determines how much engineering capacity will be required to meet future customer needs. In these environments, suppliers' capabilities may limit what we are able to do, so coordination with them is essential. If we look at this environment then the span of involvement from customers to suppliers gives us a perfect example of how to describe a supply chain. And the coordination of activities along the supply is referred to as supply chain management.

Communicating with S&OP

Like we saw earlier the demand management interacts with two other modules; one is Sales and Operations Planning and the other is the Master Production Schedule. A key requirement for demand management communication with sales and operations planning is to provide demand forecast information. In turn, sales and operations planning will provide coordinated sales and operations plans. In order for these plans to be comprehensive, all sources of demand must be accounted for, both in quantity and timing. It is not sufficient to simply determine the market needs for product. To get a complete picture of the requirements for manufacturing capacity, engineering resources, and material needs, we must gather demand information for spare parts, inter- and intra-company transfers, promotion requirements, pipeline buildups, quality assurance needs, exhibition or pilot project requirements, and even charitable donations.

The information that demand management provides to S&OP depends on which environment is being considered. For example if we consider MTS then demand management provides finished goods forecast to the S&OP and on that basis the managers then develop a plan on how to meet demand using different strategies like chase strategy, level strategy, or mixed strategy. It is important to choose the right measure for determining capacity needs because it would facilitate communication between demand management and S&OP. In case

of MTS environment, material capacity may be the most appropriate measure. Similarly, if we consider ATO environment then here also the demand forecast is provided but here it is done on the basis of components and subassemblies, which then are stored in inventories. Meaning the demand management will forecast the demand of finished goods in term of the product family mix and different options available. This forecast would then be converted into the requirements of components and subassemblies. Looking at the MTO (ETO) environment then here also demand would be forecast but as the product is completely new so obviously the demand management cannot forecast based on the product instead they can forecast the number and the level at which the orders will arrive. In MTO environment the capacity measure would most likely be machine and/or labor hours. While in ETO environment the engineering capacity is probably most critical.

Communication with MPS

The other module with which demand management interacts is MPS. Here the interactions between them are frequent and detailed. As the customer orders are received and entered by demand management, the detailed order information must be provided to master production scheduler as the orders occur. Similarly, MPS must provide information to demand management on the status of orders, capacity consumed, and capacity available so that the customer can be kept informed. Details vary significantly between different environments. But in all cases the underlying concept is that the forecasts are consumed over time by actual customer orders, as shown in Figure B.2.

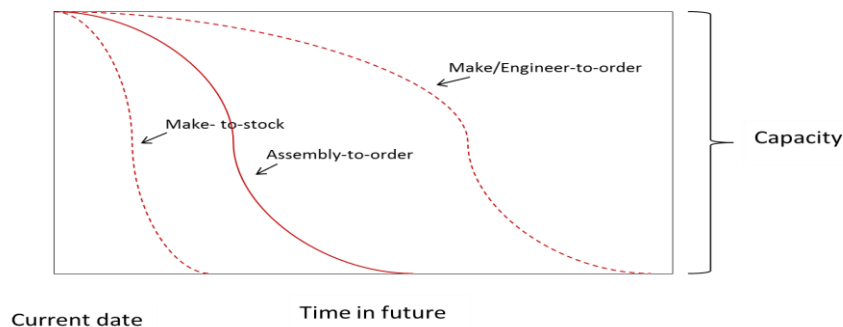


Figure B.2

In all the instances, the forecasts lie on top of the line to the right of the curve and actual customer orders lie below the line on left of the curve.

In the figure we can see that the curves are different for the different environments. For MTS environment the actual orders are very few since all the demands are normally met through the inventory. This tells us that in this environment that the need is to manage end product's inventory. In ATO environment there are customer orders well into future that tells us that delivery promise date to customer is important. While in MTO (ETO) environment the demand management confronts different set of problems. Here we see a large backlog of customer orders. This is because the first the engineering department is in communication with the customer during the design phase then come the project management phase and delivery promise. Also, in these three environments the types of uncertainties differ.

Producing Forecasts

The main role of demand management is to produce forecast. We have seen that in any environment, the forecasts are very important and using those forecasts the plan is developed.

There are mainly two types of forecasts; one is subjective forecast, the other is objective forecast. The subjective forecast's base is not quantitative data instead judgments or experiments are used. Here we will discuss only three types of judgmental forecasts and they are:

1. Sales force surveys
2. Jury of experts
3. Delphi technique

The sales force surveys can provide very good forecasts because sales force are in touch with the market. The only issue is that the forecasts can be biased if the sales force is provided bonuses for achieving annual targets. The tendency would be for the sales force to provide forecasts which would be on the lower side so that targets thus set could be achieved easily.

The other judgmental method is "jury of experts". In this method a group of experts are asked to provide forecast based on the relevant data provided to them. The only drawback in this method is that whenever there is a group discussion there are usually one or two members who are very vocal and because of that reason most other members follow their lead. Therefore, the final forecast is based on the perceptions of the vocal members rather than of the whole group. To overcome this problem, Delphi technique was developed so as to avoid this biasedness. In this technique, a group of expert is formed similar to the one in "jury of experts". The main difference is that the group members' names are hidden so they do not know each other and not get influenced with the opinions of others. There is also a moderator present who provides the members with the relevant data and information and they then provide their decisions to him. He then sees whether a consensus was reached and if not then they keep repeating these steps till the group comes to a consensus. The hiding of names stops the members from getting influenced by someone's name or superiority. The drawback of this method is that it may take too long to achieve consensus and if a member leaves the group for some reason then a new group is formed by inducting a new member and the whole process is restarted from the beginning.

Time Series Forecasting

There are mainly two types of objective forecast techniques: (1) Time series techniques; (2) Causal /relational techniques. Here we will only discuss time series forecasting techniques. The time series techniques are used mainly for mature products. Here the forecasts could be developed on periodic (daily, monthly, quarterly, yearly or any other period) basis. It could be developed at SKU level or even on an aggregate level. The logistics requirement, the sales force requirement and the production requirement are based on this forecast and then using this information, plans can be developed. These forecasting methods are used for the demand of mature products because new products do not have any historical data and for time series it is important to have historical data so that future forecasts can be made looking at previous trends. Also, this forecast is usually for short time periods a maximum of a year.

In time series methods different models are used to forecast independent demand and not dependent demand. This is because independent demand is generated by the market where as dependent demand is related to the company's decision and also that dependent demand is calculated and not forecast while independent demand is forecast. If special situations occur then they are treated differently for e.g. a company is planning promotion then in that case with time series historical data other information is also incorporated such as the sales force's opinion.

Basic Components of a Demand

This time series demand has five basic components.

- Level
- Trend
- Cyclical Movements
- Seasonal Variations
- Random Fluctuations

In the time series forecast there is a level component around which the forecast fluctuates if there is no other component involved other than randomness. The second component is the trend and in this either there is an increasing or decreasing trend. Due to this component the demand is either increasing or decreasing over the period. Usually these trends are linear but they can also be non-linear in curve shape that can either be quadratic or exponential. The third component is the cyclical movements. This is not related to calendars or a specific time periods instead it is more related to business cycles. The business cycles are based on long periods of three/four years or even longer and usually there cycles are not repeated at fixed intervals. The fourth one is seasonal variations and these occur at fixed intervals. Also, note that these seasonal variations are not necessarily related to annual calendar; it could be based on different times of a day, different days of a week and can be monthly or quarterly. Still the variations would be on fixed intervals. The seasonal variations can be forecast by time series but cyclical variations are difficult to forecast using time series model instead it is done using econometric models. This is because in a business cycle takes more than four to five years to be repeated that means for time series then we would need data of about 30-40 years and that is not possible for a product as in 30 years that product itself may be discontinued. So usually we combine cyclical variation with trend when forecasting using time series models. The random fluctuations occur wherever there is uncertainty. For example if we toss a coin then there is a 50-50 chance that either a head or a tail will appear. But this doesn't mean that if on the first attempt when you toss a coin, a head appear then on the second time tail would appear, instead a head may appear again and this happens due to randomness. But maybe if we toss the coin a large number of times, say 100,000 then there is a possibility that head and tail would appear almost 50 percent of times, each. This randomness is unpredictable and it is impossible for us to forecast it and this may be one of the reasons that the forecast are never 100 percent accurate.

Time Series Method

The time series method consists of many different techniques. Here we will only discuss five techniques.

1. Naïve method
2. Moving averages
3. Simple exponential smoothing
4. Trend adjusted exponential smoothing (Holt's method)
5. Seasonal Indices

Naïve Method

As the name suggests it is the most basic method, which is frequently employed by those who do not possess knowledge of other time series method. It is also known as "random walk". In this method the current period's actual demand becomes the forecast for the next period. That is, if the current period's actual demand is say 55 units then next period forecast will be 55 units. In some demand patterns this method quite satisfactorily.

Moving Averages (MA)

In moving averages method we take average of only fixed number of periods, which becomes the forecast for the next period. For example if it is 3 period Moving Averages, then to find the forecast of fourth period, we will take the average of first three periods which will become forecast of the fourth period.

Example 1:

Assume that the monthly demand for a particular item over the past year is as shown in Table below. Suppose it is the end of December 2016, and we want to forecast demand for January of the coming year. Determine the forecast using three period moving averages:

January	92	July	84
February	83	August	81
March	66	September	75
April	74	October	63
May	75	November	91
June	84	December	84

Solution:

$$\text{Forecast for January 2017} = \frac{84+91+63}{3} = 79.3$$

A variant of Moving Averages is weighted Moving Averages (WMA). In MA equal weight is assigned to each period. In the above example, a weight of one is assigned to each period. While in WMA different weights are assigned to different periods. Usually, higher weights are assigned to periods closer to the period for which the forecast is developed and smaller weights are assigned to distant periods. In the above example if we are determining forecast using 3-period Weighted Moving Averages then we may assign weights of 0.5, 0.3, and 0.2 to the demands of December, November, and October, respectively. The forecast for January 2017 thus can be calculated as:

$$\text{Forecast for January 2017} = \frac{(0.5 \times 84 + 0.3 \times 91 + 0.2 \times 63)}{0.5 + 0.3 + 0.2} = 81.9$$

Simple Exponential Smoothing

Simple exponential smoothing method is a variant of weighted moving averages. Here the weights are assigned to previous period demand and forecast. In this method the most recent data is given higher weights or its impact on the next period forecast is highest but as the data goes farther into the past then its impact reduces exponentially on the forecast. That is why it is called exponential smoothing method. In this model there is an important constant known as the smoothing constant and it is usually denoted by α . The value of α is determined by looking at the pattern of the demand but it ranges only from 0 to 1.

$$F_{t+1} = \alpha D_t + (1-\alpha) F_t$$

Where:

F_{t+1} = forecast for time period t+1

F_t = forecast for time period t

D_t = actual demand for time period t

α = smoothing constant, $0 \leq \alpha \leq 1$

If look at the above model then $\alpha = 1$ means that the exponential smoothing model is same as the naïve method which is basically that today's demand is tomorrow's forecast. But if this constant is 0 then that means it is same as cumulative (or average) method where the demand is constant throughout the time horizon. In other words, today's forecast is also tomorrow's forecast and is same in every period in the future.

Exponential smoothing provides a routine method for regularly updating item forecasts. It works quite well when dealing with stable items. Generally, it has been found satisfactory for short-range forecasting. It is not satisfactory where the demand is low or intermittent. Exponential smoothing will detect trends, although the forecast will lag actual demand if a definite trend exists. Also, similar to Moving Averages methods, it can only forecast one period in future.

In exponential smoothing method the initial forecast is assumed. It does not matter that what should be the value of the initial forecast since as we move in the future, its impact will decrease at an exponential rate and after some periods its impact on the forecast will be negligible. Also, the question arises that what should be the value of α ? Selecting the value of α is basically an art, but a rule of thumb is that if the raw data has more randomness then small value of α should be used in the model.

Example 2:

Let suppose we have data as given in table below and we have to determine the forecast for 11th period. Let's assume that the value of $\alpha = 0.2$.

Period	Demand	Period	Demand
1	10	6	8
2	11	7	22
3	9	8	20
4	11	9	21
5	10	10	19

Solution:

To solve the problem using simple exponential smoothing method, we first have to assume the forecast for period 1. In this case we assume $F_1 = 10$. Then

$$F_2 = \alpha D_1 + (1 - \alpha) F_1 = 0.2 \times 10 + 0.8 \times 10.00 = 10.00$$

$$F_3 = 0.2 \times 11 + 0.8 \times 10.00 = 10.20$$

Period	Demand	$\alpha=0.2$ Forecast	$\alpha=0.8$ Forecast
1	10	10	10
2	11	10.00	10.00
3	9	10.20	10.80
4	11	9.96	9.36
5	10	10.17	10.67
6	8	10.13	10.13
7	22	9.70	8.43
8	20	12.16	19.29
9	21	13.73	19.86
10	19	15.18	20.77
11		15.94	19.35

Trend Adjusted Exponential Smoothing

If a trend exists, it is possible to use a slightly more complex formula called trend adjusted exponential smoothing. This technique uses the same principles but notes whether each successive value of the forecast is moving up or down on a trend line. In this model other smoothing constant α it also has trend constant β , which also ranges from 0 to 1. The forecast for the next period is determined by:

$$AF_{t+1} = F_t + T_t$$

Where:

$$F_t = \alpha D_t + (1-\alpha) (F_{t-1} + T_{t-1})$$

$$T_t = \beta (F_t - F_{t-1}) + (1-\beta) T_{t-1}$$

F_t = Level factor for the next period

F_{t-1} = Level factor for the current period

T_t = trend factor for the next period

T_{t-1} = trend factor for the current period

β = smoothing constant for trend, $0 \leq \beta \leq 1$

In this method also we have to assume the initial value for level factor and trend factor. The impact of the initial values will decrease exponentially as was the case in simple exponential smoothing method.

Example 3:

Let suppose we have data as given in table below and we have to determine the forecast for 10th period. Let's assume that the value of $\alpha = 0.3$ and that of $\beta = 0.6$.

Period	Demand
1	30
2	34
3	37
4	40
5	44
6	48
7	51
8	55
9	58
10	?

Solution 3:

To solve this problem using trend adjusted exponential smoothing method, we first have to assume $F_0 = 27$ and $T_0 = 0$. Then

$$AF_1 = 27 + 0 = 27$$

$$F_1 = \alpha D_1 + (1-\alpha) (F_{t-1} + T_{t-1}) = 0.3 \times 30 + 0.7 \times (27 + 0) = 27.9$$

$$T_1 = \beta (F_1 - F_{t-1}) + (1-\beta) T_{t-1} = 0.6 (27.9 - 27) + 0.4 \times 0 = 0.54$$

$$AF_2 = 27.9 + 0.54 = 28.44$$

$$F_2 = 0.3 \times 34 + 0.7 \times 28.44 = 30.11$$

$$T_2 = 0.6 \times (30.11 - 27.9) + 0.4 \times 0.54 = 1.54$$

$$AF_3 = 30.11 + 1.54 = 31.65$$

Period	Demand	Level	Trend		
		Forecast, F_t	T_t	$A_{t+1} = F_t + T_t$	
0		27	0		
1	30	27.9	0.54	27+0	=27.00
2	34	30.11	1.54	27.9+0.54	=28.44
3	37	33.26	2.45		31.65
4	40	37.00	3.22		35.71
5	44	41.35	3.9		40.22
6	48	46.08	4.4		45.25
7	51	50.64	4.5		50.48
8	55	55.1	4.48		55.14
9	58	59.11	4.2		59.58
10					63.31

As mentioned earlier, simple exponential smoothing can only forecast one period in future but trend adjusted forecast method can forecast any number of periods in future. For example if we want to forecast demand for period 13 in this problem then assuming the last period's trend remains constant, we can thus determine the forecast as follows:

$$AF_{11} = AF_{10} + T_9 = 63.31 + 4.2 = 67.51$$

$$AF_{12} = 67.51 + 4.2 = 71.71$$

$$AF_{13} = 71.71 + 4.2 = 75.91$$

This way one can forecast demand any number of periods in future.

Evaluating Forecasts

Till now we have studied different methods of forecasting. We must understand that forecasts are never accurate and a simple reason for that is the randomness in the demand pattern. We have many forecasting methods available. The important question is that which method should we use to forecast demand when we know that the forecast is never accurate? To answer this question we can find out which method gives forecast closest to the actual demand or in other words, which method gives smallest error over a large periods of time? There are a number of models that can be used to evaluate forecasts. Some of the methods are:

- Mean Absolute Deviation (MAD)
- Mean Square of Error (MSE)
- Mean Absolute Percentage Error (MAPE)

One thing we must remember that when we evaluate different forecasting methods to be used to forecast demand then we must apply same evaluating model to all the methods and select the one which gives the smallest error. For example, if we use MAD on one method then it should also be used to evaluate other methods.

Once we select the best method that gives the lowest and start using it to forecast demand, we must keep in mind to track the systems forecast. This is important because it is always possible that the demand pattern changes or for some other reasons, the system starts producing poor forecasts. When that happens we must reevaluate the method and make changes in it. It is possible that by making minor changes such as the value of α , the system

starts again to produce good forecasts or it is possible that entire new method would be required to come up with good forecasts.

Mean Absolute Deviation (MAD)

Mean Absolute Deviation is most commonly used method to evaluate forecasts. In this method the forecast errors are converted into absolute values and then we take the average of these values. How this method works is shown in the following example:

Example:

Month	Forecast, F	Actual, A	Error=A-F	Absolute Value
1	100	106	6	6
2	100	93	-7	7
3	100	102	2	2
4	100	101	1	1
5	100	95	-5	5
Total	500	497	-3	21

MAD at the end of 5th month = $21/5 = 4.2$

C. Sales and Operations Planning (S&OP)

Manufacturing is complex. Some firms make a few different products, whereas others make many products. However, each uses a variety of processes, machinery, equipment, labor skills, and material. To be profitable, a firm must organize all these factors to make the right goods at the right time at top quality and do so as economically as possible. It is a complex problem, and it is essential to have a good planning and control system.

After this lecture students will be able to:

- *Understand the importance of sales & operations in MPC systems*
- *Describe the information needed to produce an S&OP*
- *Explain the different strategies used in the development of an S&OP*
- *Formulate and solve basic S&OP problems by trial-and-error method*

Sales and Operations Planning (S&OP) in a Firm

There are five major levels in a manufacturing firm using manufacturing planning and control (MPC) system:

- Strategic business plan.
- Production plan (sales and operations plan).
- Master production schedule.
- Material requirements plan.
- Purchasing and production activity control.

Each level varies in purpose, time span, and level of detail. As we move from strategic planning to production activity control, the purpose changes from general direction to specific detailed planning, the time span decreases from years to days, and the level of detail increases from general categories to individual components and workstations.

Since each level is for a different time span and for different purposes, each differs in the following:

- Purpose of the plan.
- Planning horizon—the time span from now to sometime in the future for which the plan is created.
- Level of detail—the detail about products required for the plan.
- Planning cycle—the frequency with which the plan is reviewed.

Given the objectives set by the strategic business plan, sales and operations plan is concerned with the following:

- The quantities of each product group that must be produced in each period.
- The desired inventory levels.
- The resources of equipment, labor, and material needed in each period.
- The availability of the resources needed.

The level of detail is not high. For example, if a company manufactures children's bicycles, tricycles, and scooters in various models, each with many options, the production plan will show major product groups, or families: bicycles, tricycles, and scooters.

Production planners must devise a plan to satisfy market demand within the resources available to the company. This will involve determining the resources needed to meet market demand, comparing the results to the resources available, and devising a plan to balance requirements and availability.

This process of determining the resources required and comparing them to the available resources takes place at each of the planning levels and is the problem of capacity management. For effective planning, there must be a balance between priority and capacity.

The S&OP interacts with other functions as shown in Figure C.1:

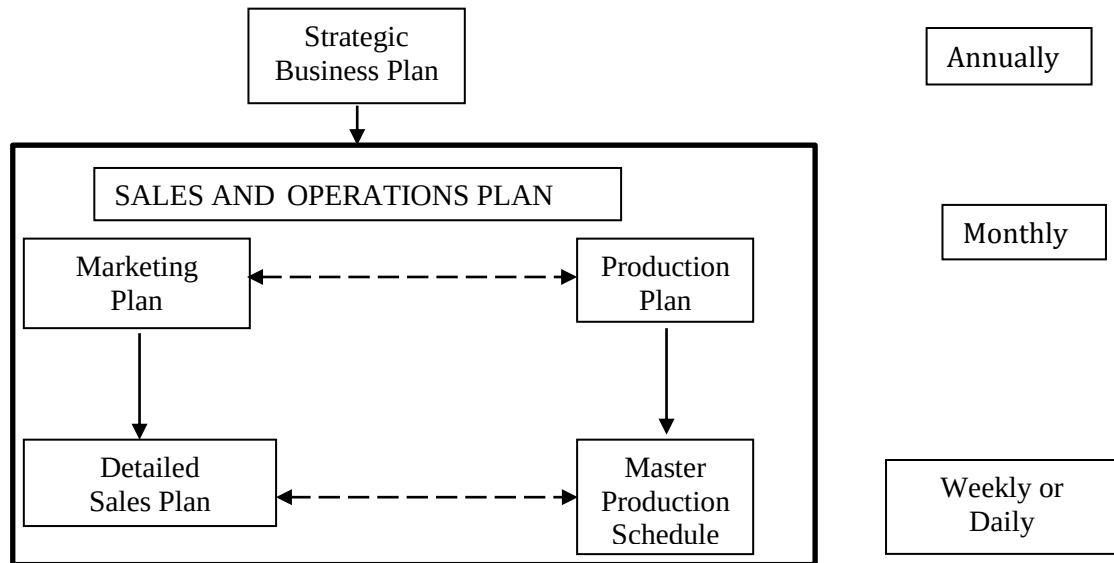


Figure C.1 S&OP interacts with other functions

Let's look at the basic way of how a sales and operation plan works in a firm. First the company makes its strategic business plan and usually CEO chairs this meeting. Strategic business plan has a minimum of 3years time horizon but it is developed on yearly basis, whereas sales and operation plan is developed on a monthly basis but has a time horizon of 1 or 1½ year and a master production schedule is developed on a weekly or daily basis but has a time horizon of three to four months.

Once the strategic plan has been developed, S&OP is developed using the input from it. Thus the sales and operation plan incorporates the targets, objectives and the strategies that were set in the strategic plan. The sales and operation plan can also be used to improve the strategic plan. This is done after evaluating the performance of the S&OP. If the changes are required e.g. in the targets for next year then the Strategic Plan will be updated.

One important thing to note is that due to the sales and operations plan, the coordination between the functional plan increases. Another thing is that the sales and operation plan is used to achieve the company's objectives since it is aligned with Strategic Business Plan.

S&OP Fundamentals

Some of the fundamentals of sales and operation plan are that we have to balance the demand and supply because if the demand is more than the supply then the customer service will suffer because there will be shortages, costs will increase as workforce will go in overtime to make up for shortages, also because faster transportation will be used and so on. Whereas if supply is greater than demand then inventories will build up due to which layoffs will occur as we don't need that much capacity and another thing is that profit margin will decrease as goods would be sold at discounts to dispose them off quickly etc. So it is important to keep a balance between demand and supply and we try to achieve that in the sales and operation plan. We achieve this by developing strategies in the sales and operation plan so that we can meet the demand over a business cycle. The important thing is that the management develops

the sales and operation plan to fulfill the strategic objective from a manufacturing point of view. The sales and operation plan is usually developed on aggregate terms.

S&OP Management

One thing one must realize is that the sales and operation plan is not a forecast. It is the planned production, stated on an aggregate basis, for which manufacturing management is to be held responsible. We should understand that if the forecast is wrong and on that basis the plan is developed then the operations manager should not be blamed, whereas if the forecast was fine but the plan he made was not good then he will be blamed and held responsible because planning is part of his job. If he makes a good plan then there will be cost saving, the demand will be met, customer service will increase, there will be a balance between supply and demand etc.

Sales and operation plan is linked with MPS, demand management, resource planning and through MPS to other MPC modules. This provides a good platform to conduct simulation to check different alternative plans that are available. Through S&OP the management can check the performance of MP because the value of the MPS function is questionable if there is no monitoring of performance – for instance deviations from the targets set in S&OP. Reconciliation of the MPS with the operations plan is a constant activity.

S&OP and MPC System

S&OP provides the key communication links for top management to coordinate various planning activities in a business. It balances sales/ marketing plans with available production resources. Along with the market and financial plans, the production plan is concerned with implementing the strategic business plan. The planning horizon is usually 6 to 18 months and is reviewed perhaps each month or quarter. The linkages with other modules of MPC system are shown in Figure C.2.

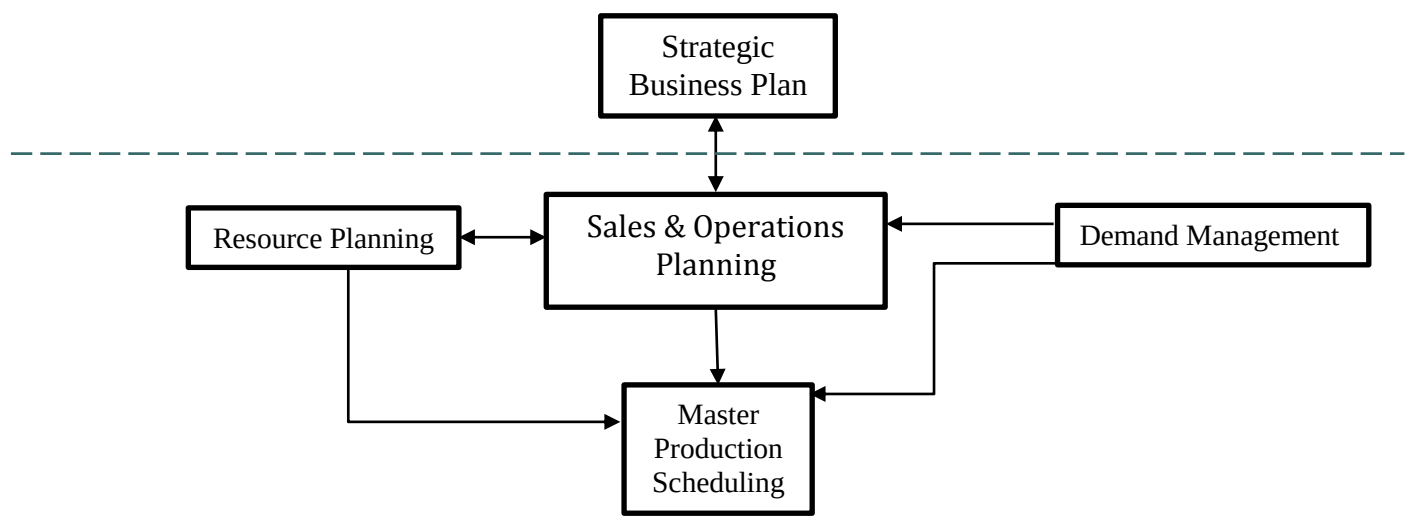


Figure C.2 S&OP linkages with other MPC modules

S&OP Process

Like stated earlier S&OP provides the key communication links for top management to coordinate various planning activities in a business. It is used to balance sales/ marketing plans with available production resources.

The monthly S&OP process is shown in Figure C.3.

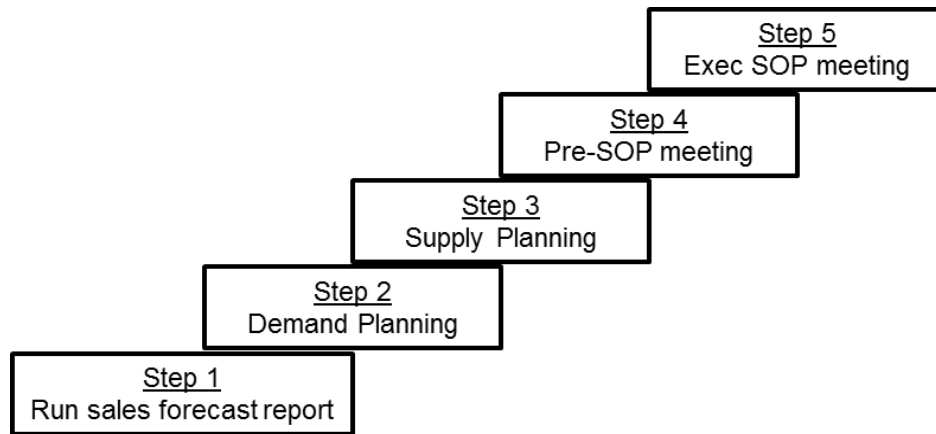


Figure C.3 Sales and Operations Planning Process

This process begins shortly after a month's end and continues for some days. It starts with the updating of the files with data from the month just ended. This information is then disseminated to relevant people. This becomes the basis to make changes in sales forecast.

The information received from the first step is used to make changes in operations plan as required. These changes are incorporated in the plan and a new plan is developed for twelve months or more. The new operations plan is compared with the changes made to check the availability of resources to meet these new requirements. If necessary the spending authorization from the top management is required so that the capacity could be enhanced to meet new targets.

The purpose of this meeting involving representatives from the various business functions is to (a) make decisions regarding the balance of demand and supply, (b) resolve problems where differences in recommendations exist, (c) identify areas that cannot be resolved to be discussed in the executive SOP meeting, (d) develop alternative courses of action, and (e) set the agenda for the executive SOP meeting.

The final step is Executive S&OP meeting. Its purpose is to (a) make decisions on the sales and operations plans for each product family, (b) authorize spending for changes in production/procurement rate changes, (c) relate the collective impact of the dollarized version of the product grouping sales and operations plans to the overall business plan, (d) break ties in areas where the pre-SOP team was unable to reach consensus, and (e) to review customer service and business performance.

S&OP Strategies

The S&OP develops plans based on different strategies. These plans, given the demand forecast for each period in the planning horizon, determine the production level, inventory level, and the capacity level for each period that maximizes the firm's (supply chain's) profit over the planning horizon. The plan is developed over a planning horizon of typically 3-18 months. The planning horizon is divided over different periods which are usually of one month duration each. Other key information are specified which are required to develop an aggregate plan. For example, the production rate, beginning and ending inventory required, beginning workforce, the cost per day per worker, number of shifts per day, inventory holding cost, hiring and layoff costs etc. The plan thus developed is a trade-off between the capacity, inventory, and backlog/lost sales.

There are different strategies that can be employed in operations plan and they are:

1. Level strategy – using inventory as the lever
2. Chase strategy – using capacity as the lever
3. Time flexibility from workforce or capacity strategy – using utilization as the lever
4. Mixed strategy – a combination of one or more of the first three strategies

The first three strategies are also called pure strategies. Let's look at them one by one.

Level Strategy

Level strategy maintains stable machine capacity and workforce levels with a constant output rate throughout the planning horizon. The workforce is neither hired nor fired during the planning horizon except at the very beginning. The demand is met through inventories, therefore, the production rate may be constant but inventory level fluctuates and shortages and surpluses result in fluctuations in inventory levels over time.

Inventories that are built up in anticipation of future demand or backlogs are carried over from high to low demand periods. Meaning that the inventories are built up during low demand period, whereas, they are consumed during high demand periods. Since the workforce is neither hired nor fired during the planning horizon, this strategy is better for worker moral. But the downside of this strategy is that large inventories and backlogs may accumulate. This strategy should be when inventory holding and backlog costs are relatively low.

Example 1:

Company XYZ Ltd. produces AA family of products. The six monthly demand of the product is given in the table below:

<i>Month</i>	<i>Demand Forecast</i>
January	1,600
February	3,000
March	3,200
April	3,800
May	2,200
June	2,200

The other data is as follows:

<i>Item</i>	<i>Cost</i>
Materials	\$10/unit
Inventory holding cost	\$2/unit/month
Marginal cost of a stockout	\$5/unit/month
Hiring and training costs	\$300/worker
Layoff cost	\$500/worker
Labor hours required	4/unit
Regular time cost	\$4/hour
Over time cost	\$6/hour
Cost of subcontracting	\$30/unit

Develop a level strategy operations plan for six months on the data provided above.

Solution:

Assuming no beginning inventory and no beginning workforce, and also assuming one shift of 8 hours per day, the plan is as given below:

Month	Jan	Feb	Mar	Apr	May	Jun
Demand	1,600	3,000	3,200	3,800	2,400	2,200
Production	2,700	2,700	2,700	2,700	2,700	2,700
Workforce	54	54	54	54	54	54
Hiring	54	-	-	-	-	-
Inventory	1,100	800	300	(800)	(500)	0

$$\text{Average Demand} = (1600 + 3000 + 3200 + 3800 + 2400 + 2200) / 6 \\ = 2,700$$

In this case the level production rate is the average demand per period. And using the production rate per worker we can calculate the number of workers required, which is:

$$\text{Number of workers} = \frac{2700 \text{ units per month} \times 4 \text{ hours per unit per worker}}{8 \text{ hours per day} \times 25 \text{ days per month}} \\ = 54 \text{ workers}$$

$$\text{Inventory} = \text{Opening Balance} + \text{Production} - \text{Demand} - \text{Backlog}$$

For Month 1

$$\text{Inventory} = 0 + 2,700 - 1,600 - 0 = 1,100$$

Total cost of the plan:

Month	Jan	Feb	Mar	Apr	May	Jun
Material cost	27,000	27,000	27,000	27,000	27,000	27,000
Regular cost	43,200	43,200	43,200	43,200	43,200	43,200
Hiring cost	16,200	-	-	-	-	-
Inventory cost	2,200	1,600	600	-	-	-
Stockout cost	-	-	-	4,000	2,500	-
Total Cost:	447,800					

Chase Strategy

In the chase strategy the capacity in terms of workforce varies, whereas, inventory remains constant. The changes in demand are met through increasing or decreasing workforce. Therefore, production rate is synchronized with demand by varying machine capacity or hiring and laying off workers as the demand rate varies. However, in practice, it is often difficult to vary capacity and workforce on short notice. Hiring and layoff frequently may demoralize the workforce. Also, it becomes difficult due to workers union, which may agitate if in every period the workforce is changed. Therefore, it is usually applied where daily wage workers are employed. Also, it is expensive if cost of varying capacity is high. For example, hiring cost may include training of a worker. If training is for longer period of time then the hiring cost could become very expensive.

The advantage of this strategy is that it results in low levels of inventory. Since the demand is usually met by varying capacity, the inventory that the company keeps may be only the safety stock. Therefore, this strategy should be used when inventory holding costs are high and costs of changing capacity are low.

Example 2:

Using the data provided in Example 1 (Level Strategy), develop a production plan for the six-month planning horizon based on Chase Strategy.

Solution

Month	Jan	Feb	Mar	Apr	May	Jun
Demand	1,600	3,000	3,200	3,800	2,400	2,200
Production	1,600	3,000	3,200	3,800	2,400	2,200
Workforce	32	60	64	76	48	44
Hiring	32	28	4	12	-	-
Layoff	-	-	-	-	28	4

Workforce required = $(1600 \times 4 \text{ hrs/unit}) / (8 \text{ hrs} \times 25) = 32$ (January)

Hiring = $Workforce_t - Workforce_{t-1}$

For February

Hiring = $Workforce_{\text{Feb}} - Workforce_{\text{Jan}} = 60 - 32 = 28$

Total Cost of the plan

Month	Jan	Feb	Mar	Apr	May	Jun
Material cost	16,000	30,000	32,000	38,000	24,000	22,000
Regular cost	25,600	48,000	51,200	60,800	38,400	35,200
Hiring cost	9,600	8,400	1,200	3,600	-	-
Layoff Cost	-	-	-	-	14,000	2,000
Total Cost:	460,000					

Time Flexibility Strategy

In time flexibility strategy, the workforce is kept stable but the hours worked over time are varied to synchronize production and demand. This strategy may be used when extra machine capacity is available. It means that the overtime or flexible work schedule can be used to meet the demand.

This strategy requires flexible workforce, but avoids morale problems of the Chase Strategy. In this strategy the inventory levels are low as it was in Chase Strategy. It should be employed when inventory holding costs are high and capacity is relatively inexpensive.

Example 3:

Using the data provided in Example 1 (Level Strategy) develop production plan based on Time Flexibility Strategy. Assume that overtime not more than 30% of the regular time can be used to meet the demand. Also, the outstanding demand can be met through subcontract after utilizing maximum overtime in a month.

Solution

Month	Jan	Feb	Mar	Apr	May	Jun
Demand	1,600	3,000	3,200	3,800	2,400	2,200
Regular time	1,600	2,900	2,900	2,900	2,400	2,200
Overtime	-	100	300	870	-	-
Subcontract	-	-	-	30	-	-
Workforce	58	58	58	58	58	58
Hiring	58	-	-	-	-	-

Number of workers required to meet the demand using this strategy can be calculated by assuming that the maximum overtime would be used to meet demand in the maximum demand period. In the current case the maximum demand period is April. Therefore, the number of workers required = $\frac{3800}{1.3} \times \frac{4}{8 \times 25} = 58.46 = 58$

Max. Regular Production in a period = $(58 \times 8 \times 25) / 4 = 2,900$ units

Max. Overtime Production in a period = $2,900 \times 0.3 = 870$ units

Total cost of the plan:

Month	Jan	Feb	Mar	Apr	May	Jun
Material cost	16,000	30,000	32,000	38,000	24,000	22,000
Regular cost	46,400	46,400	46,400	46,400	46,400	46,400
Hiring cost	17,400	-	-	-	-	-
Overtime cost	-	600	1,800	5,220	-	-
Subcontract	-	-	-	900	-	-

Total Cost: 466,320

D. Inventory Management

Inventories are materials and supplies that a business or institution carries either for sale or to provide inputs or supplies to the production process. All businesses and institutions require inventories. Often they are a substantial part of total assets. Financially, inventories are very important to manufacturing companies. On the balance sheet, they usually represent from 20% to 60% of total assets. As inventories are used, their value is converted into cash, which improves cash flow and return on investment. There is a cost for carrying inventories, which increases operating costs and decreases profits. Good inventory management is essential.

Inventory management is responsible for planning and controlling inventory from the raw material stage to the customer. Since inventory either results from production or supports it, the two cannot be managed separately and, therefore, must be coordinated. Inventory must be considered at each of the planning levels and is thus part of production planning, master production scheduling, and material requirements planning. Production planning is concerned with overall inventory, master planning with end items, and material requirements planning with component parts and raw material.

After completing this lecture, students should be able to:

- *Differentiate between different types of inventory and appreciate their importance in production planning*
- *Measure different costs associated with inventory management*
- *Demonstrate the knowledge of different types of inventory management systems employed in the industry*
- *Apply different models to solve inventory problems in different environment*

Arguments For and Against Inventory

On the one hand there are pressures on the system to maintain inventory, whereas, on the other management is under tremendous pressure to get rid of inventories due to various reasons.

Arguments for inventory

Inventory is kind of a buffer that we keep for different reasons. Some of the reasons that we keep inventory are:

1. There are several geographic locations where the product is needed and we cannot have production system located in each location to meet the demand scale economies reasons, therefore, we maintain inventory in each location to meet the demand.
2. Another reason is that to achieve economies of scale we produce large quantities although the demand is low and any quantity which is over and above the demand is stocked.
3. Through inventory we meet demand. This way the demand can be met immediately, whereas, if we have no inventory and demand arises and only then start production then the lead time will increase and the customer service will be low.
4. Another reason for keeping inventory is that because of it we can avoid stock outs.
5. Similarly due to inventories we can achieve operating efficiencies in production, transportation, and procurement. For example, if we purchase from supplier in large quantities then he might give us discounts, whereas, another way is that maybe you are importing from, let's say, Australia and your requirement is half container load but if you order a full container load then your transportation cost also decreases per unit compared to if you had ordered only what you required.

6. Inventory can also be kept if the goods have seasonal demands like with soft drinks if you believe that their demand will spike greatly in the summers then you can keep inventory so that you don't run out during that particular period when it is actually needed.
7. Also inventory is kept to create a buffer against uncertainties like fluctuations in demand.
8. Inventories are also kept to hedge against price increase in future.

Arguments against Inventory

There are also arguments against keeping inventories.

1. One of the arguments against inventory is that it is waste, which ties up the cash.
2. Another argument against inventory is that it hides inefficiencies in the system. For example if there are frequent machine breakdowns we tend to keep inventories so that we do not lose sales during breakdown period.
3. If we keep large inventory and unable to sell it before a new model is introduced, the chances are that the inventory will become obsolete and we will have to sell it at discounted price. This is true for designer clothes which become obsolete once the season is over.
4. The inventory not only ties up cash, it also has high holding cost which is normally 25% of the unit cost and it can reach as high as 40%.
5. Inventories also carry higher insurance premium.
6. Large inventories also are subject to pilferage.

Types of Inventory

Inventories can be categorized in five distinct forms in terms of their functions and these are.

1. Pipeline Stock

First, inventories may be in the pipeline. These are inventories in transit between echelons of the supply channel. Where movement is slow and/or over long distances, or movement must take place between many echelons, the amount of inventory in the pipeline may well exceed that held at the stocking points. Similarly, work-in-process inventories between manufacturing operations can be considered as inventories in the pipeline.

2. Speculative Stock

Second, some stocks may be held for speculation, but they are still part of the total inventory base that must be managed. Raw materials such as copper, gold, and silver are purchased as much for price speculation as they are to meet operating requirements.

3. Regular/Cyclical/Seasonal Stock

Third, stocks may be regular or cyclical in nature. These are the inventories necessary to meet the average demand during the time between successive replenishments. The amount of cycle stock is highly dependent on production lot sizes, economical shipment quantities, storage space limitations, replenishment lead times, price-quantity discount schedules, and inventory carrying costs.

4. Safety Stock

Fourth, inventory may be created as a hedge against the variability in demand for the inventory and in replenishment lead time. This extra measure of inventory, or safety stock, is in addition to the regular stock that is needed to meet average demand and average lead-time conditions. Safety stock is determined from statistical procedures that deal with the random nature of the variability involved. The amount of safety stock maintained depends on the extent of the variability involved and the level of stock availability that is provided.

5. Obsolete/Dead Stock

Finally, some of the inventory deteriorates, becomes out of date, or is lost or stolen when held for a time. Such inventory is referred to as obsolete, dead, or shrinkage stock. Where the products are of high value, perishable, or easily stolen, special-precautions must be taken to minimize the amount of such stock.

The inventory is also classified in terms of their physical nature:

1. Raw materials – not yet entered into the production process.
2. Work-in-process (WIP)
3. Finished goods
4. Distribution inventories
5. Maintenance, repair, and operational supplies (MRO)

Nature of Demand

The nature of demand over time plays a significant role in determining how we treat the control of inventory levels.

Perpetual demand

Perhaps the most common demand characteristic is for it to continue into the indefinite future. The demand pattern is referred to as perpetual. Although demand for most products rises and falls through their life cycles, many products have a selling life that is sufficiently long to be considered infinite for planning purposes. Even though brands turn over at the rate of 20 percent per year, a life cycle of three to five years can be long enough to justify treating them as having a perpetual demand pattern.

Seasonal demand

On the other hand, some products are highly seasonal or have a one-time spike, demand pattern. Inventories that are held to meet such a demand pattern usually cannot be sold off without deep price discounting. A single inventory replenishment order must be placed with little or no opportunity to reorder or return goods if demand has been inaccurately projected. Fashion clothing, Christmas trees, and political campaign buttons are examples of this type of demand pattern.

Lumpy demand

Similarly, demand may display a lumpy, or erratic, pattern. The demand may be perpetual, but there are periods of little or no demand followed by periods of high demand. The timing of lumpy demand is not as predictable as for seasonal demand, which usually occurs at the same time every year. Items in inventory are typically a mixture of lumpy and perpetual demand items. A reasonable test to separate these is to recognize that lumpy items have a high variance around their mean demand level. If the standard deviation of the demand distribution, or the forecast error, is greater than the average demand, or forecast, the item is probably lumpy. Inventory control of such items is best handled by intuitive procedures, or by a modification of the mathematical procedures or through collaborative forecasting.

Terminating demand

There are products whose demand terminates at some predictable time in the future, which is usually longer than one year. Inventory planning here involves maintaining inventories to just meet demand requirements, but some reordering within the limited time horizon is allowed. Textbooks with planned revisions, spare parts for military aircraft, and pharmaceuticals with a limited shelf life are examples of products with a defined life. Since the distinction between these products and those with a perpetual life is often blurred, they will not be treated differently from perpetual-life products for the purposes of developing a methodology to control them.

Derived demand

Finally, the demand pattern for an item may be derived from demand for some other item. The demand for packaging materials is derived from the demand for the primary product. The inventory control of such dependent demand items is best handled with some form of just-in-time planning such as MRP or DRP.

Inventory Management Objectives

Inventory management involves balancing product availability, or customer service, on the one hand with the costs of providing a given level of product availability on the other. Since there may be more than one way of meeting the customer service target, we seek to minimize inventory-related costs for each level of customer service.

Service objectives are setting stocking levels so that there is only a specified probability of running out of stock. While, cost objectives are balancing conflicting costs to find the most economical replenishment quantities and timing. Figure D.1 depicts the balancing act of cost objectives with service objectives.

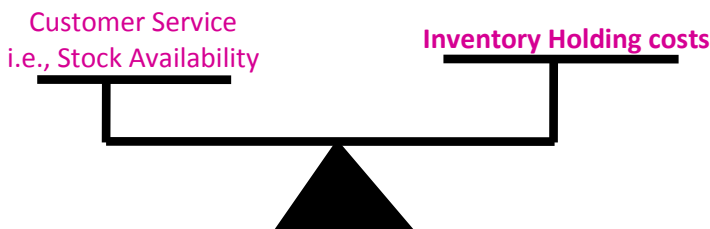


Figure D.1 Balancing of conflicting costs

Relevant Inventory Cost

Three general classes of costs are important to determining inventory policy: ordering costs, carrying costs, and stockout costs. These costs are in conflict, or in trade-off, with each other. For determining the order quantity to replenish an item in inventory, these relevant costs trade-off are shown in Figure D.2.

Ordering Cost

Costs associated with the acquisition of goods for the inventory replenishment are often a significant economic force that determines the reorder quantities. When a stock replenishment order is placed, a number of costs are incurred that are related to the processing, setup, transmitting, handling, and purchase of the order. More specifically, procurement costs may include the price, or manufacturing cost, of the product for various order sizes; the cost for setting up the production process; the cost of processing an order through the accounting and purchasing departments; the cost of transmitting the order to the supply point, usually using mail or electronic means; the cost of transporting the order when transportation charges are not included in the price of the purchased goods; and the cost of any materials handling or processing of the goods at the receiving point. When the firm is self-supplied, as in the case of a factory replenishing its own finished goods inventories, procurement costs are altered to reflect production setup costs.

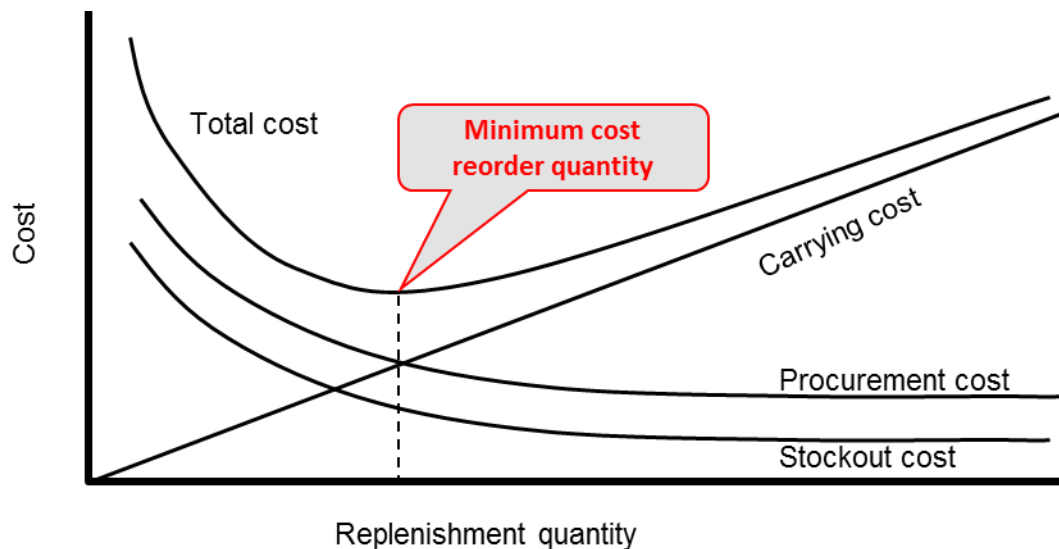


Figure D.2 Trade – offs between relevant costs

Inventory Carrying Cost

Inventory carrying costs result from storing, or holding, goods for a period and are roughly proportional to the average quantity of goods on hand. These costs can be collected into four classes: space costs, capital costs, inventory service costs, and inventory risk costs.

Space costs are charges made for the use of the volume inside the storage building, which include building rent, utilities, handling equipment etc. Space costs are irrelevant when calculating carrying costs for in-transit inventories. While capital costs refer to the cost of the money tied up in inventory. This cost may represent over 80 percent of total inventory cost. It also includes obsolescence, insurance, personal property taxes etc. Typically, carrying costs range from the cost of short term capital to about 40% per year. The average is about 25% per year of the item value in inventory.

Stockout Cost

Out-of-stock costs are incurred when an order is placed but cannot be filled from the inventory to which the order is normally assigned. There are two kinds of out-of-stock costs: lost sales costs and back order costs. In lost sales the profit is immediately gone and future profits are gone through loss of goodwill. While, in backorders, although the profit is not lost but it may cost extra order handling, as well as, cost of additional transportation, handling, and loss of goodwill.

Management Philosophy

Inventory management is developed around two basic philosophies: (1) Pull inventory control; (2) Push inventory control. The push versus pull inventory control is shown in Figure D.3.

Pull Inventory Control

This philosophy views each stocking point, for example, a warehouse, as independent of all others in the channel. It draws inventory into the stocking location. Forecasting demand and determining replenishment quantities are accomplished by taking into account only local conditions. No direct consideration is given to the effect that the replenishment quantities, each with their different levels and timing, will have on the economics of the sourcing plant. However, this approach does give precise control, over inventory levels at each location.

Push Inventory Control

When decisions about each inventory are made independently, the timing and replenishment order sizes are not necessarily well coordinated with production lot sizes, economical purchase quantities, or order size minimums. Therefore, many firms choose to allocate replenishment quantities to inventories based on projected needs for inventories at each location, available space, or some other criteria. Inventory levels are set collectively across the entire warehousing system. Typically, the push method is used when purchasing or production economies of scale outweigh the benefits of minimum collective inventory levels as achieved by the pull method.

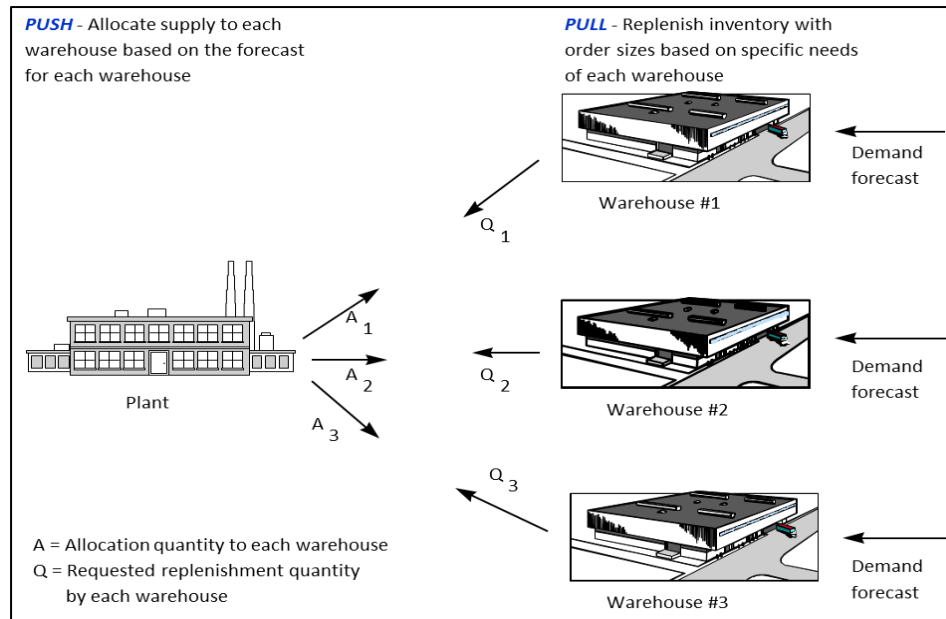


Figure D.3 Push versus pull inventory control

Single Order Quantity

Many practical inventory problems exist where the products involved are perishable or the demand for them is a one-time event. Products such as fresh fruits and vegetables, cut flowers, newspapers, and some pharmaceuticals have a short and defined shelf life, and they are not available for subsequent selling periods. In such cases only one time order can be placed.

To find the most economic order size (Q^*), determine cost of under stock (C_u) and cost of overstock (C_o). Cost of under stock is basically the loss of profit or margin since due to under stock we will lose sales which will affect our profit margin. Therefore,

$$C_u = \text{Selling price per unit} - \text{Purchase cost per unit}$$

The cost of overstock is the loss of revenue because of the markdown price of the product, which could not be sold during the season and now it is sold at a discount (salvage value), which is usually less than the purchase price. Therefore,

$$C_o = \text{Purchase cost per unit} - \text{Salvage value}$$

Let $P(D)$ be the probability of demand less than or equal to D , then

$$P(D) = \frac{C_u}{C_u + C_o}$$

It is the probability where the expected profit maximizes.

Example 1:

Clothing item is purchased for a seasonal sale. It costs \$35, but it has a sale price of \$50. After the season is over, it is marked down by 50% to clear the merchandise. The estimated quantities to be sold are:

Number of Items, n	Probability of selling exactly n items	Cumulative Probability P (D)
10	0.15	0.15
15	0.20	0.35
20	0.30	0.65
25	0.20	0.85
30	0.10	0.95
35	0.05	1.00

Solution

$$\text{Profit} = \$50 - \$35 = \$15$$

$$\text{Loss} = \$35 - (0.5)(50) = \$10$$

$$P^*(D) = 15 / (15 + 10) = 0.60$$

Demand at $P^*(D)$ is between 15 and 20 items, round up and order 20 items.

Repetitive Order Quantities

In contrast to demand that occurs only periodically or possibly only once, demand may be perpetual. Inventory replenishment orders repeat over time and may be supplied instantaneously in their entirety. The concept is depicted in Figure D.4.

When demand is continuous and the rate is essentially constant, controlling inventory levels is accomplished by specifying: (1) the quantity that will be used to replenish the inventory on a periodic basis and (2) the inventory replenishment frequency. This is a problem of balancing conflicting cost patterns. In the simplest case, it requires balancing procurement costs against carrying costs.

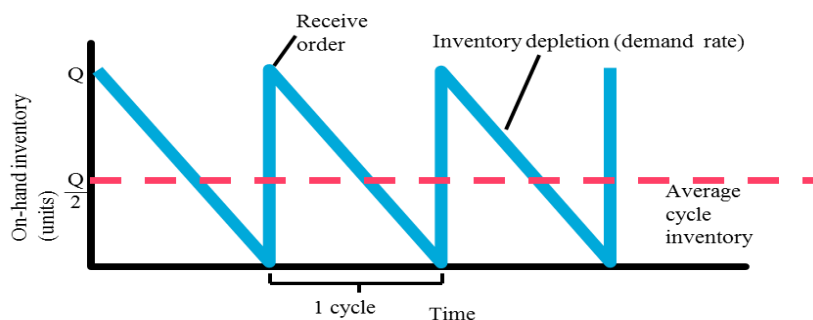


Figure D.4 Repeated inventory replenishment orders

EOQ Model

The basic EOQ formula is developed from a total cost equation involving procurement cost and inventory carrying cost. It is expressed as

$$\text{Total cost} = \text{Procurement cost} + \text{Carrying cost}$$

$$TC = \frac{D}{Q}S + \frac{Q}{2}iC$$

Where;

TC = total annual relevant inventory cost, dollars

Q = order size to replenish inventory, units

D = Item annual demand occurring at a certain and constant rate over time, units/year

S = Procurement cost, dollars/order

C = Item value carried in inventory, dollar/unit

i = carrying cost as a percent of item value, percent/year

The term D/Q represents the number of times per year a replenishment order is placed on its supply source. The term $Q/2$ is the average amount of inventory on hand. As Q varies in size, one cost goes up as the other goes down. It can be shown mathematically that an optimal order quantity (Q^*) exists where the two costs are in balance and the minimal total cost results. The formula for this EOQ is

$$EOQ = Q^* = \sqrt{\frac{2DS}{iC}}$$

The optimal time between orders is, therefore,

$$T^* = \frac{Q^*}{D} \text{ year}$$

and the optimal number of times per year to place an order is

$$N^* = \frac{D}{Q^*}$$

Example 2:

An industrial machine tools manufacturer supplies replacement parts from its inventory. For a particular part, the annual demand is expected to be 750 units. Machine setup costs are \$50, carrying costs are 25 percent per year, and the part is valued in inventory at \$35 each. The economic order quantity placed on production is

$$Q^* = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2 \times 750 \times 50}{.25 \times 35}} = 92.58 = 93$$

This order size is expected to be placed in production every $T^* = Q^*/D = 92.58/750 = 0.12$ years, or $0.12 \text{ (years)} \times 52 \text{ (weeks per year)} = 6.4$ weeks. For practical reasons, we may wish to round this to 6 or 7 weeks with some slight increase in total costs.

Total annual cost of this inventory control policy is

$$TC = \frac{D}{Q}S + \frac{Q}{2}iC = \frac{750}{93} \times 50 + \frac{93}{2} \times 0.25 \times 35 = 810.10$$

Reorder Point Control with Demand Uncertainty

Reorder point inventory control assumes that demand is perpetual and continually acts on inventory to reduce its level. When inventory is depleted to the point where its level is equal to or less than a specified quantity called the reorder point, an economic order quantity of Q^* is placed on the supplying source to replenish the inventory. The effective inventory level at a particular point in time is the quantity on hand plus the quantity on order, less any commitments against the inventory, such as customer back orders or allocations to production or customers. The entire quantity Q^* arrives at a point in time offset by the lead time. Between the time when the replenishment order is placed at the reorder point and when it arrives in stock, there is a risk that demand will exceed the remaining amount of inventory. The probability of this occurring is controlled through raising or lowering the reorder point

and by adjusting Q^* . In this system, we are interested in determining (1) Economic Order Quantity, and (2) Reorder Point. Good method for products of high value that are purchased from one vendor or plant having few economies of scale in production, purchasing, or transportation.

Economic Order Quantity

The order is determined using EOQ model, which is given by:

$$Q^* = \sqrt{\frac{2DS}{iC}}$$

where:

Q^* : Economic order quantity

D: Annual demand

S: Ordering cost per order

i: inventory holding cost as %age of unit cost per year

C: Unit cost

Reorder Point

The reorder point is determined using the following equation:

$$ROP = \bar{d}L + zs'_d$$

where:

ROP: Reorder point

$\bar{d}$: average demand per period

L: Lead time

s'_d : Standard deviation of demand during lead time

Example 3:

Buyers Products Company distributes an item known as a tie bar, which is a U-bolt used on truck equipment. The following data have been collected for this item held in inventory, find EOQ and ROP.

Average demand, d	= 50 units/week
Product cost, C	= \$5/unit
Standard deviation of demand during lead time, s_d	= 10 units/week
Lead time, L	= 3 weeks
Inventory holding cost as %age of product cost, i	= 10%/year
In-stock probability during lead time, P	= 99%
Ordering cost, S	= \$10/order
Stockout cost, k	= \$2/unit

Solution

From the EOQ formula:

$$Q^* = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(50 \times 52)(\$10)}{0.10(\$5)}} = 322$$

Now,

$$\bar{X} = \bar{d}(L) = 50(3) = 150$$

$$s'_d = s_d\sqrt{L} = 10\sqrt{3} = 17.3$$

Hence

$$ROP = \bar{X} + zs'_d = 150 + 2.33(17.3) = 190 \text{ units}$$

where 2.33 is the value of z at a probability of 0.99 taken from a normal distribution table. The average inventory level (AIL) is given by:

$$\begin{aligned} AIL &= \frac{Q}{2} + \text{safety stock} = \frac{Q}{2} + z s'_d \\ &= \frac{Q}{2} + z s_d \sqrt{L} \\ &= \frac{322}{2} + 2.33(10\sqrt{3}) = 201.36 \cong 201 \end{aligned}$$

Based on the above calculations, the ordering policy is that when the inventory level (on hand + in transit – back orders) reaches less than equal to 190 units place an order of 322 units.

Total Relevant Cost

The total relevant cost is useful for comparing alternative inventory policies or determining the impact of deviations from optimum policies. We add two new terms to the total cost formula stated in the equation above, which account for uncertainty. These are safety stock and out-of-stock terms. Total cost can now be expressed as

$$TC = \frac{DS}{Q} + \frac{QiC}{2} + z s'_d iC + k \frac{D}{Q} s'_d E(z)$$

where,

TC: Total cost

D: annual demand

Q: Order quantity

i: inventory holding cost

C: Product cost/unit

z: corresponding value of P from standard normal table

s'_d : Standard deviation of demand during lead time

k: Stockout cost

$E(z)$: 1.00

Let's assume that the out-of-stock cost (k) is \$2/unit in the above example.

Hence, the total relevant inventory cost is given by

$$\begin{aligned} TC &= \frac{2600(\$10)}{322} + \frac{322(0.1)(\$5)}{2} + 2.33(17.3)(0.1)(\$5) \\ &\quad + \$2 \frac{2600}{322} (17.3)(0.0034) = \$182.20 \end{aligned}$$

Non-instantaneous Resupply

In a number of cases, production or supply continues while demand is depleting inventories. That means it is not the case of instantaneous buildup of inventory. For example, when production is taking place then the inventory is buildup over time but also some inventory is being by the demand. The order quantity now becomes the production run, or production lot size, quantity (POQ) labeled Q_p^* . To find Q_p^* the basic order quantity formula is modified as follows:

$$Q_p^* = \sqrt{\frac{2DS}{iC}} \sqrt{\frac{p}{p-q}}$$

Where,

p = production or supply rate

d = demand rate

This is only applicable if $p > d$. In this case only Q^* changes but ROP remains unchanged from that of the instantaneous resupply.

Example 4:

An industrial machine tools manufacturer supplies replacement parts from its inventory. For a particular part, the annual demand is expected to be 750 units with standard deviation of demand during lead time of 50 units. Machine setup costs are \$50, carrying costs are 25 percent per year of the product value, and the part is valued in inventory at \$35 each.

Suppose that the production rate for these parts is 50 units per week. Also, let's assume that it takes 1.5 weeks to setup the production. Also, the management wants in-stock probability of 95% during lead time. Determine the optimum production lot size and reorder point for the replacement part.

Solution

Here

$D = 750$ units

$s_d = 50$ units

$S = \$50$

$i = 0.25$

$C = \$35$

$p = 50$ units per week

$d = 750/52 = 14.42$ units per week

The optimum production run quantity is:

$$Q_p^* = \sqrt{\frac{2DS}{iC}} \sqrt{\frac{p}{p-d}}$$

$$= \sqrt{\frac{2(750)(50)}{0.25(35)}} \sqrt{\frac{50}{50 - 14.42}} = 109.74 \cong 110$$

Reorder Point (ROP) is:

$$ROP = \bar{d}(LT) + z(s'_d)$$

$$= \frac{750}{52}(1.5) + 1.65(50) = 96.92 \cong 97 \text{ units}$$

Service Level

(The Reorder Point Method with Known Stockout Costs)

When the stockout costs are known, it is not necessary to assign a customer service level. The optimum balance between service and cost can be calculated. Since P and Q are interrelated an iterative method is used as follows:

Step 1:

Initially solve for Q using EOQ model:

$$Q = \sqrt{\frac{2DS}{iC}}$$

Step 2:

Compute the probability of being in stock during the lead-time if back ordering is allowed:

$$P = 1 - \frac{QiC}{Dk}$$

or if during a stockout the sales are lost:

$$P = 1 - \frac{QiC}{DK + QiC}$$

Step 3:

Determine a revised Q from a modified EOQ formula, which is

$$Q = \sqrt{\frac{2D[S + ks'_d E(z)]}{iC}}$$

Step 4:

Repeat Steps 2 and 3 until there is no difference between previous value of P or Q and the current value of P or Q.

Step 5:

Compute ROP and other statistics.

Example 5:

Buyers Products Company distributes an item known as a tie bar, which is a U-bolt used on truck equipment. The following data have been collected for this item held in inventory:

Monthly demand forecast, d	11,107 units
Std. error of forecast, s_d	3,099 units
Replenishment lead time, L	1.5 months
Item value, C	\$0.11 per unit
Cost for processing vendor order, S	\$10 per order
Carrying cost, i	20% per year
In-stock probability during lead time, P	Unknown
Stockout cost, k	\$0.01 per unit

Find the optimal level of in-stock probability and order quantity if back orders are allowed.

Solution

Step 1: Determine Q using EOQ model

$$Q = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(11,107 * 12)(\$10)}{0.2(\$0.11)}} = 11,008 \text{ units}$$

Step 2: Using Q, find P

$$P = 1 - \frac{QiC}{Dk} = 1 - \frac{11,008(0.2)(\$0.11)}{(11,107 * 12)(\$0.01)} = 0.82$$

Step 3: Using P, find revised Q

From Standard Normal Table find $z_{@0.82}=0.92$ and from Unit Normal Loss Integral find $E_{(0.92)}=0.0968$

For these data, s'_d is calculated as

$$s'_d = s_d \sqrt{LT} = 3,099 \sqrt{1.5} = 3,795 \text{ units}$$

$$Q = \sqrt{\frac{2D[S + ks'_d E(z)]}{iC}}$$

$$= \sqrt{\frac{2(11,107 \times 12)[\$10 + \$0.01(3,795)(0.0968)]}{0.2(\$0.11)}} = 12,872 \text{ units}$$

Repeat Step 2: Revise P

$$P = 1 - \frac{12,872(0.2)(\$0.11)}{(11,107 \times 12)(\$0.01)} = 0.79$$

Now, $z_{@0.81}=0.81$ and $E_{(0.81)}=0.1181$

Repeat Step 3: Revise Q

$$Q = \sqrt{\frac{2(11,107 \times 12)[\$10 + \$0.01(3,795)(0.1181)]}{0.2(\$0.11)}} = 13,246 \text{ units}$$

Continue to revise Q and P until no further change occurs.

Values of optimum $P=78\%$ and $Q=13,395$ units

Periodic Review Model

All alternative to the reorder point method of control is the periodic review method. Although the reorder point method offers precise control over each item in inventory and, therefore, the lowest total relevant cost, it has some economic disadvantages. For example, each item is possibly ordered at a different time, thus missing joint production, transportation, or buying economies. Administratively, reorder point control requires constant monitoring of the inventory levels. Alternatively, under periodic review control, inventory levels for multiple items can be reviewed at the same time so that they may be ordered together, thus realizing production, transportation, or purchasing economies.

In this system, the inventory is reviewed at a fixed time interval (T). The order quantity (Q) is the difference between target inventory level (TI) (or the allowable maximum inventory level (MAX)) and the quantity on hand. Therefore, in this system the quantity varies but the review period or the time between successive orders is fixed.

Here, we are interested in finding the target inventory level and the review period T^* .

Review Period (T^*) is given by

$$T^* = \frac{Q^*}{D} \text{ year}$$

Target Inventory (TI) is determined by

$$TI = \bar{d}(T^* + LT) + zs'_d$$

Example 6:

Using the data provided in the U-bolt problem in the solved example of reorder point system reproduced below, find the target inventory and review period.

Average demand, d	= 50 units/week
Product cost, C	= \$5/unit
Standard deviation of demand during lead time, s_d	= 10 units/week
Lead time, L	= 3 weeks
Inventory holding cost as %age of product cost, i	= 10%/year
In-stock probability during lead time, P	= 99%
Ordering cost, S	= \$10/order
Stockout cost, k	= \$2/unit

Solution

Determine Q using EOQ model:

$$Q^* = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2(50 \times 52)(\$10)}{0.1(\$5)}} = 322 \text{ units}$$

Using the value of Q^* find T^*

$$T^* = \frac{Q^*}{D} = \frac{322}{50 \times 52} = 0.124 \text{ years} \times 52 = 6.4 \text{ weeks}$$

Expected demand during lead time and review period $DDL T \& T^*$ is given by:

$$DDL T \& T^* = \bar{d}(LT + T^*) = 50(3 + 6.4) = 470$$

Also, $s'_d = s_d \sqrt{LT + T^*} = 10\sqrt{3 + 6.4} = 30.65$

Determine TI

$$TI = \bar{d}(LT + T) + z s'_d = 470 + 2.33(30.65) = 541.4 \cong 541 \text{ units}$$

Policy: Review the inventory every 6.4 weeks and place an order for the difference between the TI level of 541 units and the quantity on hand + quantity on order – backorders.

E. Master Production Schedule (MPS)

After production planning, the next step in the manufacturing planning and control process is to prepare a master production schedule (MPS). The MPS is a vital link in the production planning system:

- *It forms the link between production planning and what manufacturing will actually build.*
- *It forms the basis for calculating the capacity and resources needed.*
- *The MPS drives the material requirements plan.*
- *As a schedule of items to be built, the MPS and bills of material determine what components are needed from manufacturing and purchasing.*
- *It keeps priorities valid. The MPS is a priority plan for manufacturing.*

Whereas the production plan deals in families of products, the MPS works with end items. It breaks down the production plan into the requirements for individual end items, in each family, by date and quantity.

After completing this lecture, the students should be able to:

1. *Explain the role of MPS in MPC and its relation with other business activities*
2. *Demonstrate the knowledge of different techniques available to assist this process*
3. *Convert MPS into final build schedule*
4. *Apply two-level MPS in complex environment*

Master Production Scheduling Activities

We have seen that S&OP deals with the families of products in an aggregate term. While, the MPS on the other hand breaks down the production plan into the requirements for individual end product items in each family. It translates S&OP into a plan for producing specific products. Therefore, we can say that the MPS is the translation of the S&OP into producible products.

At the operational level the MPS:

- Is a statement of planned the future output.
 - It reflects the needs of the marketplace and
 - It also reflects the capacity of manufacturing and forms a priority plan for manufacturing to follow.
- Forms a vital link between sales and production as follows:
 - It makes possible valid order promises. The MPS is a plan of what is to be produced and when. As such, it tells sales and manufacturing when goods will be available for delivery.
 - It is a contract between marketing and manufacturing. It is an agreed-upon plan.
- Is developed to be compatible with the Materials Requirement Planning (MRP) system.

As the statement of output, the MPS:

- Forms the basic communication between the market and manufacturing.
- Is stated in product specification terms (part numbers) as:
 - End-item product designations
 - Options or modules from which a variety of end products could be assembled.
 - Numbers of units of an “average” final product

The Business Environment of MPS

As we have discussed previously there are three basic environments in which a manufacturing firm operates. These environments encompass the production approach used, the variety of products produced, and the markets served by the company.

For Make-to-Stock firm, the items are produced in batches, carrying finished goods inventories for most, if not all, end-items. In this environment, a limited number of standard items are assembled from many components. Televisions and other consumer products are examples. The MPS is usually a schedule of finished-goods items.

For Assemble-to-order firm there are limitless possible end-item configurations and they are all made from combinations of basic components and subassemblies. It is possible that the final assembly will not start until order arrives. In this environment, many end items can be made from combinations of basic components and subassemblies. For example, suppose a company manufactures paint from a base color and adds tints to arrive at the final color. Suppose there are 10 tints and a final color is made by mixing any three of them with the base. There are 720 possible colors. Forecasting and planning production for 720 items is a difficult task. It is much easier if production is planned at the level of the base color and the 10 tints. There are then only 10 items with which to deal: the base color and each of the 10 tints. Once a customer's order is received, the base color and the required tints can be combined (assembled) according to the order.

Make-to-Order firm, in general, carries no finished goods inventory and builds each customer order as needed. The MPS unit is defined as the particular end-item composing a customer order. Production often starts before a complete product definition or BOM has been determined. In this environment, many different end items are made from a small number of components. Custom-tailored clothes are an example. The MPS is usually a schedule of the actual customer orders.

Linkages with Other Modules

The MPS forms a basis for sales and production to determine what is to be manufactured. It is not meant to be rigid. It is a device for communication and a basis to make changes that are consistent with the demands of the marketplace and the capacity of manufacturing. The linkages with other MPC modules are shown Figure E.1.

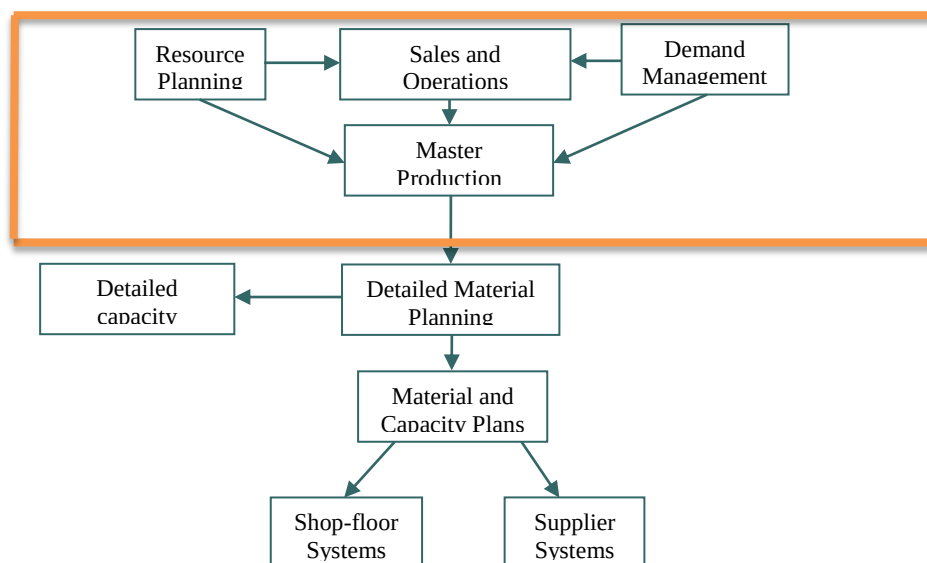


Figure E.1 MPS linkages with other MPC modules

The MPS forms a basis for sales and production to determine what is to be manufactured. It is not meant to be rigid. It is a device for communication and a basis to make changes that are consistent with the demands of the marketplace and the capacity of manufacturing.

The information needed to develop an MPS is provided by:

- The production plan informs the MPS what should be produced in a given period in an aggregate term. The aggregate operations plan constrains the MPS, because the sum of the detailed MPS quantities must always equal the whole as defined by the operations plan.
- In sales and operations planning, the forecasts from demand management will be consolidated and incorporated into the sales and operations plan. While, demand management would provide forecasts from all sources for individual end items to MPS. It also provides actual orders received from customers and for stock replenishment, delivery dates, and product details to MPS.
- Rough-cut capacity planning checks whether critical resources are available to support the preliminary master production schedules. Critical resources include bottleneck operations, labor, and critical materials. It provides an analysis of MPS and point out any capacity constraints that may limit the production flow.
- Finally it is linked with detailed material module. It drives all, the engine and subsequently the back-end systems, as well as the rough-cut capacity planning activities.

Master Production Scheduling Techniques

The objectives in developing an MPS are as follows:

- To maintain the desired level of customer service by maintaining finished-goods inventory levels or by scheduling to meet customer delivery requirements.
- To make the best use of material, labor, and equipment.
- To maintain inventory investment at the required levels.

To reach these objectives, the plan must satisfy customer demand, be within the capacity of manufacturing, and be within the guidelines of the production plan.

The Time-Phased Record

Time-phased MPS records can be easily produce. They are consistent with MRP record format. A simple example of time-phased record is given to illustrate how it works.

Example 1:

XYZ Co. Limited schedules production of one end product, Hi-Sulfur, in batches of 80 units whenever the projected ending inventory balance in a quarter falls below 10 units. It takes one quarter to make a batch of 80 units. XYZ currently has 30 units on hand. The sales forecast for the next four quarter is:

	Quarter			
	1	2	3	4
Forecast	20	70	70	20

Prepare a time-phased MPS record showing the sales forecast and MPS for Hi-Sulfur. Also determine available (inventory) balance at the end of each quarter.

Solution

	Quarter			
	1	2	3	4
Forecast	20	70	70	20
Available	10	20	30	10
MPS		80	80	
On hand	30			

Lot size: 80 units; Safety stock: 10 units

$30 - 20 = 10$ $80 + 10 - 70 = 20$

A Level Production Approach

In level production approach same level of production rate is in every period throughout the planning horizon. It calls for no production, workforce or other capacity adjustments. The demand is met through inventory which is built up during low demand periods. The following example illustrates how this approach works.

Example 2:

ABC Co. Limited uses level strategy to schedules production of one end product, Rex Lamps. They have determined to produce in batches of 10 units every week. It takes one week to make a batch of 10 units. XYZ currently has 20 units on hand. The sales forecast for the next four quarter is:

	Quarter							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15

Level production= 10 units/week; Safety stock= 20 units

Prepare an MPS record for Rex Lamp. Also, determine the available (inventory) balance at the end of each week.

Solution

	Quarter							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15
Available	25	30	35	40	35	30	25	20
MPS	10	10	10	10	10	10	10	10
On Hand	20							

Level production= 10 units/week; Safety stock= 20 units

$20 + 10 - 5 = 25$ $35 + 10 - 5 = 40$

A Chase Production Approach

In Chase production approach, the same quantity is produced as demanded. It is also known as lot-for-lot production. Here the inventory is almost negligible and the production quantity varies. Here the demand is met through capacity adjustment in shape of hiring and/or firing of workforce as required. Following example shows how this approach works.

Example 3:

Using the data of Example 2 (Level production approach) prepare an MPS record for Rex Lamp. Also, determine the available (inventory) balance at the end of each week. In this example production lot size is based on lot-for-lot (chase production approach).

	Quarter							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15

Chase production= lot-for-lot; Safety stock= 20 units

Solution

	Quarter							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15
Available	20	20	20	20	20	20	20	20
MPS	5	5	5	5	15	15	15	15
On Hand	20							

Chase production= Lot-for-lot; Safety stock= 20 units

$$20+5-5=20$$

$$20+15-15=20$$

Rolling Through Time

The MPS is a rolling schedule, which has to be updated to define how it reflects the actual conditions. This is done to show how the actual transactions took place and how the MPS is affected by them. The following example illustrates how it works.

Example 4:

(a) Using the data provided in Example 2 except that the level production does not take place but the lamps are produced in lot size of 30 units whenever they are required. Also no safety stock is maintained. Develop an MPS record for weeks 1 to 8 and determine the ending available balance in each period.

(b) Assuming that by the end of week 1, 10 units were sold and master scheduler revised the demand forecast from week 2 to week 4 to 10 units. Develop an MPS record for weeks 2 to 9.

	Quarter							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15

Production quantity= 30 unit; Safety stock= nil

Solution

(a)

	Quarter							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15
Available	15	10	5	30	15	30	15	30
MPS				30		30		30
On Hand	20							

Production quantity= 30 units; Safety stock= nil

$20 + 0 - 5 = 15$
 $15 + 30 - 15 = 30$

(b) Let's suppose that the sales were 10 units in the first week. Also, no material was due in the second week since none was planned by MPS. The master scheduler revised forecast for periods 2 through 4 to 10 units per week. Using the revised forecast, the MPS record is shown below:

Revised MPS

	Quarter							
	2	3	4	5	6	7	8	9
Forecast	10	10	10	15	15	15	15	15
Available	30	20	10	25	10	25	10	25
MPS	30			30		30		30
On Hand	10							

Production quantity= 30 units; Safety stock= nil

$10 + 30 - 10 = 30$

Order Promising

In a make-to-stock environment, customer orders are satisfied from inventory. However, in make-to-order or assemble-to-order environments, demand is satisfied from production capacity. In either case, sales and distribution need to know what is available to satisfy customer demand. Since demand can be satisfied either from inventory or from scheduled receipts, the MPS provides a plan for doing either.

Using the MPS, sales and distribution can determine the available to promise (ATP). Available to promise is that portion of a firm's inventory and planned production that is not already committed and is available to the customer. This allows delivery promises to be made and customer orders and deliveries to be scheduled accurately.

The ATP is calculated by adding MPS to the beginning inventory and then subtracting actual orders scheduled before the next MPS. Similarly, the available balance is calculated by adding MPS to the beginning inventory and then subtracting actual order to be delivered or the demand forecast in that period, whichever is larger.

Example 5:

Using the data of Example 4, determine ATP if actual orders for delivery in weeks 1, 2, and 3 are 5 units, 3 units, and 2 units, respectively.

	Week Number							
	1	2	3	4	5	6	7	8
Forecast	5	5	5	5	15	15	15	15
Orders	5	3	2					
Available	15	10	5	30	15	30	15	15
ATP	10			30		30		30
MPS				30		30		30
On hand	20							

Production quantity= 30 units; Safety stock= nil

$$ATP = 20 - (5+3+2) = 10$$

Let's suppose that the sales were 10 units in the first week. Also, more orders were received at the beginning of week 2, which were 2 more for week 2, 3 more for week 3, and 2 for week 4. The master scheduler revised MPS for periods 2 through 9 based on forecast revision for periods 2 to 4.

	Week Number							
	2	3	4	5	6	7	8	9
Forecast	10	10	10	15	15	15	15	15
Orders	5	3	2					
Available	30	20	10	25	10	25	10	25
ATP	28			30		30		30
MPS	30			30		30		30
On hand	10							

Production quantity= 30 units; Safety stock= nil

$$ATP = (30+10) - (5+5+2) = 28$$
Consuming the Forecast

Some experts believe that actual customer orders “consume” the forecast; that is, we start out with an estimate (the forecast), and actual orders come in to consume the estimate. We see this in the above Example 5. Of the 10 units forecast for week 2, 5 have been consumed. For week 3, 5 of 10 have been consumed, as have 2 of the 10 for week 4.

Let's consider Example 5 and see if the following hypothetical set of orders can be accepted, assuming that they were received in the sequence listed during week 2:

Order Number	Quantity	Desired Week
1	5	2
2	15	3
3	35	6
4	10	5

At the beginning of week 3, the situation will be as follows:

	Week Number							
	3	4	5	6	7	8	9	10
Forecast	10	10	15	15	15	15	15	15
Orders	20	2		35	10			
Available	10	0	15	-20	-5	-20	-5	-20
ATP	3			0	20		30	
MPS			30		30		30	
On hand	30							

Production quantity= 30 units; Safety stock= nil

$30 - 22 - 5 = 3$

If we look at the data then all the orders can be accepted except order number 4 of 10 units to be delivered in 5th week. Since the total amount requested during week 2 is 65 and available to promise is 58 units i.e. 30 on hand plus MPS of 30 in 5th week minus 2 (order already placed in week 1) in 4th week. Here the master scheduler can take two important decisions. Firstly, the order of 35 units in 6th week cannot be met by MPS of 30 in 5th week. Therefore, 5 excess units from the order in 6th week can be satisfied from the units on hand, meaning now only 3 units are available to promise in 3rd week instead of 8 units. Secondly, now that in 3rd week only 3 units are available to promise, therefore, the fourth order received in 5th week of 10 units cannot be satisfied. Therefore, the sales people have to be informed that this order has to be shifted to 7th week when the MPS of 30 units will be received. This way all the orders can be met, although the projected available inventory will be negative from 6th period onwards.

Master Production Scheduler

Let's look at the person behind MPS i.e. master production scheduler. But first we will discuss the use of MRP concepts for the master scheduler.

MPS as a Set of Firm Planned Orders

It is useful to consider MPS as a set of planned orders. Thereafter, the master production scheduler's job is to convert planned orders to firm planned orders, and to manage the timing and amounts of the firm planned orders. The "available" row in the phased record provides the primary signal for performing this task. Standard MRP record can provide indications of when and to what extent firm planned orders might not meet the needs.

Managing the timing and the amounts of the firm planned orders means that any changes to the MPS have to be carefully evaluated in terms of their impact on material and capacity plans. The key need is to clearly understand trade-offs between customer needs and other MPC objectives.

The Job

The master production scheduler has the primary responsibility for making any addition or changes to MPS records. He or she also has the responsibility of disaggregating the production plan to create the MPS and for ensuring that the sum of the detailed MPS production decisions matches the production plans. This entails analyzing trade-offs and telling top management about situations requiring decisions beyond the scheduler's authority level.

As part of the general feedback process, the master production scheduler should monitor actual performance against the MPS and production plan and distill operating results for higher management. The master production scheduler can also help in the analysis of what-if questions by analyzing the impact on the MPS of changes in plans.

F. Material Requirements Planning

This topic deals with material requirements planning, which is involved in detailed material planning for the manufacture of components and sub-assemblies, which are used to assemble finished product. If any component or sub-assembly is missing, the end product cannot be built and shipped on time. Material requirements planning (MRP) is the system used to avoid missing parts. It establishes a schedule (priority plan) showing the components required at each level of the assembly and, based on lead times, calculates the time when these components will be needed.

After the completion of this topic, students should be able to:

- *Explain where MRP fits in the overall framework of MPC and how it is related to other MPC components*
- *Demonstrate the knowledge about Bill of Material and how it is used in MRP*
- *Compare different techniques used in MRP for lot sizing*
- *Identify uncertainties in MRP and explain how to protect against them*

Material Requirements Planning in MPC

The master production schedule drives the material requirements plan. The MRP is a priority plan for the components needed to make the products in the MPS. The plan is valid only if capacity is available when needed to make the components, and the plan must be checked against available capacity. The process of doing so is called capacity requirements planning and is discussed in the next lecture.

Material requirements planning (MRP) drives, or is input to, production activity control (PAC) and purchasing. MRP plans the release and receipt dates for orders. PAC and purchasing must plan and control the performance of the orders to meet the due dates. Figure F.1 shows a diagram of the manufacturing planning and control system with its inputs and outputs.

There are three inputs to MRP systems:

1. Master production schedule.
2. Inventory records.
3. Bills of material.

Master production schedule

The master production schedule is a statement of which end items are to be produced, the quantity of each, and the dates they are to be completed. It drives the MRP system by providing the initial input for the items needed.

Inventory records

A major input to the MRP system is inventory. When a calculation is made to find out how many are needed, the quantities available must be considered.

There are two kinds of information needed. The first is called planning factors and includes information such as order quantities, lead times, safety stock, and scrap. This information does not change often; however, it is needed to plan what quantities to order and when to order for timely deliveries.

The second kind of information necessary is on the status of each item. The MRP system needs to know how much is available, how much is allocated, and how much is available for future demand. This type of information is dynamic and changes with every transaction that takes place. These data are maintained in an inventory record file, also called a part master file or item master file. Each item has a record, and all the records together form the file.

Bill of Material

A bill of material shows, for each part number, what other part numbers are required as direct components. For example, for a car, it could show five wheels required. For each wheel, the bill of materials could be a hub, tire, valve system etc.

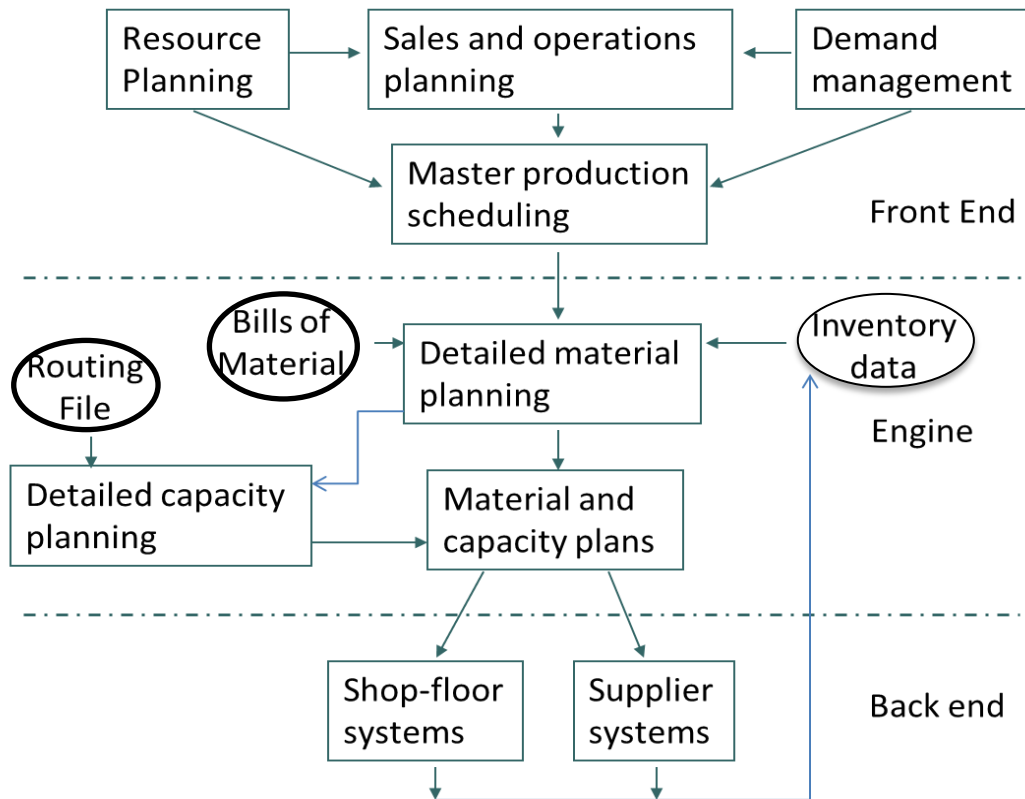


Figure F.1 MRP linkages with other MPC modules

The Basic MRP Record

The MRP record displays the following information:

- The anticipated future usage/demand, which are mentioned as *gross requirements*. They are the MPS
- Existing replenishment orders at the beginning of each period, which are shown as *scheduled receipts*
- The current and projected inventory status at the end of each period, which are shown as *projected available balance*
- Planned replenishment order receipts at the beginning of each period, which are shown as *planned order receipts*
- Planned replenishment orders released at the beginning of each period, which are shown as *planned order releases*

The basic MRP record is shown in Table F.1. We must remember that:

1. The current time is the beginning of the first period.
2. The top row shows periods, called time buckets. These are often a week but can be any length of time convenient to the company. Some companies are moving to daily time buckets.
3. The number of periods in the record is called the planning horizon, which shows the number of future periods for which plans are being made. It should be at least as long

as the cumulative product lead time. Otherwise, the MRP system is not able to release planned orders of items at the lower level at the correct time.

4. An item is considered available at the beginning of the time bucket in which it is required.
5. The quantity shown in the projected on-hand row is the projected on-hand balance at the end of the period.
6. The immediate or most current period is called the action bucket. A quantity in the action bucket means that some action is needed now to avoid a future problem.

Table F.1 Basic MRP record

	Period				
	1	2	3	4	5
Gross requirements		10		40	10
Scheduled Rec.	50				
Projected available balance	4	54	44	44	4
Planned orders				50	
Lead time = one period Lot size = 50					

Bill of Materials

American Production and Inventory Control Society (APICS) defines a bill of material as “a listing of all the subassemblies, intermediates, parts, and raw materials that go into making the parent assembly showing the quantities of each required to make an assembly.” Figure F.2 shows a simplified bill of material.

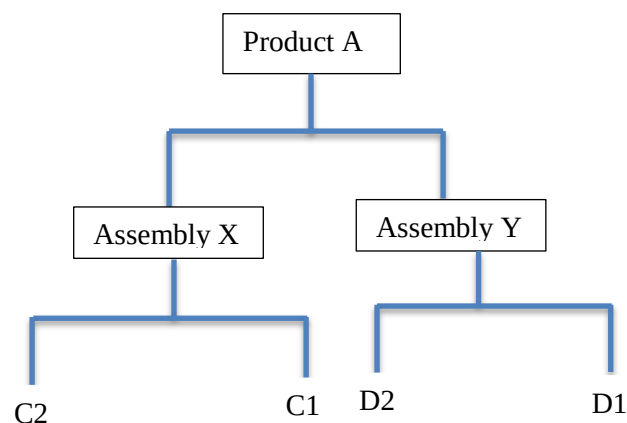


Figure F.2 Bill of Material

There are three important points:

1. The bill of material shows all the parts required to make one end item.
2. Each part or item has only one part number. A specific number is unique to one part and is not assigned to any other part. Thus, if a particular number appears on two different bills of material, the part so identified is the same.

3. A part is defined by its form, fit, or function. If any of these changes, then it is not the same part and it must have a different part number. For example, a part when painted becomes a different part and must have a different number. If the part could be painted in three different colors, then each must be identified with its unique number.

The bill of material shows the components that go into making the parent. It does not show the steps or process used to make the parent or the components. That information is recorded in a routing file.

Linking the MRP Records

Figure F.3 below shows the linkages between the final product A and the components and subassemblies used to produce it. These linkages are further explained by the linked time-phased MRP records for Assembly X shown in the Table F.2.

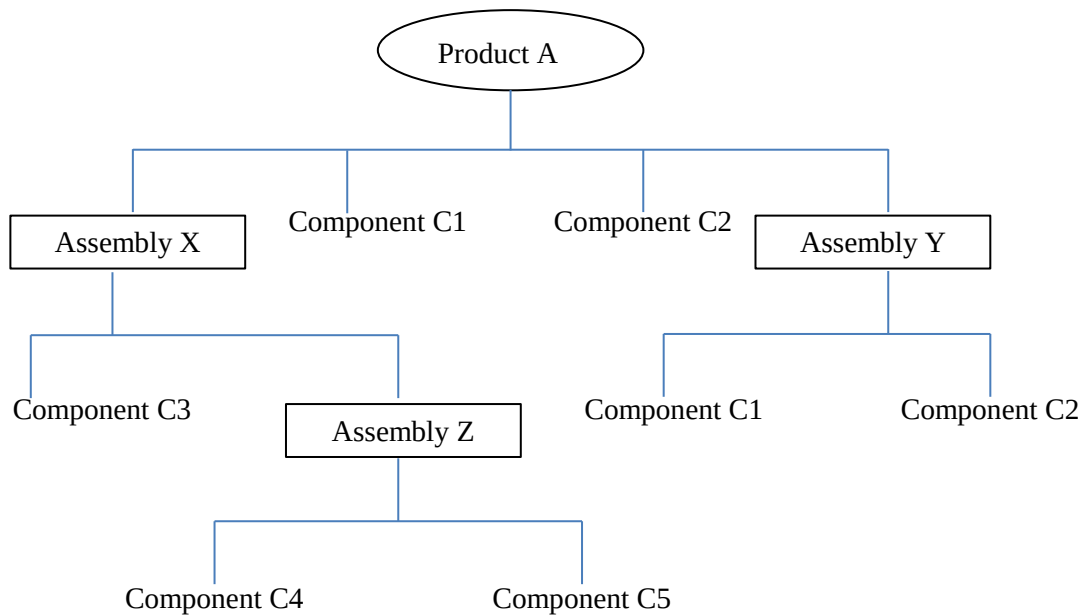


Figure F.3 Linkages between final product A and components and assemblies

The gross requirements of Assembly X are extracted from the MPS of end product A. Let's assume that master production schedule of Product A is that 20 units are to be produced in week 3, 10 units in week 4, and 35 units in week 5. Since Assembly X is directly used to produce Product A, therefore 20 units are shown as gross requirement of X in week 3, 10 units in week 4, and 35 units in week 5. To meet this requirement, production order of 5 units of X is released in week 2 so that it is available for use in week 3 because the lead time for X is one week. Similarly, the production orders of 10 in week 3 and of 35 units in week 4 of X are released.

It can be seen from the bill of material diagram above that one Assembly Z is used to produce one unit of Assembly X. Therefore, the "planned order release" row of X becomes the "gross requirement" row of Z. Similarly, since one component C3 is used to produce one X, therefore, here also the "planned order release" row of X becomes "gross requirement" row of C3. Also, one component C4 and one component C5 together are used to produce one Z, therefore, the "planned order release" row of Z becomes "gross requirements" rows of C4 and C5. That means that the gross requirements of C4 and C5 are determined from the planned order release of Z.

Table F.2 Linked time-phased MRP records for Assembly X

		Week				
		1	2	3	4	5
X Assembly Lead time = 1 Lot size = Lot-for-lot Safety stock = 0	Gross Requirements			20	10	35
	Scheduled Receipts					
	Projected available balance 15	15	15	0	0	0
	Planned order receipts			5	10	35
	Planned order releases		5	10	35	
		Week				
		1	2	3	4	5
Z Assembly Lead time = 1 Lot size = 20 Safety stock = 0	Gross Requirements		5	10	35	
	Scheduled Receipts					
	Projected available balance 10	10	5	15	0	0
	Planned order receipts			20	20	
	Planned order releases		20	20		

Processing Frequency

Thus far we've looked only at the static construction of the MRP records and how they're linked together. Since conditions change and new information is received, the MRP records must be brought up to date so plans can be adjusted. This means processing the MRP records anew, incorporating current information. Two issues are involved in the processing decision: how frequently the records should be processed and whether all the records should be processed at the same time.

Processing all of the records in one computer run is called regeneration. This signifies that all part number records are completely reconstructed each time the records are processed. When a regeneration run is conducted, all current planned orders are removed. Then, starting with the end items, each item is completely rescheduled. This can generate very large processing demands on the system.

The problem with processing less frequently is that the portrayal of component status and needs expressed in the records becomes increasingly out of date and inaccurate. This decrease in accuracy has both anticipated and unanticipated causes. As the anticipated scheduled receipts are received and requirements satisfied, the inventory balances change. As unanticipated scrap, requirement changes, stock corrections, or other such transactions occur, they cause inaccuracies if not reflected in all the time-phased records influenced by the transactions. Changes in one record are linked to other time-phased records as planned order releases become gross requirements for lower-level components. Thus, some change

transactions may cascade throughout the product structure. If these transactions are not reflected in the time-phased records early enough, the result can be poor planning.

More frequent processing of the MRP records increases computer costs but results in fewer unpleasant surprises. When the records reflecting the changes are produced, appropriate actions will be indicated to compensate for the changes.

The logical answer to these issues is that the required amount of processing could be reduced if frequently only those records are updated which are affected by the changes. An alternative to regeneration is the net change approach. With net change, only those items that are affected by the new or changed information are reprocessed.

Bucketless Systems

To some extent, the problems of timing are tied to the use of time buckets. When the buckets are small enough, the problems are reduced significantly. However, smaller buckets mean more buckets, which increases review, storage, and computation costs. A bucketless MRP system specifies the exact release and due dates for each requirement, scheduled receipt, and planned order. The managerial reports are printed out on whatever basis is required, including by exact dates.

Bucketless MRP systems are a better way to use the computer. Above and beyond that, the approach allows better maintenance of lead time offsets and provides more precise time-phased information. The approach is consistent with state-of-the-art software, and many firms now use bucketless systems. The major addition is that the planning cycle in itself is bucketless. That is, plans are revised as necessary, not on a periodic schedule, and the entire execution cycle is also shortened.

Lot Sizing

The production of assemblies and components are done in lot sizes. We saw in the above example of linking MRP records that Assembly Z is produced in a fixed size of 20 units. Whereas, X was produced in the exact quantity as it was needed. This is known as lot-for-lot production. Similarly, there are other lot sizing rules, which are used for this purpose.

Lot-for-Lot

As mentioned above, lot-for-lot rule is the one where the exact number of units is produced as they are required. This rule is similar to the chase strategy studied in Sales and Operation Planning lecture. In that case also as in the current case, the number of units produced is the same as they are required.

Example:

Week Number 1 2 3 4 5 6 7 8 9 10

Requirements 10 10 15 20 50 140 216 230 200 30

Ordering cost = C_p = \$300 per order

Inventory carrying cost = C_H = \$2 per unit per week

Average requirements = $\bar{D}$ = 92.1

Lot-for-Lot

Week Number	1	2	3	4	5	6	7	8	9	10
Requirements	10	10	15	20	50	140	216	230	200	30
Order Q	10	10	15	20	50	140	216	230	200	30
Beginning Inventory	10	10	15	20	50	140	216	230	200	30
Ending Inventory	0	0	0	0	0	0	0	0	0	0

Ordering cost $10 \times \$300 = \$3,000$

Inventory carrying cost $\frac{Q}{2} \times H = \frac{921}{2} \$2 = \$921$

Total cost **\$3,921**

Economic Order Quantity (EOQ)

Because of its simplicity, people often use the economic order quantity (EOQ) formula as a decision rule for placing orders in a requirements planning system. As the following example shows, however, the EOQ model frequently must be modified in requirements planning system applications. Because we base the EOQ on the assumption of constant uniform demand, the resulting total cost expression won't necessarily be valid for requirements planning applications.

Example:

Week Number	1	2	3	4	5	6	7	8	9	10
Requirements	10	10	15	20	50	140	216	230	200	30

Ordering cost = C_p = \$300 per order

Inventory carrying cost = C_H = \$2 per unit per week

Average requirements = $\bar{D}$ = 92.1

Economic Order Quantity

Week Number	1	2	3	4	5	6	7	8	9	10
Requirements	10	10	15	20	50	140	216	230	200	30
Order Q	166					166	166	193	200	166
Beginning Inv.	166	156	146	131	111	227	253	230	200	0
Ending Inv.	156	146	131	111	61	87	37	0	0	136

$$\text{Economic lot size} = \sqrt{2C_p\bar{D}/C_H} = \sqrt{2(\$300)(92.1)/2} = 166$$

Ordering cost $6 \times \$300 = \$1,800$

Inventory carrying cost $\frac{Q}{2} \times H = \frac{2,515}{2} \$2 = \$2,515$

Total cost \$4,315

Periodic Order Quantity

One way to reduce the high inventory carrying cost associated with fixed lot sizes is to use the EOQ formula to compute an economic time between orders (TBO). We do this by dividing the EOQ by the mean demand rate. In the preceding example, the economic time interval is approximately two weeks ($166 / 92.1 = 1.8$). The procedure then calls for ordering exactly the requirements for a two-week interval. This is termed the periodic order quantity (POQ).

Example:

Week Number	1	2	3	4	5	6	7	8	9	10
Requirements	10	10	15	20	50	140	216	230	200	30

Ordering cost = C_p = \$300 per order

Inventory carrying cost = C_H = \$2 per unit per week

Average requirements = $\bar{D}$ = 92.1

Periodic Order Quantity

Week Number	1	2	3	4	5	6	7	8	9	10
Requirements	10	10	15	20	50	140	216	230	200	30
Order Q	20		35		190		446		230	
Beginning Inv.	20	10	35	20	190	140	446	230	230	30

Ending Inv. 10 0 20 0 140 0 230 0 30 0

Time between orders (TBO) = $Order\ Q / \bar{D} = \frac{166}{92.1} = 1.8 \cong 2$

Ordering cost $5 \times \$300 = \$1,500$

Inventory carrying cost $\frac{Q}{2} \times H = \frac{1,781}{2} \$2 = \$1,781$

Total cost \$3,281

Safety Stock / Safety Lead Time

There are two basic ways to buffer uncertainty in an MRP system. One is to specify a quantity of safety stock in much the same manner as with statistical inventory control techniques. The second method, safety lead time, plans order releases earlier than indicated by the requirements plan and schedules their receipt earlier than the required due date. Both approaches produce an increase in inventory levels to provide a buffer against uncertainty, but the techniques operate quite differently, as shown in the following two examples.

Safety Stock Example

No Buffering Used		Period				
		1	2	3	4	5
Gross requirements		20	40	20	0	30
Scheduled Rec.			50			
Projected available balance	40	20	30	10	10	30
Planned order receipt						50
Planned order release				50		

Lead time = 2 periods; Lot size = 50

Safety Stock = 20 Units		Period				
		1	2	3	4	5
Gross requirements		20	40	20	0	30
Scheduled Rec.			50			
Projected available balance	40	20	30	60	60	30
Planned order receipt				50		
Planned order release		50				

Lead time = 2 periods; Lot size = 50

Safety Lead Time Example

Safety Lead Time = 1 Period		Period				
		1	2	3	4	5
Gross requirements		20	40	20	0	30
Scheduled Rec.			50			
Projected available balance	40	20	30	10	60	30
Planned order receipt					50	
Planned order release			50			

Lead time = 2 periods; Lot size = 50

Allocation & Availability Checking

Before a manufacturing order is released, component availability must be checked. The computer program checks the component inventory records to be sure that enough material is available and only then to allocate the necessary quantity to that work order. If the material is not available, the computer program will advise the planner of the shortage.

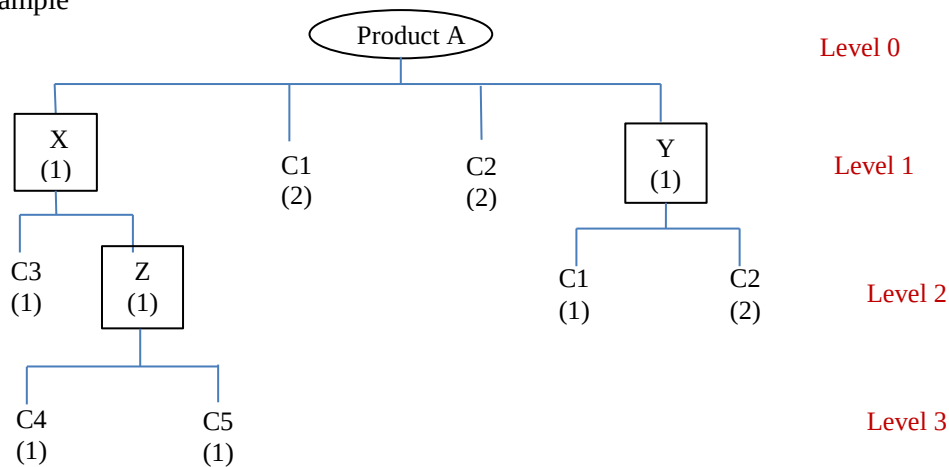
When a manufacturing order is released the computer will allocate the required quantities of a parent's components to that order. This does not mean the components are withdrawn from inventory but that the projected available quantity is reduced. The allocated quantity of components is still in inventory, but they are not available for other orders. They will stay in inventory until withdrawn for use.

Low Level Coding

A component may reside on more than one level in a bill of material. If this is the case, it is necessary to make sure that all gross requirements for that component have been recorded before netting takes place. Consider the product shown in Figure F.4. Components C1 and C2 occur twice in the product tree and at different levels. It would be a mistake to net the requirements for the C1s and C2s before calculating the gross requirements for those required for parent Y.

The process of collecting the gross requirements and netting can be simplified by using low-level codes. The low-level code is the lowest level on which a part resides in all bills of material. Every part has only one low-level code.

Example



Low Level Coding

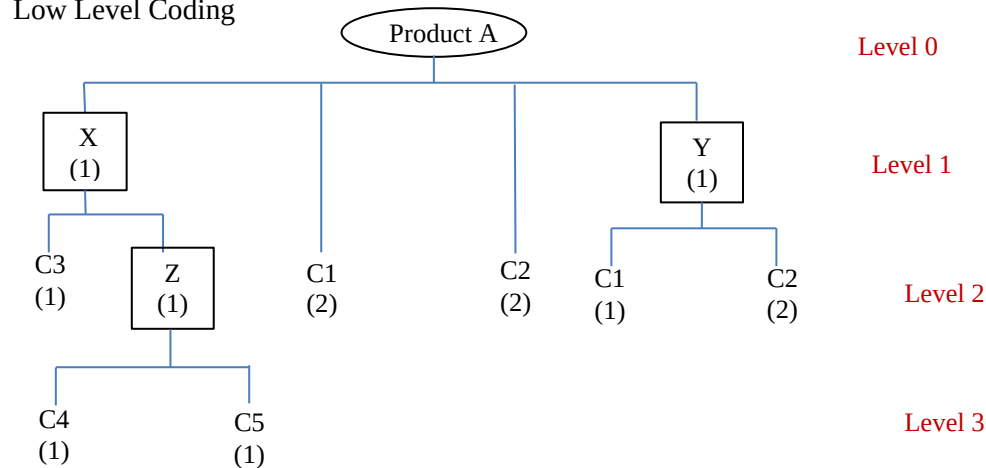


Figure F.4 Low level coding

Firm Planned Orders

Releasing or launching a planned order is the responsibility of the planner. When released, the order becomes an open order to the factory or to purchasing and appears on the MRP record as a scheduled receipt. It is then under the control of the planner, who may expedite, delay, or even cancel the order. Firm planned orders. The computer-based MRP system automatically recalculates planned orders as the gross requirements change. At times, the planner may prefer to hold a planned order firm against changes in quantity and time despite what the computer calculates. This might be necessary because of future availability of material or capacity or special demands on the system. The planner can tell the computer that the order is not to be changed unless the planner advises the computer to do so. The order is “firmed” or frozen against the logic of the computer.

The MRP software nets, offsets, and explodes requirements and creates planned order releases. It keeps priorities current for all planned orders according to changes in gross requirements for the part. But it does not issue purchase or manufacturing orders or reschedule open orders. However, it does print action or exception messages, suggesting that the planner should act and what kind of action might be appropriate.

Service Parts

Service part demand must be included in the MRP record if the material requirements are not to be understated. The service part demand is typically based on a forecast and is added directly into the gross requirements for the part. From the MRP system point of view, the service part demand is simply another source of gross requirements for a part, and the sources of all gross requirements are maintained through pegging records. The low-level code for a part used exclusively for service would be zero. If it's used as a component part as well, the low-level code would be determined the same way as for any other part.

As actual service part needs occur, it's to be expected that demand variations will arise. These can be partially buffered with safety stocks (inventories specifically allocated to service part usage) or by creative use of the MRP system. By careful examination of pegging records, expected shortage conditions for manufacturing part requirements can sometimes be satisfied from available service parts. Conversely, critical service part requirements can perhaps be met with orders destined for higher-level items. However, only one safety stock inventory is needed to buffer uncertainties from both sources.

Scheduled Receipts versus Planned Order Releases

It is important to understand the difference in the scheduled receipt and planned order release. Scheduled receipts are orders placed on manufacturing or on a vendor and represent a commitment to make or buy. For an order in a factory, necessary materials are committed, and work-center capacity is allocated to that order. For purchased parts, similar commitments are made to the vendor. The scheduled receipts row shows the quantities ordered and when they are expected to be completed and available. Scheduled receipts on the MRP record are open orders on the factory or a vendor and are the responsibility of purchasing and of production activity control. When the goods are received into inventory and available for use, the order is closed out, and the scheduled receipt disappears to become part of the on-hand inventory.

Whereas, planned order releases are just planned; they have not been released. It is the responsibility of the material planner to release planned orders, not the computer. Since the objective of the MRP is to have material available when it is needed and not before, orders for

material should not be released until the planned order release date arrives. Thus, an order is not normally released until the planned order is in the current week. Releasing an order means that authorization is given to purchasing to buy the necessary material or manufacturing to make the component.

Bottom-up Replanning

Action to correct for changed conditions should occur as low in the product structure as possible. Suppose the part in the “safety lead time” example is a component of another part. The first alternative is to expedite the scheduled receipt of 50 into week 2. If this can be done, there is no need to make any changes to the parent. If the 50 units cannot be expedited, the planned order release and net requirement of the parent must be changed.

The MRP Planner

The persons most directly involved with the MRP system outputs are planners. They are typically in the production planning, inventory control, and purchasing departments. Planners have the responsibility for making detailed decisions that keep the material moving through the plant. Their range of discretion is carefully limited (e.g., without higher authorization, they cannot change plans for end items destined for customers). Their actions, however, are reflected in the MRP records. Well-trained MRP planners are essential to effective use of the MRP system.

Computerized MRP systems often encompass tens of thousands of part numbers. To handle this volume, planners are generally organized around logical groupings of parts. Even so, reviewing each record every time the records are processed would not be an effective use of the planners’ time. At any time, many records require no action, so the planner only wants to review and interpret those that do require action.

The primary actions taken by MRP planner are:

- Launch Orders – Production or Purchasing
- Reschedule orders (due dates) as required
- Reconcile errors and search for causes
- Solve critical material shortages:
 - Re-plan
 - Expedite
- Coordinate with other functions to resolve problems
- Find key problem areas
- Indicate where enhancements would make job easier

Order Launching

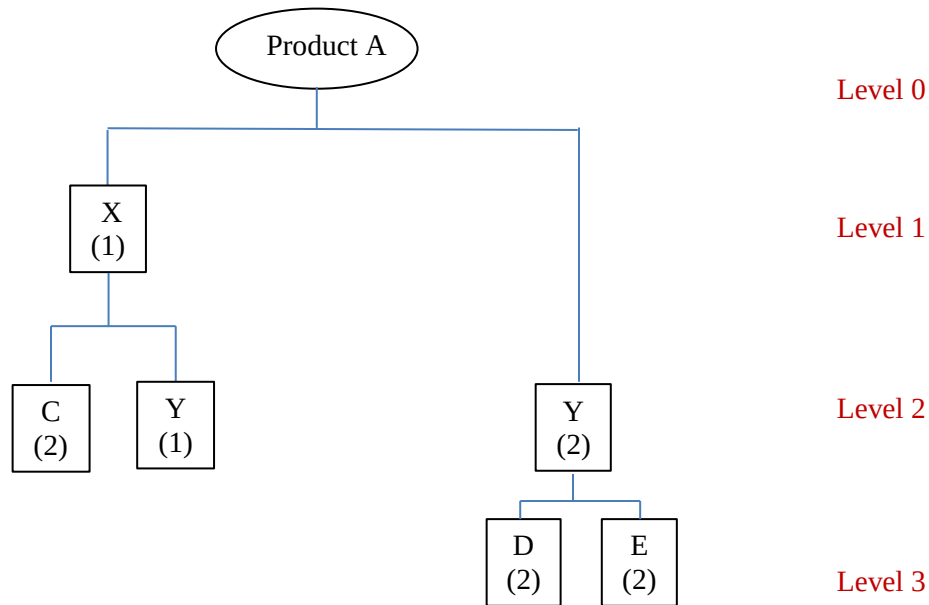
Order launching is the process of releasing orders to the shop or to vendors (purchase orders). This process is prompted by MRP when a planned order release is in the current time period, the action bucket. Order launching converts the planned order into a scheduled receipt reflecting the lead time offset. Order launching is the opening of shop and purchase orders; closing these orders occurs when scheduled receipts are received into stockrooms. At that time, a transaction must be processed—to increase the on-hand inventory and eliminate the scheduled receipt. Procedures for opening and closing shop orders have to be carefully defined so all transactions are properly processed.

The orders indicated by MRP as ready for launching are a function of lot sizing procedures and safety stock as well as timing. A key responsibility of the planner is managing

with awareness of the implications of these effects. For example, not all of a fixed lot may be necessary to cover a requirement, or a planned order that's solely for replenishment of safety stock may be in the action bucket.

Comprehensive Example A

Using the product tree and lead times shown below, complete the MRP records to determine the planned order receipts and releases for X, Y, C, D, and E. There are 35, 20, and 15 As required in week 3, week 4 and week 5, respectively.



Solution

X Assembly Lead time = 1 Lot size = Lot-for-lot Safety stock = 0	Gross Requirements			35	20	15
	Scheduled Receipts					
	Projected available balance 15	15	15	0	0	0
	Planned order receipts			20	20	15
	Planned order releases		20	20	15	

		Week				
		1	2	3	4	5
Y Assembly Lead time = 1 Lot size = 40 Safety stock = 10	Gross Requirements		40+35	40+20	30+15	15
	Scheduled Receipts					
	Projected available balance 10	10	15	35	30	15
	Planned order receipts		80	80	40	
	Planned order releases	80	80	40		

E Component Lead time = 2 Lot size = 120 Safety stock = 20	Gross Requirements	160	80	80		
	Scheduled Receipts	120				
	Projected available balance 60	100	20	60	60	60
	Planned order receipt			120		
	Planned order releases	120				

D Component Lead time = 1 Lot size = POQ=2 Safety stock=20	Gross Requirements	160	80	80		
	Scheduled Receipts	120				
	Projected available balance 60	20	100	20	20	20
	Planned order receipt		160			
	Planned order releases	160				

C Component Lead time = 2 Lot size = 40 Safety stock = 10	Gross Requirements		40	40	30	
	Scheduled Receipts	40				
	Projected available balance 15	55	15	15	25	25
	Planned order receipt			40	40	
	Planned order releases	40	40			

G. Capacity Planning

So far we have been concerned with planning priority, that is, determining what is to be produced and when. The system is hierarchical, moving from long planning horizons and few details (production plan) through medium time spans (master production schedule) to a high level of detail and short time spans (material requirements plan). At each level, manufacturing develops priority plans to satisfy demand. However, without the resources to achieve the priority plan, the plan will be unworkable. Capacity management is concerned with supplying the necessary resources. This lecture looks more closely at the question of capacity: what it is, how much is available, how much is required, and how to balance priority and capacity.

After the completion of this lecture, students should be able to:

- *Illustrate the role of capacity planning in MPC system*
- *Apply capacity planning and control techniques*
- *Apply finite scheduling techniques and carry out their cost-benefit analysis*
- *Schedule capacity and materials simultaneously*

Capacity Planning in MPC

Capacity is the amount of work that can be done in a specified time period. In the eleventh edition of the *APICS Dictionary*, capacity is defined as “the capability of a worker, machine, work center, plant, or organization to produce output per time period.” Capacity is a *rate* of doing work, not the *quantity* of work done.

Capacity planning involves calculating the capacity needed to achieve the priority plan and finding ways of making that capacity available. If the capacity requirement cannot be met, the priority plans have to be changed. The planning occurs at each level varying only in the level of detail and time spans involved.

Resource planning involves long-range capacity resource requirements and is directly linked to production planning. Typically, it involves translating monthly, quarterly, or annual product priorities from the production plan into some total measure of capacity, such as gross labor hours. Resource planning involves changes in staffing, capital equipment, product design, or other facilities that take a long time to acquire and eliminate. If a resource plan cannot be devised to meet the production plan, the production plan has to be changed. The two plans set the limits and levels for production. If they are realistic, the master production schedule should work.

Rough-cut capacity planning takes capacity planning to the next level of detail. The master production schedule is the primary information source. The purpose of rough-cut capacity planning is to check the feasibility of the MPS, provide warnings of any bottlenecks, ensure utilization of work centers, and advise vendors of capacity requirements.

Capacity requirements planning is directly linked to the material requirements plan. Since this type of planning focuses on component parts, greater detail is involved than in rough-cut capacity planning. It is concerned with individual orders at individual work centers and calculates work center loads and labor requirements for each time period at each work center. Figure G.1 shows the linkages at different level of planning in an MPC system.

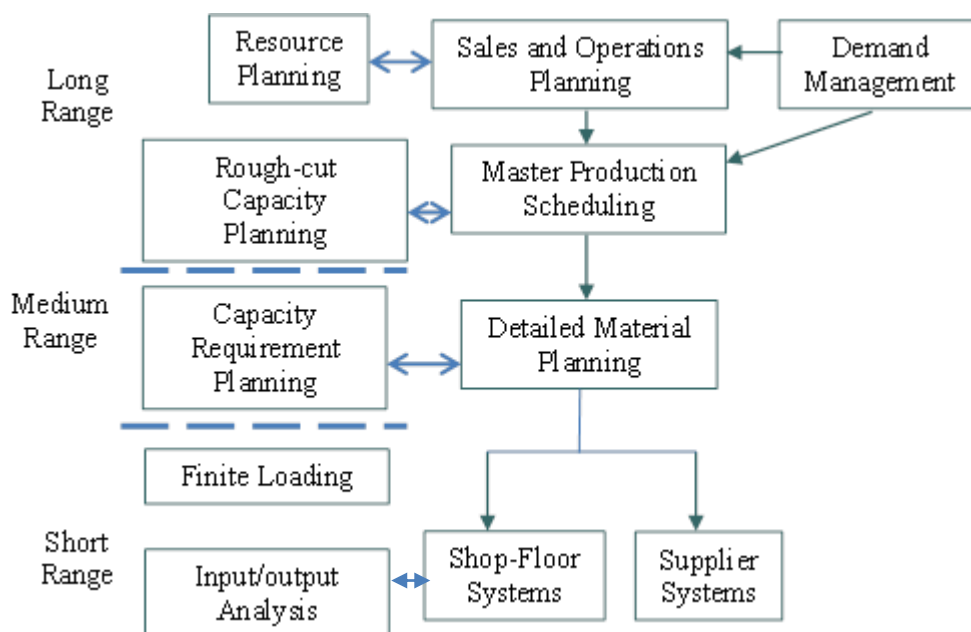


Figure G.1 Capacity planning linkages at different level

Capacity Planning Using Overall Factors

Capacity planning using overall factors (CPOF) is the simplest rough-cut capacity planning approach. The data inputs from master production schedule. It is based on planning factors from historical data. Overall labor- or machine-hour capacity requirements are estimated from MPS data. Estimate is allocated to work centers based on historical workloads. Since it is based on historical usage and not actual load calculations, there may be some inherent inaccuracies, which may limit usefulness of this method. The method is explained in the following example.

Example 1:

End Product	Period								
	1	2	3	4	5	6	7	8	9
A	33	33	33	40	40	40	30	30	30
B	17	17	17	13	13	13	25	25	25

End Product	Total Direct Labor in Standard Hours/Unit
A	0.95
B	1.85

Solution 1:

Work Centre	Historical Percentage	Period							
		1	2	3	4	5	6	7	8
100	60.3	37.87	37.87	37.87	37.41	37.41	37.41	45.07	45.07
200	30.4	19.09	19.09	19.09	18.86	18.86	18.86	22.72	22.72
300	9.3	5.84	5.84	5.84	5.78	5.78	5.78	6.96	6.96
Total Capacity		62.80	62.80	62.80	62.05	62.05	62.05	74.75	74.75

$$62.80 = (0.95 \times 33) + (1.85 \times 17)$$

$$62.80 \times 0.603 = 37.87$$

RCCP Using Capacity Bills

Rough-cut capacity planning method using capacity bills provides more direct link to individual end products. Bill of capacity indicates total standard time to produce one unit of an end product. Master production schedule data is then used to estimate capacity requirements for each work center. This method requires more data than CPOF procedure. In addition to what's provided by CPOF, capacity bills takes into account any shifts in product mix.

Example 2:



$0.05 = \text{setup hour per unit} + \text{runtime per unit} = 0.025 + 0.025$

$0.025 = \text{Setup time/Lot size} = 1.0/40$

Routing and Standard Time Data						
Lot Size	Operation	Work Center	Setup Hours	Setup Time Hours Per Unit	Run Time Hours Per Unit	Total Hours Per Unit
End Products						
A 40	1 of 1	100	1.0	0.025	0.025	0.05
B 20	1 of 1	100	1.0	0.050	1.250	1.30
Components						
C 40	1 of 2	200	1.0	0.025	0.575	0.60
	2 of 2	300	1.0	0.025	0.175	0.20
D 60	1 of 1	200	2.0	0.033	0.067	0.10
E 100	1 of 1	200	2.0	0.020	0.080	0.10
F 100	1 of 1	200	2.0	0.020	0.0425	0.0625

Bill of Capacity: End Product

Work Center	A	B
	Total Time/Unit	Total Time/Unit
100	0.05	1.30
200	0.70	0.55
300	<u>0.20</u>	<u>0.00</u>
Total Time/Unit	0.95	1.85

$0.70 = 0.60 + 0.10$ for one C and one D

$0.55 = 0.10 + 2(0.10) + 4(0.0625)$ for one D, two E's and 4 F's

Solution 2:

To develop a bill of capacity for the example problem, we use the product structure data for A and B shown in the following figure. We also need the routing and operation time standard data, which is provided in the tables given below for assembling products A and B, as well as for manufacturing component items C, D, E, and F.

Once the bill of capacity for each end product is prepared, we can use the master production schedule to estimate capacity requirements at individual work centers. The table in the solution of example 2 provides the capacity requirement of each work center. The resultant work center estimates differ substantially from the CPOF estimates.

Capacity Requirement Using Capacity Bills

Work Centre	Period							
	1	2	3	4	5	6	7	8
100	23.75	23.75	23.75	18.90	18.90	18.90	34.00	34.00
200	32.45	32.45	32.45	35.15	35.15	35.15	34.75	34.75
300	6.60	6.60	6.60	8.00	8.00	8.00	6.00	6.00
Total Capacity	62.80	62.80	62.80	62.05	62.05	62.05	74.75	74.75

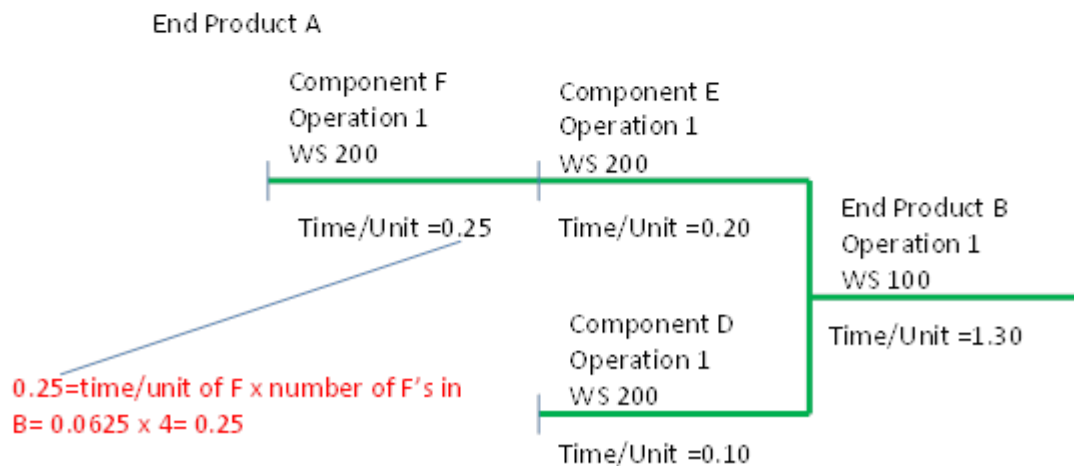
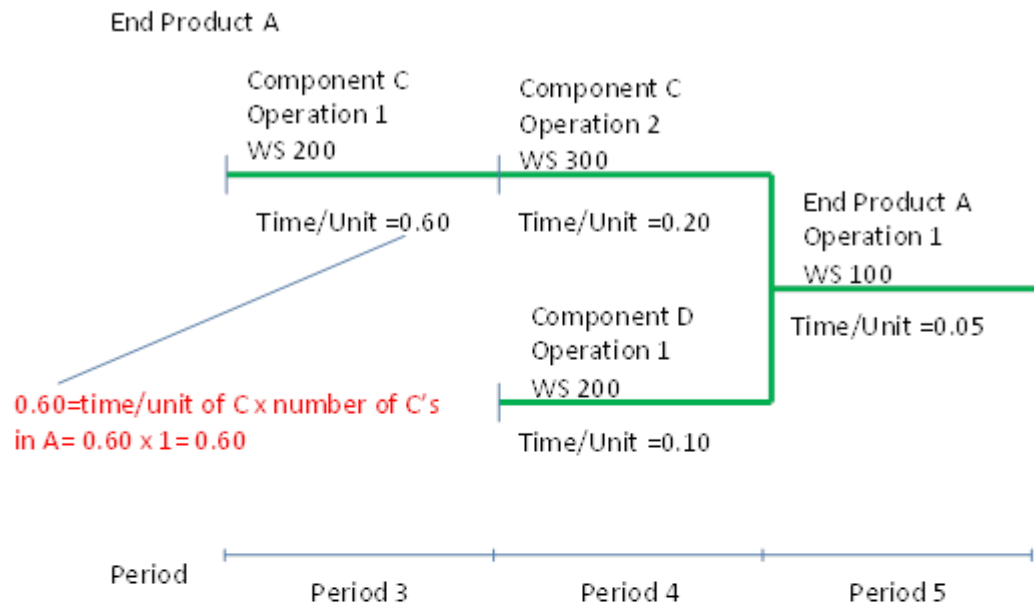
$23.75 = (0.05 \times 33) + (1.30 \times 17)$
 $(0.70 \times 33) + (0.55 \times 17) = 32.45$

RCCP Using Resource Profile

Bill of Resources is a listing of the required capacity and key resources needed to manufacture one unit of a selected (typical) item or family. In the resource profile method, the standard hours of load placed on a work center is determined by time period. That is, production lead time data has to be taken into account to provide time-phased projections of the capacity requirements for individual production facility. The resource requirements are further defined by a lead-time offset so as to predict the impact of the item/family scheduled on the load of the key resource by time period. Thus, resource profiles provide a somewhat more sophisticated approach to rough-cut capacity planning.

Example 3:

To apply the resource profile procedure to our example, we use the bills of material, routing, and time standard information given in example 2. We must also add the production lead time for each end product and component part to our database. In this simplified example, we use a one-period lead time for assembling each end product and one period for each operation required to produce component parts. Because only one operation is required for producing components D, E, and F, lead time for producing these components is one time period each. For component C, however, lead time is two time periods: one for the operation in work center 200 and another for work center 300.



Solution 3: Capacity Requirement Using Resource Profiles

Work Centre	Past Due	Period							
		1	2	3	4	5	6	7	8
100	000	23.75	23.75	23.75	18.90	18.90	18.90	34.00	34.00
200	56.50	32.45	35.56	35.15	35.15	32.15	34.75	34.75	39.45
300	660	660	660	800	800	800	600	600	600
Total Capacity	63.10	6280	6600	6690	6205	5905	5965	74.75	79.45

$$56.50 = [(.6 \times 33 + .1 \times 33) + (.25 \times 17 + .2 \times 17 + .1 \times 17)] + [(.6 \times 33) + (.25 \times 17)]$$

Capacity Requirement Planning

Capacity Requirements Planning (CRP) differs from RCCP in four respects: (1) CRP utilizes the time-phased material plan information produced by an MRP system. (2) It takes into

account capacity stored as inventories. (3) The shop-floor control system accounts for the current status of WIP. (4) CRP takes into account demand for service parts that are not accounted for in the MPS.

CRP requires same input as resource profile procedure plus information on MRP-planned orders and open shop orders (Scheduled Receipt). In this system, a larger database as well as larger computational effort is required. Thus the inputs required for CRP system are:

- Open Order File – found as scheduled receipts on MRP
- Planned order releases from MRP – Potential future orders
- Work Center file
- Information on capacity in the work center
- Move, wait, and queue time information
- Routing file – the path that the work will follow
- Operations to be performed
- Operation sequence
- Work centers used
- Potential alternative work centers
- Tooling needed
- Standard setup times and run times

Example 4:

Period 4

		Period							
		1	2	3	4	5	6	7	8
Product A	MPS	33	33	33	40	40	40	30	30
<i>Component C</i>									
Lot size = 40		Period							
Lead time = 2		1	2	3	4	5	6	7	8
Gross Requirements		33	33	33	40	40	40	30	30
Scheduled receipts			40						
Projected available									
Balance	37	4	11	18	18	18	18	28	38
Planned order receipts				40	40	40	40	40	40
Planned order releases		40	40	40	40	40	40		

Period 5

		Period							
		1	2	3	4	5	6	7	8
Hours of capacity		8	8	8	8	8	8	8	0

Component C has two operations. First is performed on WC 200 and second is performed on WC 300. Time/unit on WC 300 is 0.2 hours multiplied by lot size of 40 = 8 hours

Finite Capacity Scheduling

Finite scheduling systems simulate actual job order starting and stopping times to produce a detailed schedule for each shop order and each machine center; that is, finite scheduling loads all jobs in all necessary work centers for the length of the planning horizon. It establishes a detailed schedule for each job in each work center. Prioritizing rules are used when work center's capacity is not sufficient.

One output of finite scheduling is a simulation of how each machine center is to operate on a minute-by-minute basis for whatever time horizon is planned. Selection of the next job to schedule is not based just on those jobs physically waiting at the work center. Randomness leads to actual times that don't match scheduled times. Should the work center wait for a job that isn't available on time (idleness = lost capacity)? Over time, the accuracy of the plan deteriorates. Frequent rescheduling may be needed to maintain accuracy. The rescheduling process is computationally expensive.

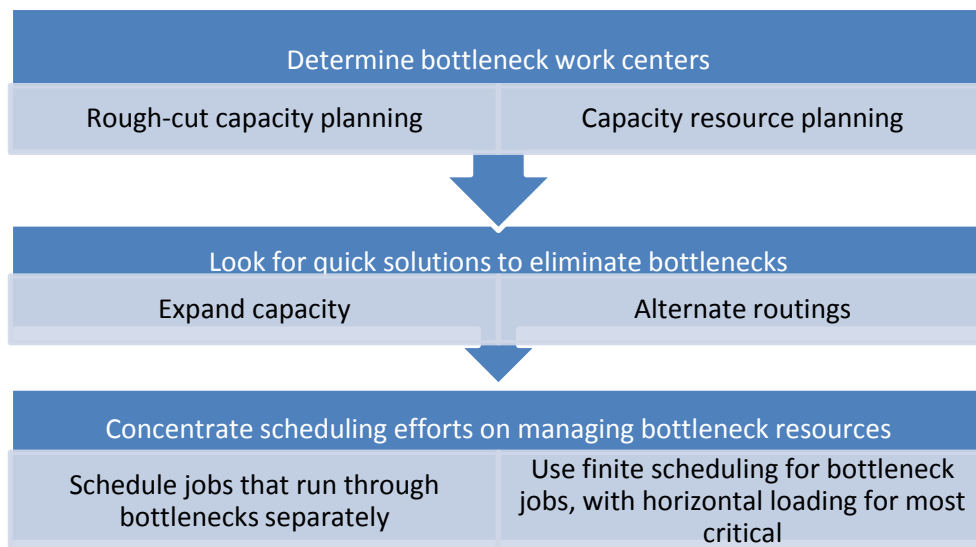
Input / Output Control

The capacity planning technique used delineates the planned input. Planned output results from managerial decision making to specify the capacity level; that is, planned output is based on staffing levels, hours of work, and so forth. In capacity-constrained work centers, planned output is based on the rate of capacity established by management. It depends upon the nature of the work center. Planned inputs are determined by the capacity planning process. The capacity-constrained-planned output is determined by the processing rate of the work center. Whereas, non-capacity-constrained planned outputs match planned inputs. Differences between plan and actual must be addressed.

Managing Bottleneck Capacity

For the purposes of capacity planning and management, TOC teaches that the capacities of bottleneck work centers need to be planned and managed much more carefully than those of non-bottlenecks. In fact, for non-bottlenecks it may not be important to even have decent data. If sufficient capacity exists, execution of capacity plans is easy. Spend the time and energy on execution of what at first seems impossible.

The TOC approach to capacity planning is essentially to first determine the bottleneck work centers. This can be done with a rough-cut capacity planning model or with CRP. Where are the bottlenecks? Next, TOC would try to find the quick solutions for eliminating bottlenecks. Finally, scheduling will concentrate on best managing bottleneck capacity. Essentially, TOC will separate those jobs that pass through the bottlenecks from those that do not. Only the jobs or work orders requiring capacity in the bottleneck resource are finite scheduled, using horizontal loading and back scheduling for the most critical jobs.



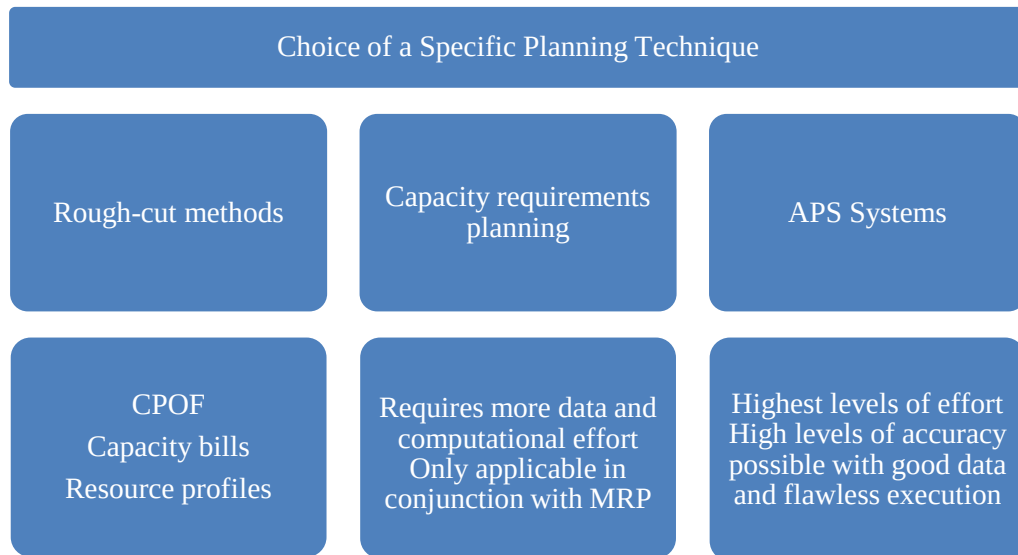
Measure of Capacity

If the variety of products produced at a work center or in a plant is not large, it is often possible to use a unit common to all products. Paper mills measure capacity in tons of paper, oil refineries in barrels of oil, and automobile manufacturers in numbers of cars. However, if a variety of products is made, a good common unit may not exist. In this case, the unit common to all products is time. Therefore, capacity can be measured in many ways. The measure could be labor hours, machine hours, physical units, monetary units etc. The firm's needs and constraints should determine the capacity measure.

The work content of a product is expressed as the time required to make the product using a given method of manufacture. Using time-study techniques, the standard time for a job can be determined—that is, the time it would take a qualified operator working at a normal pace to do the job. It provides a yardstick for measuring work content and a unit for stating capacity. It is also used in loading and scheduling.

Choice of a Specific Technique

The choice of a specific technique depends heavily on characteristics of the manufacturing environment. The three rough-cut methods are most general, being applicable even in companies using JIT methods for shop-floor control. Its approaches do vary in accuracy, aggregation level, and ease of preparation. There's a general relationship between the amount of data and computational time required, and the quality and detail of the capacity requirements estimated. The issue is whether additional costs of supporting more complex procedures are justified by improved decision making and subsequent plant operations. The capacity bills procedure has an advantage over capacity planning using overall factors (CPOF) because it explicitly recognizes product mix changes. On the other hand, the capacity requirements planning is only applicable in companies using time-phased MRP records for detailed material planning and shop-order-based shop scheduling systems.



Using the Capacity Plan

The capacity can be changed by utilizing overtime/undertime, hiring/layoff of workforce, or by increasing/ decreasing the number of machine tools. Whereas, capacity requirement can be changed by utilizing alternate routing, make-or-buy decision, subcontracting, raw material substitution, inventory changes, or revised customer promise dates.

Capacity planning choices dictate the diameter of the manufacturing pipeline. Only as much material can be produced as there's capacity for its production, regardless of the material plan. Not understanding the critical nature of managing capacity can lead a firm into production chaos and serious customer service problems.

H. Distribution Requirements Planning (DRP)

So far we have been studying the planning of product manufacturing, that is, what, how much and when to produce. Whereas, distribution requirement planning (DRP) is a system that forecasts what, how many, and when demand will be required by the distribution centers. This gives the central supply and the factory an opportunity to plan for the production of finished goods that will be needed in the near future.

After the completion of this lecture, the student should be able to:

- *Identify the role played by DRP in MPC system*
- *Demonstrate the ability to apply DPR techniques to manage the demand and supply of goods*
- *Identify the management issues with DRP*

DRP in the Supply Chain

Managing the flow of material in a supply chain is not an easy task since the material flows between firms, warehouses, distribution centers, and sometimes even back to the firm after the addition of value to the material. DRP manages these flows of materials between firms, warehouses, and distribution centers just like MRP did in manufacturing. It links firms in the supply chain by providing planning records that carry demand information between receiving and supply point and returns supply information to receiving points. Both DRP and MRP depend on a forecast of demand with an objective of avoiding shortages with minimum inventory investment.

Distribution inventory can either be "pushed" from the central supply down through the network or "pulled" up through the network by orders from the consumer. Pull provides the best availability for the customer (local management has control of what's available), but it is difficult to manage distribution inventory in a pull system environment because every order is a surprise to the supplying location as demand flows up the network.

Though several linkages in the supply network can be accommodated in a distribution requirements planning system, in our description of DRP we will take the perspective of a supplying firm distributing product to other manufacturers or to retail customers. In addition to responding to customer demands, it can also coordinate planning and control of manufacturing and distribution: The DRP for each distribution center is executed by TPOP, then using MRP logic to explode the planned order releases for the central supply and factory.

DRP and the MPC System

DRP provides the basis for integrating supply chain inventory information and physical distribution activities with the Manufacturing Planning and Control system. The distribution requirements planning (DRP) linkages that span the boundary from our internal systems to our customers' internal systems are shown in Figure H.1. In the Front End one of the linkages is with demand management which connects it with the customers and in the Back End one of the linkages is with the vendors.

DRP and the Marketplace

Though several linkages in the supply network can be accommodated in a distribution requirements planning system, in our description of DRP we will take the perspective of a supplying firm distributing product to other manufacturers or to retail customers. We can say that DRP starts in the marketplace or as close to it as possible. But in most of the cases it starts inside the company's manufacturing system linking it with the firm's warehouses.

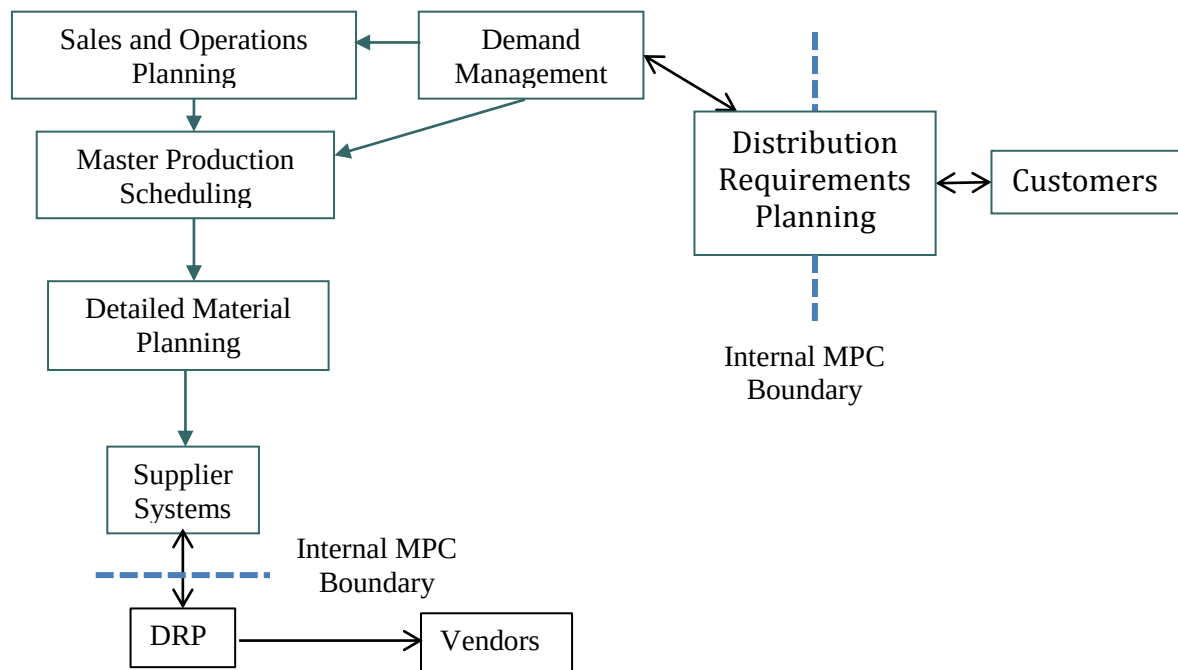


Figure H.1 DRP linkages with MPC system

Some firms gather information on inventory levels and product usage from customers. This knowledge of their customer requirements provides firms the opportunity to make-to-knowledge. This is especially true when they have vendor managed inventories.

DRP enables the firm to capture data, including local demand conditions, for modifying the forecast and to report current inventory positions. It provides data for managing the distribution facility and the database for consistent communications with the customers and the rest of the company.

DRP and Demand Management

Demand management is the connection between manufacturing and the marketplace through DRP. Plans derived from the DRP information and shipping requirements are the basis for managing the logistics. It continually adjusts changes in the demand, sending inventories from central warehouse to distribution centers where they are needed. DRP is connected to the logistics system as shown in Figure H.2:

DRP generated shipment schedules help to determine vehicle capacity planning, which is the process of planning the vehicle availability for the set of future shipments. Shipping requirements are also used to determine vehicle loads, dispatch vehicles, and plan the resources necessary to receive the goods at the warehouse. It also helps in determining warehouse capacity. DRP data provides information about when the availability of material will be improved and the delivery is expected.

DRP and Master Production Scheduling

DRP's greatest payoff to master production scheduling is from integrating records and information. Since DRP uses same format as MPS and MRP it is easier for DRP to extend MPC visibility into distribution systems.

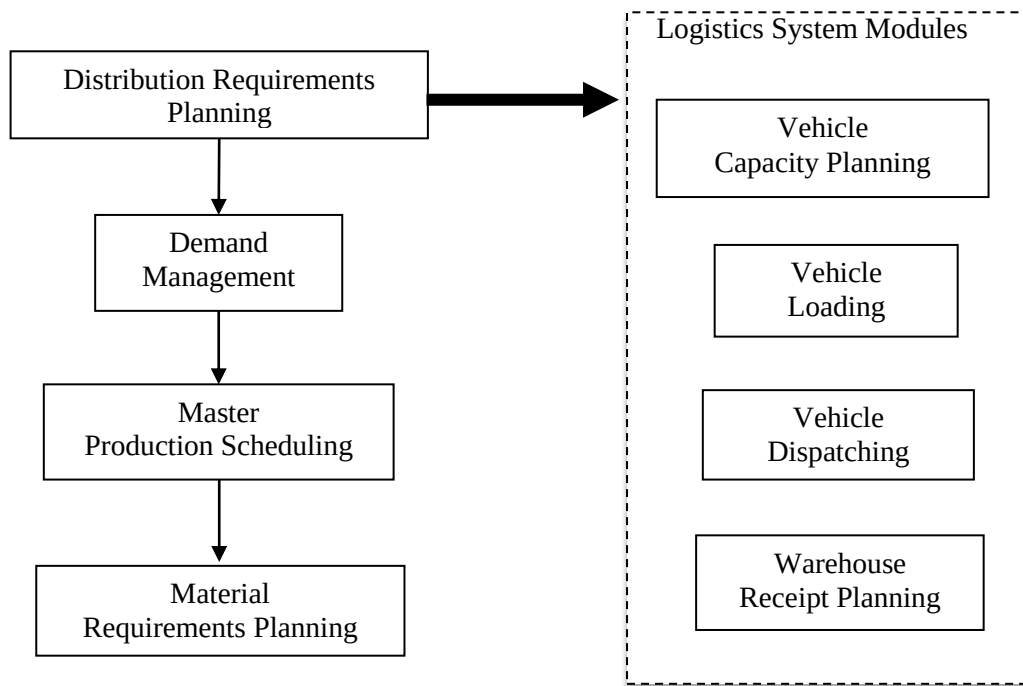


Figure H.2 Linkage between DRP and logistics system

Moving the MPC boundaries into the supply chain means that there is some cost associated with it. Crossing the area into inter-firm MPC system means that it has to negotiate with supply chain partners for sharing costs and benefits. It permits evaluation of current conditions to determine if manufacturing priorities need to be revised. It provides great help to master scheduler because DRP provides better info to match manufacturing output with shipment needs.

Basic DRP Record

One of the key elements of DRP is the DRP record, which includes the following elements:

- Forecast demand for each stock-keeping unit (SKU), which is gross requirement in MRP record
- In transit inventory, which is scheduled receipt in MRP
- Current inventory level of the SKU, which is projected available in MRP
- Planned shipments, which are planned order releases
- Replenishment lead time

The concept of DRP very closely mimics the logic of MRP. As with MRP, gross requirements consist of actual customer orders, forecasted demand, or some combination of both; scheduled receipts are the goods the distributor expects to receive from orders that already have been released, while goods that already are received and entered into inventory constitute the on-hand inventory balance. Subtracting scheduled receipts and on-hand inventory from gross requirements yields net requirements. Based upon the distributor's lot-sizing policy and receiving behavior, planned order receipts are generated.

Firms may order only what they need for the next planning period or for a designated time period. It can order based on what is known as economic order quantity (EOQ). Alternatively, firms may be limited to multiples of a lot size simply because the supplying firm packages or palletizes their goods in standard quantities. Also, some distributors may

require some time interval between the arrival of goods on their docks and the entry of the goods into the inventory system. The basic DRP record is shown in Table H.1.

Table H.1 Basic Distribution Requirements Planning Record

	Period						
	1	2	3	4	5	6	7
Forecast requirements	20	20	20	20	30	30	30
In transit		60					
Projected available balance 45	25	65	45	25	55	25	55
Planned shipments			60				

Time-Phased Order Point (TPOP)

As mentioned earlier most of the companies used EOQ model to determine order quantity and reorder position using (Q,R) system based on demand forecast. It should be noted that TPOP can be used for constant usage as well as when the usage forecast vary from period to period. TPOP approach is based on MRP logic that prevents ending balance falling below safety stock level. TPOP calculation is shown in Table H.2.

Table H.2 TPOP Record

	Period						
	1	2	3	4	5	6	7
Forecast requirements	15	15	15	15	15	15	15
In transit							
Projected available balance 22	7	32	17	42	27	12	37
Planned receipts		40		40			40
Planned shipments	40		40			40	

Safety stock = 5; shipping quantity = 40; lead time = 1

Example H.1

XYZ Chemicals Ltd. Distributes its Urea fertilizer through its Lahore warehouse. The sales forecast for this product is 20 tons per week. 43 tons of the product is currently on hand. Whereas, shipment quantity is 60 tons, there is no safety stock, and the planned shipment lead time is one week. The product is packed in a lot of 50 tons. Similar data for plant warehouse is given in Table H.3.

Table H.3 Data for Plant Warehouse

Lahore Warehouse	Week						
	1	2	3	4	5	6	7
Forecast requirements	20	20	20	20	20	20	20
In transit							
Projected available balance 43	23	3	43	23	3	43	23
Planned receipts			60			60	
Planned shipments		60			60		

Safety stock = 0; shipping quantity = 60; lead time = 1

Plant Warehouse	Week						
	1	2	3	4	5	6	7
Gross requirements		60			60		
Scheduled receipts		50					
Projected available balance 30	30	20	20	20	10	10	10
Planned order releases					50		
Firm planned orders			50				

Safety stock = 0; shipping quantity = 50; lead time = 2

Linking Several Warehouses

The bill of distribution (BOD) is used to specifically link the branch warehouse with the supplying facility. It is sometimes referred to as an inverted bill of materials, since the BOM "explodes" the parent requirements down to the individual components, while the BOD "implodes" the branch warehouse requirements upward to the parent, or supplying, facility. The establishment of these relationships is important to ensure total logistic control throughout the supply chain as shown in Figure H.3.

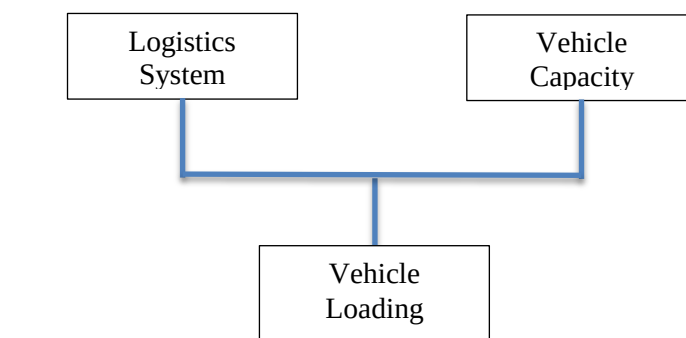


Figure H.3 Bill of Distribution (Implosion)

Example H.2

A plant in Lahore supplies material to two warehouses and from there to customers. Assume that the warehouse 1 and warehouse 2 will sell 40 units and 60 per week, respectively. It takes one week to transport the product to warehouses or to produce it at the plant. The beginning inventory at the warehouses is 60 units and at the plant it is 140 units. No safety stock is planned at any location. Develop a DRP record for this system.

Warehouse 1

	1	2	3	4	5	6	7
Forecast requirements	40	40	40	40	40	40	40
In transit							
Projected available balance 60	20	0	0	0	0	0	0
Planned receipts		20	40	40	40	40	40
Planned shipments	20	40	40	40	40	40	

Safety stock = 0; shipping quantity = lot-for-lot; lead time = 1

Warehouse 2

	1	2	3	4	5	6	7
Forecast requirements	60	60	60	60	60	60	60
In transit							
Projected available balance 60	0	0	0	0	0	0	0
Planned receipts		60	60	60	60	60	60
Planned shipments	60	60	60	60	60	60	

Safety stock = 0; shipping quantity = lot-for-lot; lead time = 1

Warehouse 1	20	40	40	40	40	40	
Warehouse 2	60	60	60	60	60	60	

Plant

	1	2	3	4	5	6	7
Forecast requirements	80	100	100	100	100	100	
In transit							
Projected available balance 140	60	0	0	0	0	0	0
Planned receipts		40	100	100	100	100	100
Planned shipments	40	100	100	100	100	100	

Safety stock = 0; shipping quantity = lot-for-lot; lead time = 1

Managing Day-to-Day Variations

On a daily basis, transactions are processed and DRP records are updated, regularly. Accordingly, the shipping plans are changed, which have destabilizing impact on MPS. The process involved in day-to-day variations is shown in the Example H.3.

Example H.3

	1	2	3	4	5
Forecast requirements	20	20	20	20	20
In transit	40				
Projected available balance 6	26	6	26	6	26
Planned receipts			40		40
Planned shipments		40		40	

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 1 = 18

	1	2	3	4	5
Forecast requirements	20	20	20	20	20
In transit					
Projected available balance 28	8	28	8	28	8
Planned receipts		40		40	
Planned shipments	40		40		

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 2 = 24

	3	4	5	6	7
Forecast requirements	20	20	20	20	20
In transit	40				
Projected available balance 4	24	44	24	44	24
Planned receipts		40		40	
Planned shipments	40		40		

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 3 = 16

	4	5	6	7	8
Forecast requirements	20	20	20	20	20
In transit	40				
Projected available balance 28	48	28	8	28	8
Planned receipts				40	
Planned shipments			40		

Safety stock = 6; shipping quantity = 40; lead time = 1

Error Addback

An alternative for stabilizing the information is the error addback method. This approach assumes forecasts are unbiased or accurate on the average. This means any unsold forecast in one period will be made up for in a subsequent period, or any sales exceeding forecast now will reduce sales in a subsequent period. With this method, errors are added (or subtracted) from future requirements to reflect the expected impact of actual sales on projected sales. Table H.4 applies this concept to the warehouse example. Note the planned shipments are under system control; that is, firm planned orders aren't used.

Table H.4 Error Addback

	1	2	3	4	5
Forecast requirements	20	20	20	20	20
In transit	40				
Projected available balance 6	26	6	26	6	26
Planned receipts			40		40
Planned shipments		40		40	

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 1 = 18; cumulative error = +2

	2	3	4	5	6
Forecast requirements	22	20	20	20	20
In transit					
Projected available balance 28	6	26	6	26	6
Planned receipts		40		40	
Planned shipments	40		40		

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 2 = 24; cumulative error = -2

	3	4	5	6	7
Forecast requirements	18	20	20	20	20
In transit	40				
Projected available balance 4	26	6	26	6	26
Planned receipts			40		40
Planned shipments		40		40	

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 3 = 16; cumulative error = +2

	4	5	6	7	8
Forecast requirements	22	20	20	20	20
In transit					
Projected available balance 28	6	26	6	26	6
Planned receipts		40		40	
Planned shipments	40		40		

Safety stock = 6; shipping quantity = 40; lead time = 1

Actual demand in period 4 = 15; cumulative error = +7

Safety Stocks in DRP

When the uncertainty is in quantity then safety stock may be better for protection against this uncertainty. When there is more uncertainty in terms of timing, then it may be better to use safety lead time.

The issue of where to hold safety stock was addressed in a comprehensive simulation study in which lead time, inventory levels, number of shipments, the number of customers, demand uncertainty and inventory control system were varied randomly. From this simulation study it was established that the safety stock should be carried where there is uncertainty (near the customer) or where there is some element of independent demand.

Data Integrity and Completeness

A key issue is the use of aggregate forecasts which are later on broken down into detailed forecasts. Aggregate forecasts are more accurate than forecasts at SKU level. For example, it is much easier to forecast the total score of a cricket team than forecasting scores of individual players.

It is imperative that the forecast errors should be avoided especially biased errors. Because these types of errors either build large inventories or shortages, both are costly errors. In all cases, standard forecast monitoring techniques need to be applied, particularly to discover bias introduced through the adjustment process.

Also, management programs should be established to monitor the process because inventory accuracy depends on transaction process routines and discipline. Procedures for quick and accurate reporting of shipments to customers, allocations to customers, returns, adjustments, receipts, and the like must all be in place.

Problem Solving

Bulk Material Record and MPS

Table H.5 shows how the various sizes of packaged products can be combined into a bulk inventory record for creating the factory's MPS. In the example, two package sizes consume the bulk inventory. The packages are in grams, while the bulk item is in kilograms. The explosion process works from packaged item to bulk, but the grams have been converted to kilograms to get the gross requirements for the bulk material (e.g., for period 1: 100 units x 200 grams = 20,000 grams = 20 kilograms). The firm planned orders for the bulk material are the factory MPS, stating when the bulk inventory must be replenished to meet the packaging schedules.

Table H.5 Bulk Material Record

	Period						
200-Gram Product	1	2	3	4	5	6	7
Planned orders					60	40	
Firm Planned orders	100		100				

	Period						
500-Gram Product	1	2	3	4	5	6	7
Planned orders				10	10		20
Firm Planned orders		20					

	Period						
Bulk Material-Kilogram	1	2	3	4	5	6	7
Gross Requirements	20	10	20	5	17	8	10
Scheduled Receipt							
Projected Available Balance 5	25	15	35	30	13	5	35
Planned order receipts	40		40				40
Planned orders							40
Firm Planned Orders	40		40				

Example Sales Promotion

Table H.6 presents a sales promotion served by a warehouse. For simplicity, we consider only one product at a single warehouse and the product's packaging line. The process starts with modifying the demand forecast at the warehouse. In the example, the promotion is planned

for weeks 5 through 8. The impact is estimated to double sales (from 20 to 40) during the first two weeks and to have a reduced impact during the next two weeks. Note the promotion “steals” from demand in weeks 9 and 10.

Table H.6 Sales Promotion

Packaging	Period						
	1	2	3	4	5	6	7
Gross requirements	0	20	20	40	40	40	
Scheduled receipts							
Projected available balance 0	0	12	24	16	8	0	0
Planned order receipts		32	32	32	32	32	
Planned order release							
Firm planned orders	32	32	32	32	32		

Safety stock = 5; quantity = 20; lead time = 1

Warehouse	Period						
	1	2	3	4	5	6	7
Forecast requirements	20	20	20	20	40	40	30
In transit	20						
Projected available balance 27	27	7	7	7	7	7	17
Planned receipts			20	20	40	40	40
Planned shipments		20	20	40	40	40	

Safety stock = 5; quantity = Lot for lot; lead time = 1

Note: Packaging capacity = 35 units/period

Example Warehouse Closure

In Table H.7, warehouse 1 is scheduled to close at the end of four weeks, and warehouse 2 is to start supplying the customers. Again, the process of managing the cutover starts with the forecasts. The requirements at warehouse 1 stop at the end of week 4 and are picked up by warehouse 2, reflecting the timing and quantities of the closedown and transfer.

In the example, warehouse 1 would normally have had a planned shipment for 60 units in week 3. The planner has overridden the planned order with a firm planned order for the exact need, reducing safety stock to zero. Note the system plans an order to restore the safety stock and, eventually, the planner will need to change the safety stock parameter to zero in order not to send the wrong signal to the master production scheduler.

Table H.7 Warehouse Closure

Warehouse 1	Period						
	1	2	3	4	5	6	7
Forecast requirements	30	30	30	30	0	0	0
In transit	60						
Projected available balance 43	73	43	13	60	60	60	60
Planned receipts				77			
Planned shipments			60				
Firm Planned Shipments			17				

Safety stock = 10; quantity = 60; lead time = 1

Warehouse 2	Period						
	1	2	3	4	5	6	7
Forecast requirements	100	100	100	100	130	130	130
In transit							
Projected available balance 207	107	207	107	207	77	147	217
Planned receipts		200		200		200	200
Planned shipments					200	200	
Firm planned shipments	200		200				

Safety stock = 20; quantity = 200; lead time = 1

I. Production Activity Control (PAC)

The time comes when plans must be put into action. PAC is responsible to execute MPS and MRP schedules. The activities of the PAC system can be classified into planning, implementation, and control functions.

After the completion of this lecture, students should be able to:

- Describe in their own words the basic concepts of shop control and specify the models used therein.
- Understand how PAC is related to other aspects of MPC?
- Use different concepts and models of production activity control for shop floor and vendor scheduling and control.
- Apply Theory of Constraints (TOC) and other techniques to schedule multiple constraint resources.

A Framework for PAC

Production activity control (PAC) is responsible for executing the master production schedule and the material requirements plan. At the same time, it must make good use of labor and machines, minimize work-in-process inventory, and maintain customer service.

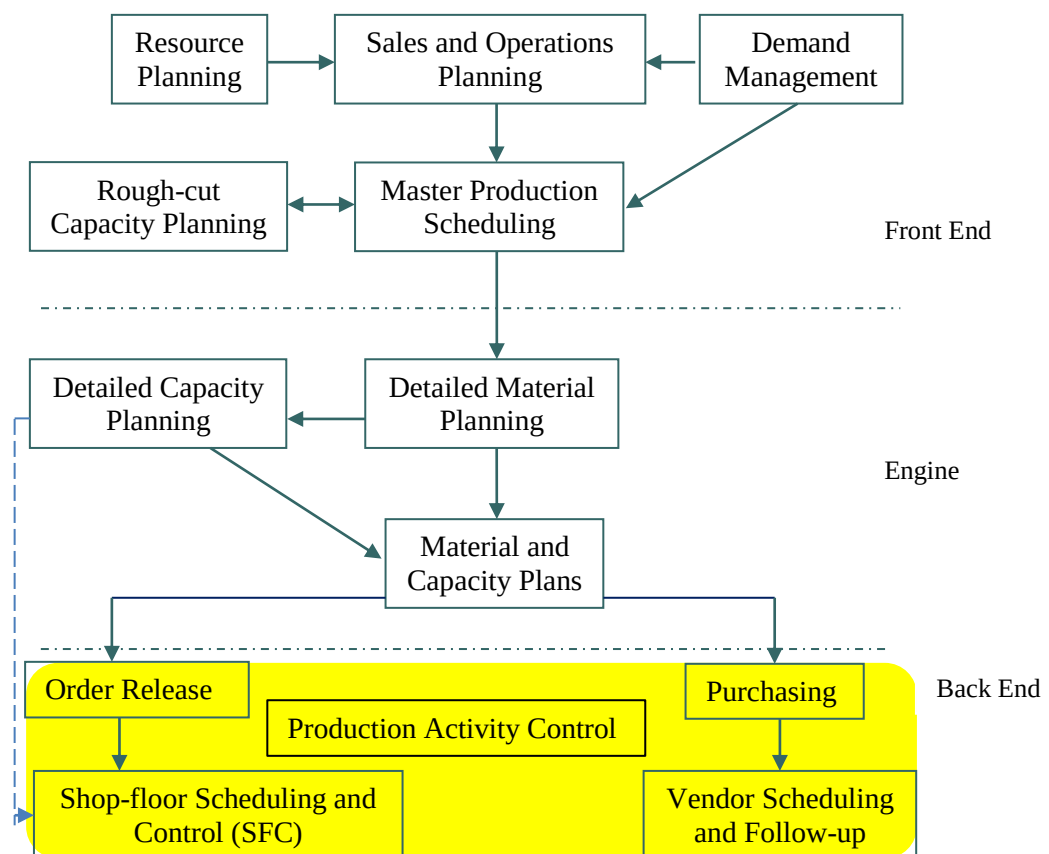


Figure I.1 MPC system linkages

MPC System Linkages

The PAC's linkages to other modules of an MPC system are shown Figure I.1. The box titled "Shop-floor scheduling and control," which we refer to as shop-floor control, falls completely within PAC. Vendor scheduling and follow-up is depicted as largely being part of production activity control, but not completely. Many firms, particularly those with JIT material control

approaches, assign most vendors' scheduling to PAC. Order release (which authorizes release of individual orders to the factory and provides accompanying documentation) is similarly becoming more a part of PAC.

The particular type of production control system used varies from company to company, but all should perform the preceding functions. However, the relative importance of these functions will depend on the type of manufacturing process. Manufacturing processes can be conveniently organized into three categories:

1. Flow manufacturing.
2. Intermittent manufacturing.
3. Project manufacturing.

Flow Manufacturing

Flow manufacturing is concerned with the production of high-volume standard products. If the units are discrete (e.g., cars and appliances), the process is usually called repetitive manufacturing, and if the goods are made in a continuous flow (e.g., gasoline), the process is called continuous manufacturing.

Production activity control concentrates on planning the flow of work and making sure that the right material is fed to the line as stated in the planned schedule. Since work flows from one workstation to another automatically, implementation and control are relatively simple.

Intermittent Manufacturing

Intermittent manufacturing is characterized by many variations in product design, process requirements, and order quantities. Production activity control in intermittent manufacturing is complex. Because of the number of products made, the variety of routings, and scheduling problems, PAC is a major activity in this type of manufacturing. Planning and control are typically exercised using shop orders for each batch being produced. Our discussion of PAC assumes this kind of environment.

Project Manufacturing

Project manufacturing usually involves the creation of one or a small number of units. Large shipbuilding is an example. Because the design of a product is often carried out or modified as the project develops, there is close coordination between manufacturing, marketing, purchasing, and engineering.

Plan, Implement & Control

Plan: The flow of work through each of the work centers must be planned to meet delivery dates, which means production activity control must do the following:

- Ensure that the required materials, tooling, personnel, and information are available to manufacture the components when needed.
- Schedule start and completion dates for each shop order at each work center so the scheduled completion date of the order can be met. This will involve the planner in developing a load profile for the work centers.

Implementation: Once the plans are made, production activity control must put them into action by advising the shop floor what must be done. Usually instructions are given by issuing a shop order. Production activity control will:

- Gather the information needed by the shop floor to make the product.
- Release orders to the shop floor as authorized by the material requirements plan. This is called dispatching.

Control: Once plans are made and shop orders released, the process must be monitored to learn what is actually happening. The results are compared to the plan to decide whether corrective action is necessary. Production activity control will do the following:

- Rank the shop orders in desired priority sequence by work center and establish a dispatch list based on this information.
- Track the actual performance of work orders and compare it to planned schedules. Where necessary, PAC must take corrective action by re-planning, rescheduling, or adjusting capacity to meet final delivery requirements.
- Monitor and control work-in-process, lead times, and work center queues.
- Report work center efficiency, operation times, order quantities, and scrap.

The functions of planning, implementing, and controlling are shown schematically in Figure I.2.

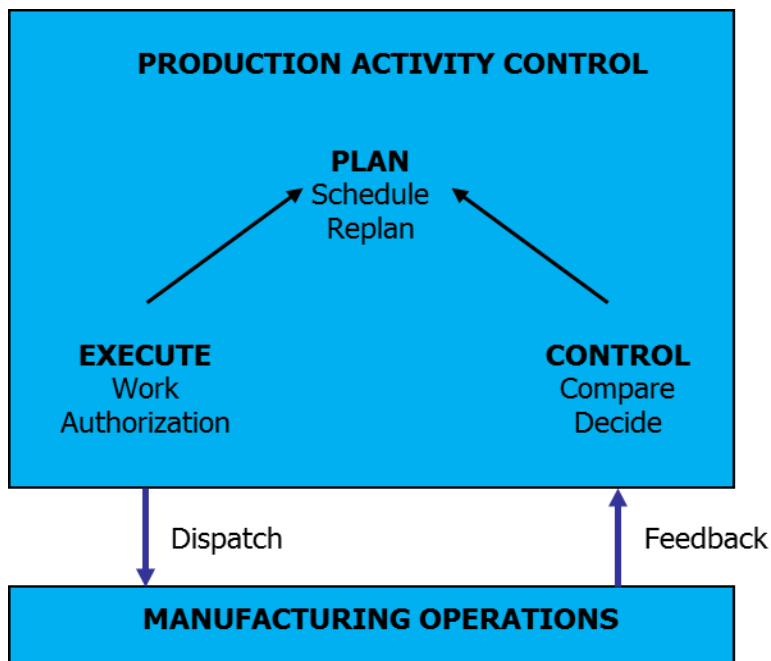


Figure I.2 The functions of planning, implementing, and control

DATA REQUIREMENTS

To plan the processing of materials through manufacturing, PAC must have the following information:

- What and how much to produce?
- When parts are needed so the completion date can be met?
- What operations are required to make the product and how long the operations will take?
- What the available capacities of the various work centers are?

Production activity control must have a data or information system from which to work. Usually the data needed to answer these questions are organized into databases. The files contained in the databases are of two types: planning and control.

Planning Files

Four planning files are needed: item master file, product structure file, routing file, and work center master file.

Item master file: There is one record in the item master file for each part number. The file contains, in one place, all of the pertinent data related to the part. For PAC, this includes the following:

- Part number, a unique number assigned to a component.
- Part description.
- Manufacturing lead time, the normal time needed to make this part.
- Quantity on hand.
- Quantity available.
- Allocated quantity, quantities assigned to specific work orders but not yet withdrawn from inventory.
- On-order quantities, the balance due on all outstanding orders.
- Lot-size quantity, the quantity normally ordered at one time.

Product structure file (bill of material file): The product structure file (bill of material file) contains a list of the single-level components and quantities needed to assemble a parent. It forms a basis for a “pick list” to be used by storeroom personnel to collect the parts required to make the assembly.

Routing file: The routing file contains a record for each part manufactured. It gives details of the following:

- The operations required to make the product and the sequence in which those operations are performed.
- A brief description of each operation.
- Equipment, tools, and accessories needed for each operation.
- Setup times, the standard time required for setting up the equipment for each operation.
- Run times, the standard time required to process one unit through each operation.
- Lead times for each operation.

Work center master file: The work center master file collects all of the relevant data on a work center. For each work center, it gives details on the following:

- Work center number.
- Capacity.
- Number of shifts worked per week.
- Number of machine hours per shift.
- Number of labor hours per shift.
- Efficiency.
- Utilization.
- Queue time, the average time that a job waits at the work center before work is begun.
- Alternate work centers, work centers that may be used as alternatives.

Control Files

Control in intermittent manufacturing is exercised through shop orders and control files that contain data on these orders. There are generally two kinds of files: the shop order master file and the shop order detail file.

Shop order master file: Each active manufacturing order has a record in the shop order master file. The purpose is to provide summarized data on each shop order, such as the following information:

- Shop order number, a unique number identifying the shop order.
- Order quantity.
- Quantity completed.
- Quantity scrapped.
- Quantity of material issued to the order.
- Due date, the date the order is expected to be finished.
- Priority, a value used to rank the order in relation to others.
- Balance due, the quantity not yet completed.
- Cost information.

Shop order detail file: Each shop order has a shop order detail file contains a record for each operation needed to make the item. Each record contains the following information:

- Operation number.
- Setup hours, planned and actual.
- Run hours, planned and actual.
- Quantity reported complete at that operation.
- Quantity reported scrapped at that operation.
- Due date or lead time remaining.

Scheduling

The objective of scheduling is to meet delivery dates and to make the best use of manufacturing resources. It involves establishing start and finish dates for each operation required to complete an item. To develop a reliable schedule, the planner must have information on routing, required and available capacity, competing jobs, and manufacturing lead times (MLT) at each work center involved.

Manufacturing lead time is the time normally required to produce an item in a typical lot quantity. Typically, MLT consists of five elements:

1. Queue time, amount of time the job is waiting at a work center before operation begins.
2. Setup time, time required to prepare the work center for operation.
3. Run time, time needed to run the order through the operation.
4. Wait time, amount of time the job is at the work center before being moved to the next work center.
5. Move time, transit time between work centers.

The total manufacturing lead time will be the sum of order preparation and release plus the MLTs for each operation. Figure I.3 shows the elements making up manufacturing lead time. The largest of the five elements is queue time. Typically, in an intermittent manufacturing operation, it accounts for 85%–95% of the total lead time.

Cycle time: A term that is closely related to manufacturing lead time is cycle time. Its synonym is throughput time.

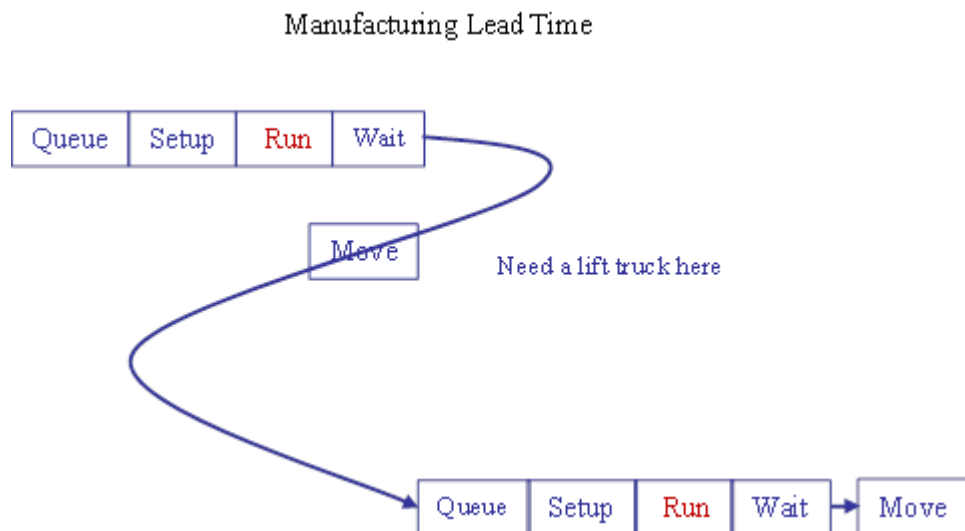


Figure I.3 The elements making up manufacturing leaf time

Scheduling Techniques

There are many techniques to schedule shop orders through a plant, but all of them require an understanding of forward and backward scheduling as well as finite and infinite loading.

Forward scheduling assumes that material procurement and operation scheduling for a component start when the order is received, whatever the due date, and that operations are scheduled forward from this date. The first line in Figure I.4 illustrates this method. The result is completion before the due date, which usually results in a buildup of inventory. This method is used to decide the earliest delivery date for a product.

Backward scheduling is illustrated by the second line in the figure. The last operation on the routing is scheduled first and is scheduled for completion at the due date. Previous operations are scheduled back from the last operation. This schedules items to be available as needed and is the same logic as used in the MRP system. Work-in-process inventory is reduced, but because there is little slack time in the system, customer service may suffer.

Forward and Backward Scheduling:
Infinite Load

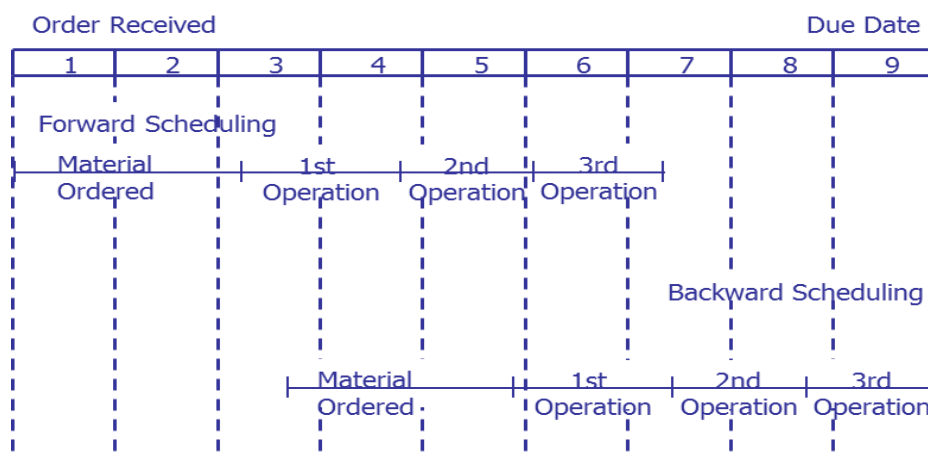


Figure I.4 Forward and backward scheduling: Infinite load

Infinite Scheduling

Infinite loading is also illustrated in the figure above. The assumption is made that the workstations on which operations 1, 2, and 3 are done have capacity available when required. It does not consider the existence of other shop orders competing for capacity at these work centers. It assumes infinite capacity will be available. Figure I.5 shows a load profile for infinite capacity.

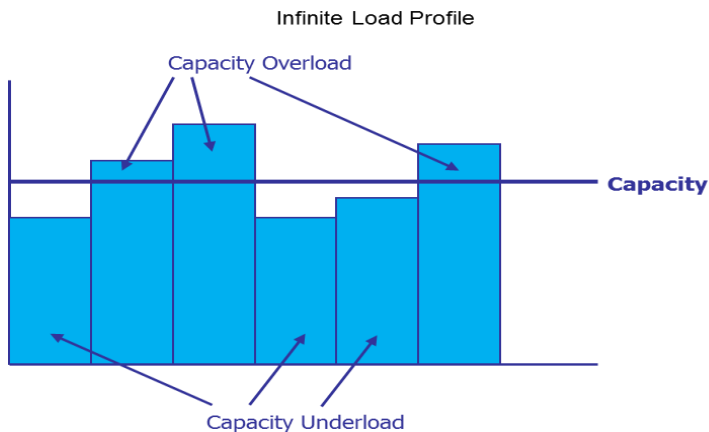


Figure I.5 Infinite load profile

Finite Scheduling

Finite loading assumes there is a defined limit to available capacity at any workstation. If there is not enough capacity available at a workstation because of other shop orders, the order has to be scheduled in a different time period. Figures I.6 illustrate the condition. In the forward-scheduling example shown in the figure, the first and second operations cannot be performed at their respective workstations when they should be because the required capacity is not available at the time required. These operations must be rescheduled to a later time period. Similarly, in the example of scheduling back, the second and first operations cannot be performed when they should be and must be rescheduled to an earlier time period. Figure I.6 shows a load profile for finite loading. Notice the load is smoothed so there is no overload condition.

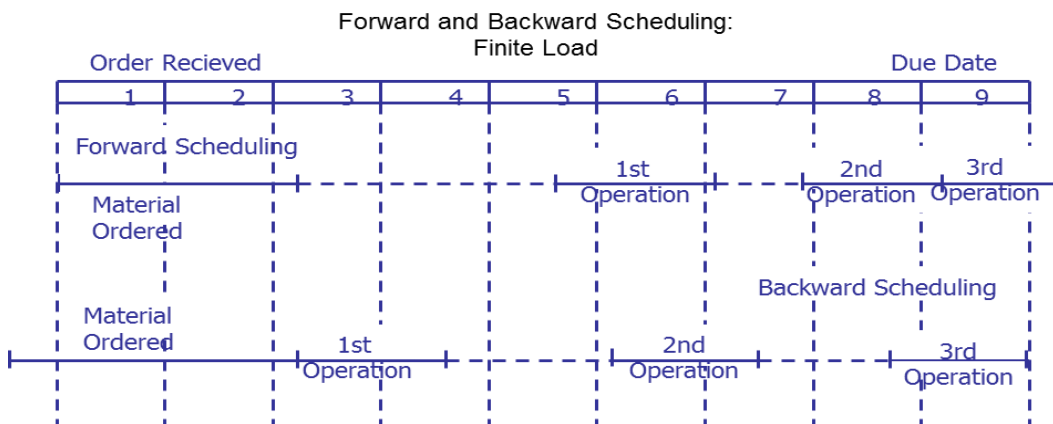


Figure I.6 Forward and backward scheduling: Finite load

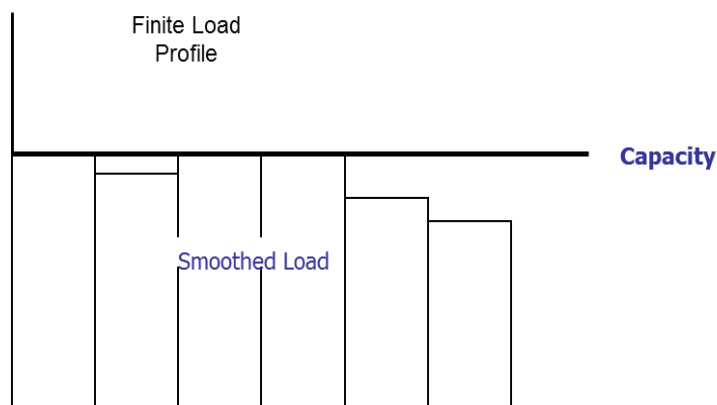
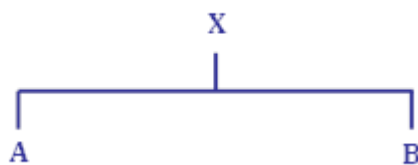


Figure I.7 Load profile for Finite loading

Example Problem

A company has an order for 50 units of brand X to be delivered on day 100. Only one machine is available for each operation. The factory works one 8 hour shift 5 days a week. The parts move in a lot of 50. Using the following data develop a schedule using backward scheduling.

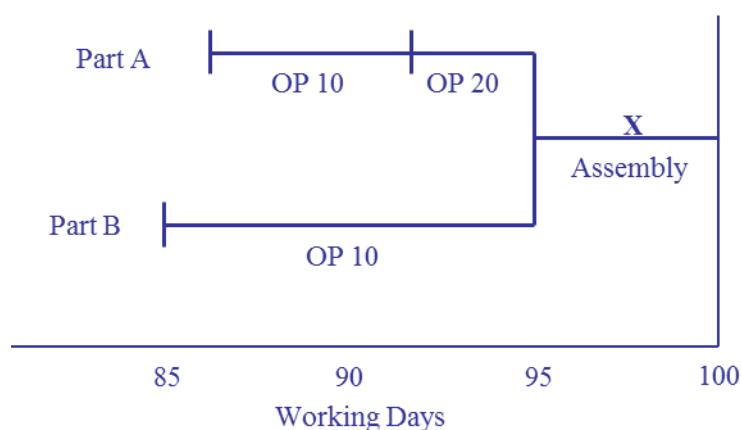
Backward Scheduling



Part	Operation	Time
A	10	5
	20	3
B	10	10
X	Assembly	5

Solution:

Backward Scheduling



Operations Overlapping

In operation overlapping, the next operation is allowed to begin before the entire lot is completed on the previous operation. This reduces the total manufacturing lead times because the second operation starts before the first operation finishes all the parts in the order. Figure I.8 divided into at least two lots.

Operation A

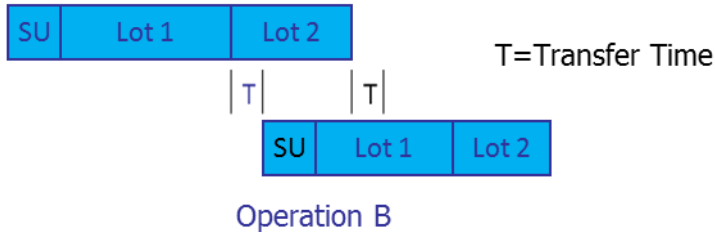


Figure I.8 Operations overlapping

Optimal Transfer

An order for 100 units of a product is processed on work centers A and B. The setup time on A is 30 minutes, and run time is 10 minutes per piece. The setup time on B is 50 minutes, and the run time is 5 minutes per piece. Determine the size of transfer batch if overlapping operations are used.

Solution:

SU_A = Set up time operation A

SU_B = Set up time operation B

RT_A = Run time per piece operation A

RT_B = Run time per piece operation B

QT = Total order size

T_1 = Size of the first transfer batch

$$T_1 = \frac{Q_T \times RT_A - SU_B}{RT_A + RT_B} = \frac{100 \times 10 - 50}{10 + 5} \approx 63 \text{ units}$$

$$T_2 = Q_T - T_1 = 100 - 63 = 37$$

Note:

If the second operation is slower than the first make the first transfer batch small. If the second machine is faster than the first make the first transfer batch large.

Example

A batch of 1,000 whatzits is to be run through 2 operations, A and B. Times for the operations are as follows:

Setup time on A=30 minutes

Setup time on B=50 minutes

Run time on A=10 minutes

Run time on B=5 minutes

Move time between A and B=10 minutes

Move time to store=15 minutes

Determine the size of transfer batch if overlapping operations are used.

Solution:

$$T_1 = \frac{Q_T \times RT_A - SU_B}{RT_A + RT_B} = \frac{1000 \times 10 - 50}{10 + 5} \approx 663 \text{ units}$$

$$T_2 = Q_T - T_1 = 1000 - 663 = 337$$

Operation Splitting

Operation splitting is a second method of reducing manufacturing lead time. The order is split into two or more lots and run on two or more machines simultaneously. If the lot is split in two, the run-time component of lead time is effectively cut in half, although an additional setup is incurred. Figure I.9 shows a schematic of operation splitting. Operation splitting is practical when:

- Setup time is low compared to run time.
- A suitable work center is idle.
- It is possible for an operator to run more than one machine at a time.

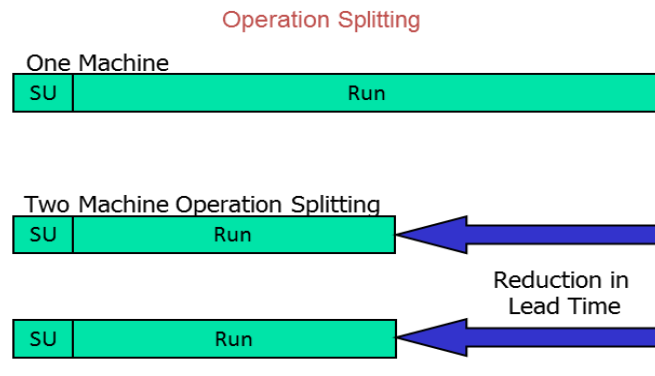


Figure I.9 Operation splitting

Load Leveling

The load profile for a work center is constructed by calculating the standard hours of operation for each order in each time period and adding them together by time period. Figure I.10 is an example of a load report.

Work Center: 10	Available Time: 120 Hours per week
Description: Lathes	Efficiency: 115%
Number of Machines: 3	Utilization 80%
Rated Capacity: 110 standard hours / wk	

Week	18	19	20	21	22	23	Total
Released Load	105	100	80	30	0	0	315
Planned Load			60	80	130	80	350
Total Load	105	100	140	110	130	80	665
Rated Capacity	110	110	110	110	110	110	660
(Over) / Under Capacity	5	10	(30)	0	(20)	30	(5)

Figure I.10 Load report

Scheduling Bottlenecks

In intermittent manufacturing, it is almost impossible to balance the available capacities of the various workstations with the demand for their capacity. As a result, some workstations are overloaded and some underloaded. The overloaded workstations are called bottlenecks and, by definition, are those workstations where the required capacity is greater than the available capacity.

Throughput is the total volume of production passing through a facility. Bottlenecks control the throughput of all products processed by them. If work centers feeding bottlenecks produce more than the bottleneck can process, excess work-in-process inventory is built up. Therefore, work should be scheduled through the bottleneck at the rate it can process the work.

Example Problem

Suppose a manufacturer makes wagons composed of a box body, a handle assembly, and two wheel assemblies. Demand for the wagons is 500 a week. The wheel assembly capacity is 1200 sets a week, the handle assembly capacity is 450 a week, and final assembly can produce 550 wagons a week.

- What is the capacity of the factory?
- What limits the throughput of the factory?
- How many wheel assemblies should be made each week?
- What is the utilization of the wheel assembly operation?
- What happens if the wheel assembly utilization is increased to 100%?

Solution:

- 450 units a week.
- Throughput is limited by the capacity of the handle assembly operation.
- 900 wheel assemblies should be made each week. This matches the capacity of the handle assembly operation.
- Utilization of the wheel assembly operation is
- Excess inventory builds up.

Managing Bottlenecks

Since bottlenecks control the throughput of a facility, some important principles should be noted:

- Utilization of a non-bottleneck resource is not determined by its potential, but by another constraint in the system.
- Utilization of a non-bottleneck 100% of the time does not produce 100% utilization.
- Utilization of a non-bottleneck resource is not determined by its potential, but by another constraint in the system.
- Utilization of a non-bottleneck 100% of the time does not produce 100% utilization.
- Utilization of a non-bottleneck resource is not determined by its potential, but by another constraint in the system.
- Utilization of a non-bottleneck 100% of the time does not produce 100% utilization.

Since bottlenecks are so important to the throughput of a system, scheduling and controlling them is extremely important. The following must be done:

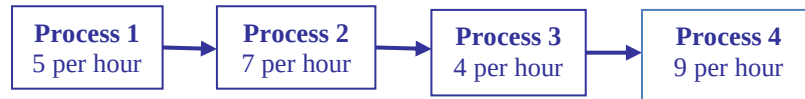
- Establish a time buffer before each bottleneck.
- Control the rate of material feeding the bottleneck.

- Do everything to provide the bottleneck with capacity.
- Utilization of a non-bottleneck resource is not determined by its potential, but by another constraint in the system.
- Utilization of a non-bottleneck 100% of the time does not produce 100% utilization.

Theory of Constraints

Once a constraint has been identified, there is a five-step process that is recommended to help improve the performance of the operation. The five steps are summarized as follows:

1. Identify the constraint



2. Exploit the constraint. (Idle time?)
3. Subordinate everything to the constraint.
4. Elevate the constraint.
5. Once the constraint is a constraint no-longer, find the new one and repeat the steps.

Example

Parent X requires 1 each of component Y and Z. Both Y and Z are processed on work center 20 which has an available capacity of 40 hours. The setup time for component Y is 1 hour and the run time 0.3 hour per piece. For component Z, setup time is 2 hours and the run time is 0.20 hour per piece. Calculate the number of Ys and Zs that can be produced.

Solution

Available capacity for Ys and Zs = 40 hours

$\text{Time}_Y + \text{Time}_Z = 40 \text{ hours}$

$1 + 0.3x + 2 + 0.2x = 40 \text{ hours}$

$0.5x = 37 \text{ hours}$

$x = 74$

(We can produce 74 Y's and 74 Z's)

Example Problem

Parent A requires 1 component B and two components C. Both A and B are processed on work center 1, while C is processed on work center 2. Both work centers have available capacity of 40 hours per week. The other data are provided in the table given below:



Item	Setup (hrs)	Run Time (hrs/unit)
A	2	.1
B	2	.2
C	1	.3

Work Station 1 makes A's and B's; Capacity = 40 hrs/week

Work Station 2 makes C's; Capacity = 40 hrs/week

Solution:

The number of B's should equal the number of A's produced and the load in workstation 1 can be expressed as the number of A's produced.

$$2 \text{ hrs} + .1 \times A \text{ hrs} + 2 \text{ hrs} + .2 \times A \text{ hrs} = 40 \text{ hrs}$$

$$.3 \times A \text{ hrs} = 36 \text{ hrs}$$

$$A = 120$$

Workstation 1 has the capacity to make 120 A's and 120 B's

Workstation 2 (there are 2 C's in every A)

$$1 \text{ hr} + 2 \times .3 \times A \text{ hrs} = 40 \text{ hrs}$$

$$.6 A = 39$$

$$A = 65$$

Workstation 2 can support the number of C's to make 65 A's (130 C's).

Implementation

Orders that have tooling, material, and capacity have a good chance of being completed on time and can be released to the shop floor. Other orders that do not have all of the necessary elements should not be released because they only cause excess work-in-process inventory and may interrupt work on orders that can be completed. The process for releasing an order is shown in Figure I.11.

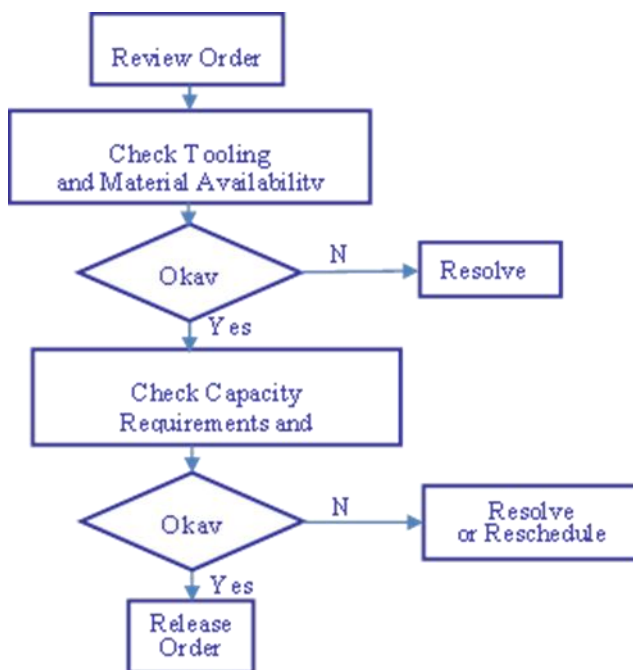


Figure I.11 Process flow diagram

Implementation is arrived at by issuing a shop order to manufacturing authorizing them to proceed with making the item. A shop packet is usually compiled and contains the shop order and whatever other information is needed by manufacturing. It may include any of the following:

- Order number, description
- Engineering Drawings
- Bills of Material

- Route Sheets
- Material Issue Tickets
- Tool Requisitions
- Job Tickets
- Move Tickets

Control

Once work orders have been issued to manufacturing, their progress has to be controlled. To control progress, performance has to be measured and compared to what is planned. If what is actually happening (what is measured) varies significantly from what was planned, either the plans have to be changed or corrective action must be taken to bring performance back to plan. The input/output control can be seen graphically as shown in Figure I.12. To control queue and meet delivery commitments, production activity control must:

- Control the work going into and coming out of a work center. This is generally called input /output control.
- Set the correct priority of orders to run at each work center.

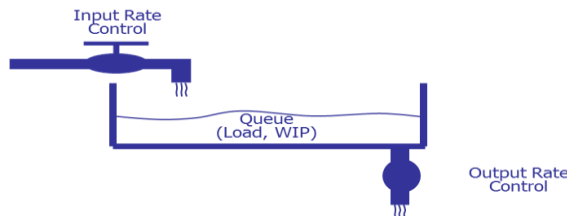


Figure I.12 Input / output control

The example of an input/output control is given below.

Example Problem

Work Center: 201
Capacity per
period: 40
standard hours

Period	1	2	3	4	5	Total
Planned Input	38	32	36	40	44	190
Actual Input	34	32	32	42	40	180
Cumulative Variance	-4	-4	-8	-6	-10	-10
Planned Output	40	40	40	40	40	200
Actual Output	32	36	44	44	36	192
Cumulative Variance	-8	-12	-8	-4	-8	-8
Planned Backlog	32	30	22	18	18	22
Actual Backlog	32	34	30	18	16	20

Input/output report: To control input and output, a plan must be devised, along with a method for comparing what actually occurs against what was planned. This information is shown on an input/output report. The above table is an example of such a report. The values are in standard hours.

Cumulative variance is the difference between the total planned for a given period and the actual total for that period. It is calculated as follows:

Cumulative variance = previous cumulative variance + actual – planned

Cumulative input variance week 2 = -4 + 32 - 32 = -4

Backlog is the same as queue and expresses the work to be done in hours. It is calculated as follows:

Planned backlog for period 1 = previous backlog + planned input - planned output
 = 32 + 38 – 40
 = 30 hours

The report shows the plan was to maintain a level output in each period and to reduce the queue and lead time by 10 hours, but input and output were lower than expected.

Planned and actual inputs monitor the flow of work coming to the work center. Planned and actual outputs monitor the performance of the work center. Planned and actual backlogs monitor the queue and lead time performance.

Dispatching

Dispatching is a function of selecting and sequencing jobs to be run at a work center. Through the dispatch list we control the priorities. It usually consists of the following:

- Plant, department, work center
- Part number, shop order number, operation number and description
- Standard hours
- Priority information
- Jobs coming to the work center

Dispatching Rules

There are a number of dispatching rules that are used to create ranking of jobs for batching list. None of these rules is perfect. Some of the commonly used rules are:

- FCFS - First come, first served
The job which arrived first should be processed first.
- EDD - Earliest job due date
The job which has the earliest due date should be processed first.
- ODD - Earliest operation due date
The job which has the earliest operations due date should be processed first.
- SPT - Shortest processing time
The job which has the shortest processing time should be processed first.
- CR - Critical ratio
The job with the smallest critical ratio should be processed first. The critical ratio is calculated as shown below:

Critical Ratio = $\frac{\text{due date} - \text{present date}}{\text{Lead time remaining}}$ = $\frac{\text{Actual time remaining}}{\text{Lead time remaining}}$

(If CR<1 behind schedule; CR=1 on schedule; CR>1 ahead of schedule; CR<0 already late)

Example Problem

Application of sequencing rules:

Job	Process Time (days)	Arrival Date	Due Date	Operation Due Date	Sequencing Rule			
					FCFS	EDD	ODD	SPT
A	4	223	245	233	2	4	1	3
B	1	224	242	239	3	2	2	1
C	5	231	240	240	4	1	3	4
D	2	219	243	243	1	3	4	2

J. Just-in-Time (JIT)

Just-in-time (JIT) manufacturing is a philosophy that relates to the way a manufacturing company organizes and operates its business. It is not a magic formula or a set of new techniques that suddenly makes a manufacturer more productive. Rather, it is the very skillful application of existing industrial and manufacturing engineering principles. The Japanese have not taught us new tricks but have forced us to examine some of our basic assumptions and approach manufacturing with a different philosophy.

Once the lecture is completed, the student should be able to:

- Describe the key features of JIT and their impact on MPC system
- Illustrate the JIT principle in a simplified example
- Identify key areas of research in JIT which relate to MPC
- Explain the impact of JIT decisions on MPS, production floor control, and operating performance

Just-in-Time Philosophy

Just-in-time (JIT) is a philosophy which has been defined in many ways. It not only targets inventory but is geared to eliminate waste of all kind in an organization. The most common definition is the elimination all wastes and continuous improvement of productivity. It encompasses the whole organization and not just the manufacturing facility.

JIT originated in Japan in early 1960 and got prominence during the oil embargo of 1974. In that year almost all the automobile companies made losses except for Toyota, which showed profit. The reason attributed to this was JIT and people started studying this new philosophy. The broad view of JIT philosophy is that the whole organization has the same goal and that is customer focus. It believes in simplicity, nothing complicated is accepted. It targets continuous improvement.

Waste means anything other than the minimum amount of equipment, parts, space, material, and workers' time absolutely necessary to add value to the product. This means there should be no surplus, there should be no safety stocks, and lead times should be minimal. Also, all wastes should be visible so that they could be eliminated. Flexibility is also very important in JIT because it is important to adapt to changes in the environment.

Just-in-Time Goal

The ultimate goal of JIT is a balanced system. The supporting goals are:

- **Eliminate disruptions:** Zero disturbances mean routine execution of schedules day in-day out.
- **Eliminate Waste:** As mentioned in the previous section, everything that is surplus is a waste. In other words, anything in the product development cycle that does not add value to the product is waste. This waste should be eliminated from the system.
- **Flexible system:** Flexible system helps the company to react swiftly to changes in the volume and mix of their products. To achieve this, operators and machinery must be flexible, and the system must be configured to be changed over quickly from one product to another.

The building blocks of JIT are:

1. Product design
2. Process design
3. Personnel elements
4. Manufacturing planning

Just-in-time goals and its building blocks are shown graphically in Figure J.1.

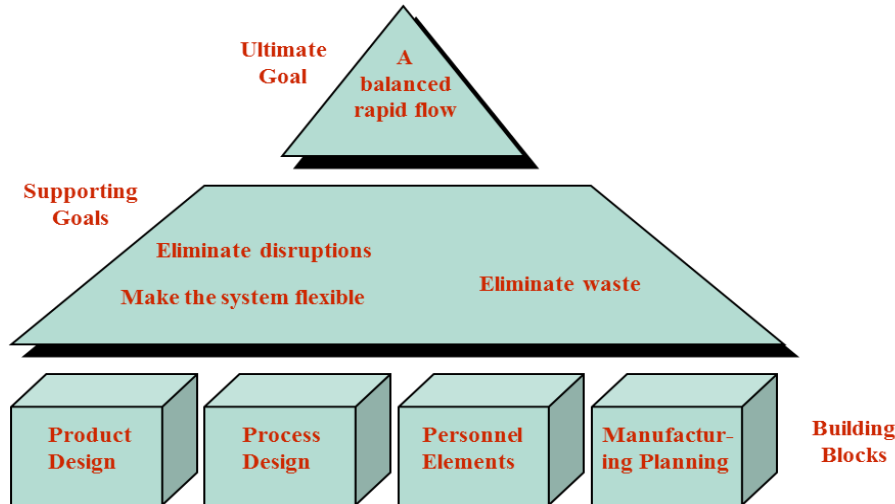


Figure J.1

Just-in-time Building Blocks

Sources of Waste

Toyota has identified seven important sources of waste in manufacturing. The first four relate to the design of the manufacturing system and the last three to the operation and management of the system:

1. **The process:** The waste generated by the process is if the wrong type or size of machine is used, if the process is not being operated correctly, or if the wrong tools and fixtures are used.
2. **Methods:** If the methods of performing tasks cause wasted movement, time, or effort then the waste is added. Activities that do not add value to the product should be eliminated.
3. **Movement:** Unnecessary movement of components adds cost but not value, therefore, it is waste. For example, goods received may be stored and then issued to production. This requires labor to put away, find, and deliver to production. This may be due to poorly planned layouts.
4. **Product defects:** Producing defective product is adding waste in the system. If the defective product is not identified, the next workstation will waste time trying to use it or trying to rework on it.
5. **Waiting time:** There are two types of waiting times. (1) Waiting by the operator and (2) waiting by the material in queues. Both types of waiting times are waste.
6. **Overproduction:** When product is produced more than is required it is a waste because it will increase inventory which would require more space and to store them.
7. **Inventory:** In JIT system inventories are considered biggest evil because they hide inefficiencies in the system. One of the goals of JIT system is to reduce them.

Kaizen Philosophy:

Kaizen is Japanese for "improvement". When used in the business sense and applied to the workplace, kaizen refers to activities that continuously improve all functions and involve all employees from the CEO to the assembly line workers. It also applies to processes, such as purchasing and logistics, which cross organizational boundaries into the supply chain.

The main points of Kaizen are:

- Waste is the enemy

- Improvement should be done gradually and continuously
- Everyone should be involved from CEO to assembly line workers
- Built on a cheap strategy, spend no money
- Can be applied anywhere
- Supported by a visual system
- Focuses attention where value is created
- Process oriented
- Stresses main effort of improvement should come from new thinking and work style
- The essence of organizational learning is to learn while doing

JIT Building Blocks

As mentioned earlier, there are four building blocks of just-in-time system.

1. Product design
2. Process design
3. Personnel/organizational elements
4. Manufacturing planning and control

Product Design

Critical activities in product design include quality, designing for manufacture in cells, and reducing the number of levels in the bill of materials to as few as possible. Since each level in a bill of material represents a stock point, reducing the number can significantly reduce inventory requirements and speed processing.

The product design should be based on standard parts. This will help in reducing inventory since same parts would be used in different products. Also, it is necessary that it should be modular design, which makes it easy to assemble products. The product design should be based on concurrent engineering so that from the very beginning the product is designed for manufacturability.

Process Design

For fewer levels to be practical, the number of product conversion steps must be reduced through process design changes, often through cellular manufacturing. Equipment in cellular manufacturing is positioned to achieve rapid flow of production with minimal inventories. The object is to concentrate on material velocity. Jobs must flow through in short cycle times, so detailed tracking is unnecessary.

JIT systems are designed to be responsive to as large a set of demands as possible. Superior manufacturing processes support greater bandwidth. The objective is for MPC systems to schedule any product, right behind any other, with minimal disruption.

The process design in JIT focuses on:

1. Small lot size
2. Reduced set up time
3. Layout
4. Limited work in process
5. Quality improvement
6. Limited inventory storage

Small Lot Size

Due to small lot size production the inventory is reduced as shown in Figure J.2. Also, the rework is reduced. This is because if there is a problem with the process and the quality is affected then if the lot size is small then less number of defective units will be produced before the defects are detected, therefore, less number of units will be reworked. On the other hand if the large lot is produced then large number of units are produced before the defects are detected which will require large rework. This also requires less storage space since the inventory reduces due to small lot size.

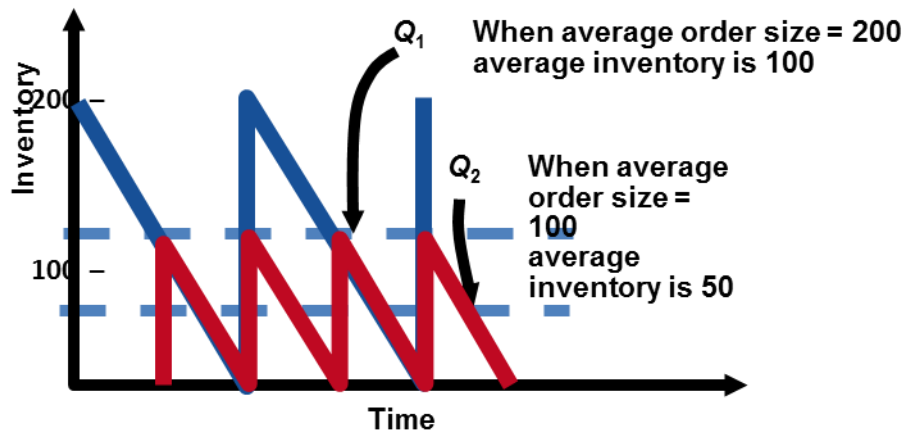


Figure J.2 Average inventory with small lot size

Small lot size also increases product flexibility, which makes it easier to balance operations. The Ideal situation is a lot size of one which is often not feasible. We can use EOQ analysis to calculate desired setup time. That means the small lot size will be made possible with small setup time. To achieve small lot size, two key changes are necessary. First is to improve material handling and second is to reduce setup time. If we target setup cost then by reducing it will reduce lot size, thereby, reducing inventory. The effect of small setup time on lot size is shown in Figure J.3.

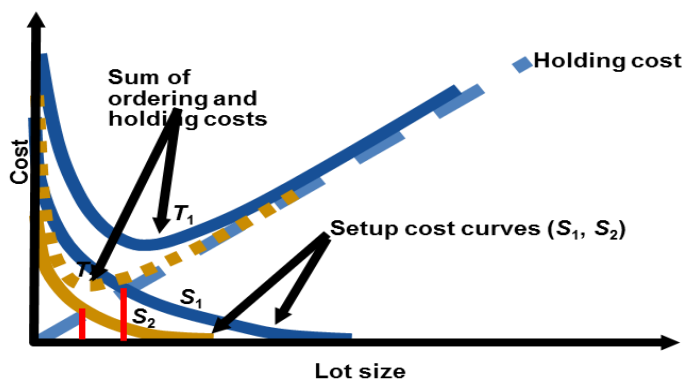


Figure J.3 Effect of small setup time on lot size

Layout

Many companies do not have a product line that lends itself to flow manufacturing. For example, many companies do not have sufficient volume of specific parts to justify setting up a line. Companies with this kind of product line usually organize their production on a

functional basis by grouping together similar or identical operations in one. Product moves from one workstation to the other in lots or batches. This type of production produces long queues, high work-in-process inventory, long lead times, and considerable materials handling.

Usually this kind of layout can be improved. It depends on the ability to detect product flows. This can be done by grouping products together into product families. Products will be in the same family if they use common work flow or routing, materials, tooling, setup procedures, and cycle times. Workstations can then be set up in miniature flow lines or work cells. The work centers required to make this family can be laid out according to the steps to make that family. Parts can now pass one by one, or in very small lots, from one workstation to the next. This has several benefits:

- Queue and lead times going through the cell are reduced drastically.
- Production activity control and scheduling are simplified. The cell has only one work center to control as opposed to five in a conventional system.
- Floor space needed is reduced.
- Feedback to preceding operations is immediate. If there is a quality problem, it will be found out immediately.

Quality Improvement

Quality is important for two reasons. If quality is not present in what is supplied to the customer and the product is defective, the customer will be dissatisfied. If a process produces scrap, it creates disrupted schedules that delay supplying the customer, increases inventory or causes shortages, wastes time and effort on work centers, and increases the cost of the product.

In JIT system, the quality is integrated into all processes. The focus is on continuous improvement. Quality at the source means doing it right the first time and, if something does go wrong, stopping the process and fixing it. People become their own inspectors, personally responsible for the quality of what they produce. The operators are trained to practice jidoka – authority to stop production line if there is a problem at their work centers. Poka-yoke is another concept used in JIT. It implies the concept of removing faults at the first instance and making a process or product “foolproof.” It tries to change either the process or its resources, thus eliminating the need to rely on human experience and knowledge.

For a process to continue to produce the required quality, machinery must be maintained in excellent condition. This can best be achieved through a program of preventive maintenance. This is important for more reasons than quality. Low work in process inventories mean there is low level of buffer is available. If a machine breaks down, it will quickly affect other work centers. Preventive maintenance starts with daily inspections, lubrication, and cleanup. Since operators usually understand how their equipment should “feel” better than anyone else, it makes more sense to have them handle this type of regular maintenance. In preventive maintenance workers perform maintenance as part of their regular work. It is costly, but less expensive than unexpected machine breakage. Therefore, care of equipment and well-trained workers are very important.

Variability Reduction

JIT systems require managers to reduce variability because variability adds waste in the system. If there is less variability in demand we will need smaller safety stocks, which will reduce overall inventory being held in the system. Inventory hides inefficiencies in the system and variability creates inefficiencies. Therefore, by reducing variability, the inefficiencies in the system are reduced, thereby, the inventories are reduced.

Source of Variability: The variability in the system increases due to:

1. Incomplete or inaccurate design or specifications of a product.
2. Poor production processes resulting in incorrect quantities, late, or non-conforming units.
3. Unknown customer demands.

Production Flexibility

JIT requires highly flexible production system. This flexibility is achieved by:

1. Reduce downtime by reducing changeover time. This will increase productivity. Also, by reducing changeover time, it is possible to produce small lot sizes, which will make it possible to respond quickly to the changes in product demand.
2. Use preventive maintenance to reduce breakdowns. This also increases productivity and reduces inventories/wastes.
3. Cross-train workers to help clear bottlenecks. This helps in increasing flexibility and productivity by eliminating breakdowns of machinery during production.
4. Use many small units of capacity. In JIT, the production line is usually in the form of cells for the production of specific product family. This way scale economy is achieved as well as flexibility in the production facility.
5. Reserve capacity for important customers. Instead of using regular capacity, in JIT reserve capacity is used for important customers. This way meeting regular demand is not affected by demand from important customers.
6. Balance system. **Uniform plant loading** means that the work done at each workstation should take about the same time. In repetitive manufacturing, this is called **balancing the line**, which means that the time taken to perform tasks at each workstation on the line is the same or very nearly so. The result will be no bottlenecks and no buildup of work-in-process inventory.

Inventories

In JIT system inventory is kept at the minimum level necessary to keep operations running. To keep minimum inventory level, pull system should be used to move inventory as well as lot sizes should be reduced which will decrease the inventory level.

Inventories are considered evil in the production system because they hide system's inefficiencies. Following are some of the other ways to eliminate inventories in JIT system.

1. Develop just-in-time delivery systems with suppliers. Since components are delivered just in time for their use, the inventory is minimized.
2. Deliver directly to point of use. Since the components are delivered direct to the point of use and there is no intermediary storage place, the inventory would be minimized.
3. Perform to the schedule. If the production is performed as per schedule, there would be no surprises and no need to maintain extra inventories.
4. Reduce setup time. We have seen from EOQ model that to reduce lot size we need to reduce setup cost. Therefore, reducing setup time will impact positively in reducing inventories.
5. Use cellular manufacturing (group technology). Using cells for manufacturing instead of one large production line, which would require large production to achieve scale economy, the inventories would be reduced.

If we look at a river bed, we see that on the surface water flow seems calm but underneath the surface there are rocks which are actually creating blockages in the flow. In the production system these rocks represent problems/inefficiencies and water represents

inventory. As we reduce water level, these rocks will be exposed one by one. We can remove the exposed rock and again reduce the water level to expose another rock, which will then be removed. We keep on doing this until all the rocks are removed and water flows smoothly. In the same analogy, we can reduce inventory slowly until a problem surfaces. We identify its causes, remove them and thus eliminate the problem. Then we repeat the steps until all the problems are removed and we are left with no problem and almost no inventory. This is shown in Figures J.4 and J.5:

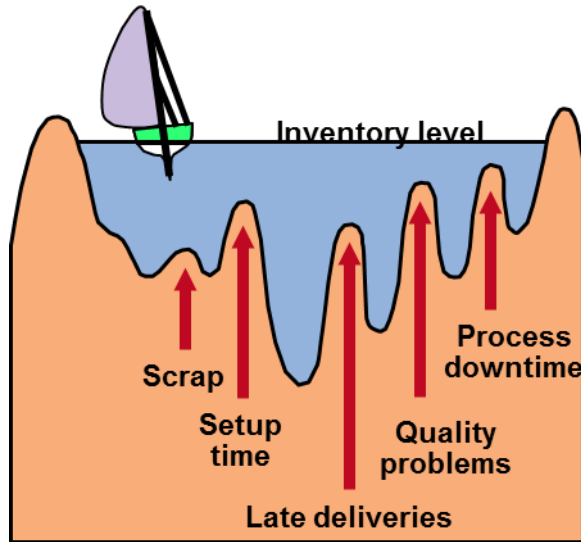


Figure J.4 System with problems depicted as rock.

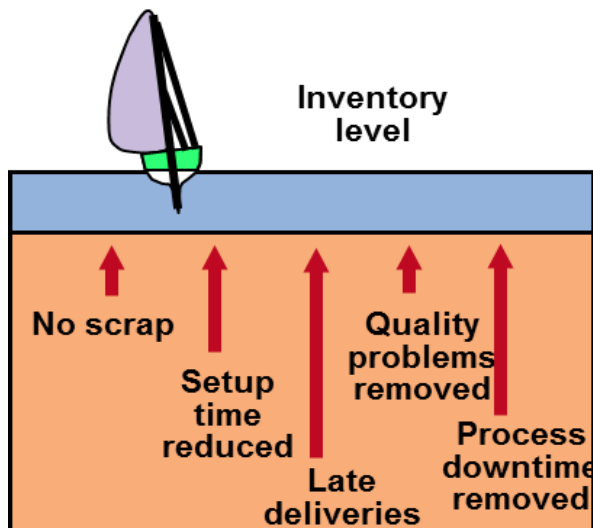


Figure J.5 System with all the problems eliminated or reduced.

Personnel and Management

A successful JIT environment can be achieved only with the cooperation and involvement of everyone in the organization. The ideas of elimination of waste and continuous improvement that are central to the JIT philosophy can be accomplished only through people cooperating.

Instead of being receivers of orders, operators must take responsibility for improving processes, controlling equipment, correcting deviations, and becoming vehicles for continuous improvement. Their jobs include not only direct labor but also a variety of

traditionally indirect jobs such as preventive maintenance, some setup, data recording, and problem solving. As discussed previously, employees must be flexible in the tasks they do. Just as machines must be flexible and capable of quick changeover, so must the people who run them.

The role of management must change. Traditionally, management has been responsible for planning, organizing, and supervising operations. Many of their traditional duties are now done by line workers. In a JIT environment, more emphasis is placed on the leadership role. Managers and supervisors must become coaches and trainers, develop the capability of employees, and provide coordination and leadership for improvements. Traditionally, staff has been responsible for such things as quality control, maintenance, and record keeping. Under JIT, line workers do many of these duties. Staff responsibilities then become those of training and assisting line workers to do the staff duties assigned to them.

MPC

MPC in just-in-time environment needs changes made to the system from traditional manufacturing to JIT manufacturing. Some of the changes required are:

- **Level loading:** The loads for jobs in every workstation are equal. This makes the pull system possible. If uneven loading exists, the following workstation may have to wait for the materials from the preceding workstation. Uniform loading allows the materials to flow through the production line smoothly. Every workstation runs at a constant rate. If the demand increases, the production rates in all workstation increase together. If the demand drops, all workstations may have the same level of idleness.
- **Pull system.** The traditional manufacturing system is based on the push system, where the material is produced and push on to downstream work center whether it requirement it or not. JIT is based on pull system, where demand on a workstation should come from the next workstation. The pull system starts at the end of the line and pulls product from the preceding operation as needed. The preceding operation does not produce anything unless a signal is sent from the following operation to do so.
- **Visual systems:** Visible control tools are used wherever possible. Cards attached to the materials, containers at sight, tags in stock indicating order points, etc. are examples of visual control tools. These signals are processed by human intelligence at the speed of light, and are superior to any computer in the world. JIT philosophy reminds us that natural human senses are effective tools but are frequently ignored.
- **Close vendor relationships:** In order to establish a smooth flow of materials into the factory, a close and reliable relationship with the suppliers is very important. Supplier partnership is the establishment of a working relationship with a supplier whereby the two organizations act as one. Relationships with the suppliers should be based on mutual trust, cooperation, and long-term commitment.
- **Preventive maintenance:** Traditional maintenance might be called “breakdown maintenance,” meaning maintenance is done only when a machine breaks down. The motto of breakdown maintenance is “If it ain’t broke, don’t fix it.” Unfortunately, breakdowns occur only when a machine is in operation, resulting in disrupted schedules, excess inventory, and delayed deliveries. In addition, lack of proper maintenance results in wear and poor performance. For example, if a car is not properly maintained, it will break down, not start, or perform poorly on the road. For a process to continue to produce the required quality, machinery must be maintained

in excellent condition. This can best be achieved through a program of preventive maintenance. This is important for more reasons than quality. Low work-in-process inventories mean there is little buffer available. If a machine breaks down, it will quickly affect other work centers. Preventive maintenance starts with daily inspections, lubrication, and cleanup. Since operators usually understand how their equipment should “feel” better than anyone else, it makes more sense to have them handle this type of regular maintenance.

JIT Scheduling Tactics

It is important that to have smooth flow of material, suppliers should be communicated schedules so that they do not have any problem in on time delivery of material. In addition to eliminating waste, JIT systems attempt to maintain uniform production levels by smoothing the production requirements on the final assembly line. Changes in final assembly often have dramatic effects on component production upstream. When this happens in a kanban system, kanbans for certain parts will circulate very quickly at some times and very slowly at others. Adjustments of plus or minus 10 percent in monthly demand can be absorbed by the kanban system, but wider demand fluctuations cannot be handled without substantially increasing inventory levels or scheduling large amounts of overtime.

Another important aspect is that part of this schedule should be frozen because freezing the schedule closest to the due dates can improve performance. Not only part of the schedule should be frozen but also the production should be performed as per schedule and not deviate from it. Also, producing in small lot sizes help make level schedule more economical. But then it is important that each operation should produce a perfect part. That is, quality at source is extremely important in this environment.

Kanban Production System

The developers of the JIT concepts utilized a simple card system called Kanban (often pronounced con-bon), which roughly translated from Japanese means card or ticket. The system works very simply. The Kanban signal (often a piece of cardboard) identifies the material to which it is attached. The information on the Kanban will often include:

- Component part number and identification.
- Storage location.
- Container size (if the material is stored in a container).
- Work center (or supplier) of origin.

How it works. The following Figure J.6 illustrates the use of what is often called a two-card Kanban system. The two types of cards are a production card (authorizing production of whatever part number is identified on the card in the quantity specified) and a withdrawal card (authorizing the movement of the identified material).

At the start of the process there is no movement, since all the cards are attached to full containers. It is only when a card is unattached that activity is allowed. In this way the number of cards will clearly limit the inventory authorized to be at any location.

At some point, a downstream process needs some of the parts produced by work center 2 (in its “Finished Production” stock). It takes a container of the material, leaving the work center 2 the production card with the center. This illustrates two additional rules of the system—all material movement is in full containers (recall that the container lot size is supposed to be very small) and Kanban cards are attached to a work center.

The unattached production card is the signal to start the work center 2 production to replace the container that was taken. To do that work they need raw material, which is in the

containers in front of the work center with the move cards attached. When that material is used to replace the work center 2 finished material, the raw material container is now empty and the associated move card is unattached.

The unattached move card authorized movement of material to replace the material that was used. That material is found in the “finished goods” section of work center 1. The operator (or material handler) will now move the material and place the move card on the container as proof of the authorization to move the material. Before doing so, however, they must remove the production card that had first authorized its production. That represents another critical rule for Kanban: every container with material must have one, but only one, card attached. Therefore, when the move card is attached the production card must be removed. The system is illustrated in Figure J.6.

Determination of the Number of Kanbans - Kanban Formula

$$N = \frac{DT(1+X)}{C}$$

N = Total number of containers

D = Planned usage rate of using work center

T = Average waiting time for replenishment of parts plus average production time for a container of parts

X = Policy variable set by management - possible inefficiency in the system

C = Capacity of a standard container

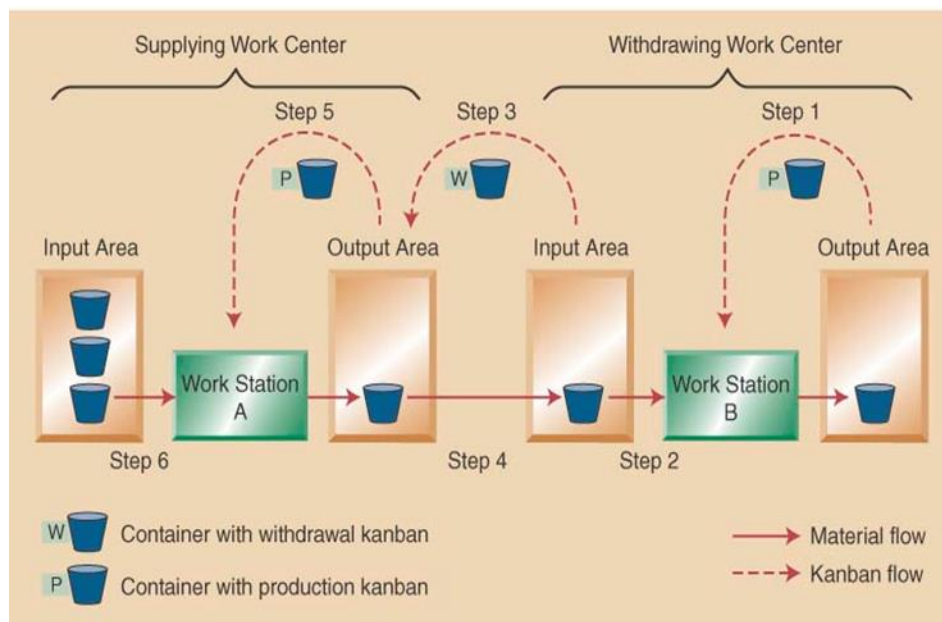


Figure J.6 Kanban manufacturing system

Example Problem

An aspirin manufacturer has converted to JIT manufacturing using kanban containers. They must determine the number of containers at the bottle filling operation which fills at a rate of 200 per hour.

Each container holds 25 bottles, it takes 30 minutes to receive more bottles, safety stock is 10% of demand during LT.

Solution:

D = 200 bottles per hour

T = 30 minutes = 0.5 hour

C = 25 bottles per container

S = 10% of demand during lead time

$$N = \frac{DT(1+S)}{C}$$

$$N = \frac{200 \times 0.5(1+0.1)}{25} = 4.4 \approx 4 \text{ containers}$$

JIT Demand Pull Logic

The pull system was developed as an alternative to classical “push” MRP. The underlying concept is not to preplan and generate schedules but instead to react to the final customer order and produce only what is needed to satisfy demand and then only when it is needed. Essentially, this system is much the same as the basic reorder point system used for independent inventory. If this is the case, why can it work now when it did not work effectively for so many years before MRP? MRP was primarily designed as a more effective alternative to reorder points because reorder points did not work well.

The major reason reorder points normally do not work well in a dependent inventory environment is a significant violation of the assumption of relatively constant demand that allows a reorder point to work well in some independent inventory environments. A simple example may help illustrate the problem.

Suppose the product is a specific model of bicycle. The bicycles are made in batches, which is a typical mode of production for an assemble-to-order environment. The batch size is 200 bicycles. Now we look at an item of dependent inventory that is one level lower on the bill of materials—the bicycle seat. Suppose it has a lot size of 300, a two-week lead time, and, since we are examining the use of a reorder point, a reorder point of 80.

Example: In this case suppose we have an inventory of 290 seats. A new batch of bicycles has just been ordered, requiring us to use 200 of the seats in a very short time. We are left, therefore, with 90 seats—10 above the reorder point. We do not reorder since the reorder point has not been reached. The 90 will stay in inventory until the next order for the bicycles is generated, which may be a significant time. When that order does come to build another 200 bicycles, we can only build 90 because that is the only inventory we have. We need to immediately order another lot of 300, but it will be two weeks before they are available.

As the example illustrates, the lot-sizing problem with dependent inventory often results in either a crisis shortage or a replenishment of stock well before it is actually needed. This example shows that the critical conditions causing the problem are the large lot sizes and the long lead times, both of which are major targets of JIT waste reduction.

In Pull system the material is pulled through the system when needed. It is the reversal of traditional push system where the material is pushed through the system as per forecast of demand even though the actual demand of the material is not there. The pull system actually forces cooperation among the supply chain’s different entities. It prevents over and underproduction because the product is produced when there is demand for it. This is depicted in Figure J.7.

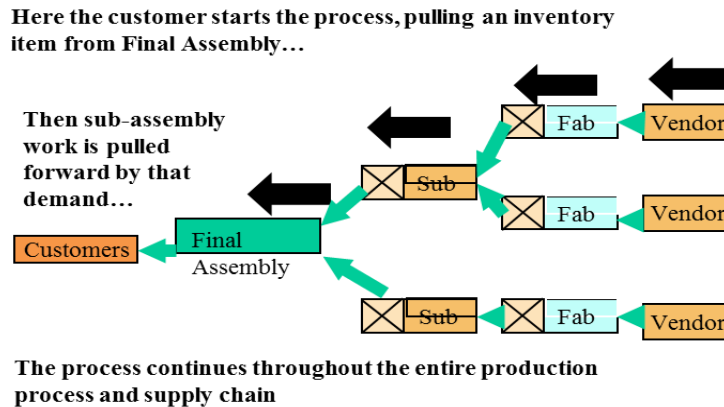


Figure J.7 Just-in-time pull logic

Supplier Relationship

If good schedules are to be maintained and the company is to develop a just-in-time environment, it is vital to have good, reliable suppliers. They establish the flow of materials into the factory.

Partnering implies a long-term commitment between two or more organizations to achieve specific goals. Just-in-time philosophy places much emphasis not only on supplier performance but also on supplier relations. Suppliers are looked on as co-producers, not as adversaries. The relationship with them should be one of mutual trust and cooperation.

There are three key factors in partnering.

1. Long-term commitment. This is necessary to achieve the benefits of partnering. It takes time to solve problems, improve processes, and build the relationship need.
2. Trust. Trust is needed to eliminate an adversarial relationship. Both partners must be willing to share information and form a strong working relationship. Open and frequent communications are necessary. In many cases the parties have access to each other's business plans and technical information.
3. Shared vision. All partners must understand the need to satisfy the customer. Goals and objectives should be shared so that there is a common direction. If properly done, partnering should be a win-win situation. The benefits to the buyer include the following:
 - a. The ability to supply the quality needed all the time so there will be no need for inbound inspection. This implies that the supplier will have, or develop, an excellent process quality improvement program.
 - b. The ability to make frequent deliveries on a just-in-time basis. This implies that the supplier will become a just-in-time manufacturer.
 - c. The ability to work with the buyer to improve performance, quality, and cost. For a supplier to become a just-in-time supplier, a long-term relationship must be established. Suppliers need to have that assurance so they can plan their capacity and make the necessary commitment to a single customer.

In return, the supplier has the following benefits.

- A greater share of the business with long-term security.
- Ability to plan more effectively.
- More competitive as a just-in-time supplier.

JIT partnerships exist when a supplier and purchaser work together to remove waste and drive down costs. There are four goals of JIT partnerships:

1. Elimination of unnecessary activities
2. Elimination of in-plant inventory
3. Elimination of in-transit inventory
4. Elimination of poor suppliers

Preventive Maintenance

Machines cannot operate continuously without some attention. Maintenance activities can be performed when a machine breaks down to restore the machine to its original operating condition or at different times during regular operation of the machine in an attempt to prevent a breakdown from occurring. The first type of activity is referred to as breakdown maintenance; the second is called preventive maintenance.

Breakdowns seldom occur at convenient times. Lost production, poor quality, and missed deadlines from an inefficient or broken-down machine can represent a significant expense. In addition, the cost of breakdown maintenance is usually much greater than preventive maintenance. (Most of us know that to be true from our own experience at maintaining an automobile. Regular oil changes cost pennies compared to replacing a car engine.) For these reasons, most companies do not find it cost-effective to rely solely on breakdown maintenance. The question then becomes, how much preventive maintenance is necessary and when should it be performed?

With accurate records on the time between breakdowns, the frequency of breakdowns, and the cost of breakdown and preventive maintenance, we can mathematically determine the best preventive maintenance schedule. But even with this degree of precision, breakdowns can still occur. JIT requires more than preventive maintenance--it requires total productive maintenance.

Total productive maintenance (TPM) combines the practice of preventive maintenance with the concepts of total quality--employee involvement, decisions based on data, zero defects, and a strategic focus. Machine operators maintain their own machines with daily care, periodic inspections, and preventive repair activities. They compile and interpret maintenance and operating data on their machines, identifying signs of deterioration prior to failure. They also scrupulously clean equipment, tools, and workspaces to make unusual occurrences more noticeable. Oil spots on a clean floor may indicate a machine problem, whereas oil spots on a dirty floor would go unnoticed. In Japan this is known as the five S's - seiri, seiton, seiso, seiketsu, and shitsuke - roughly translated as organization, tidiness, cleanliness, maintenance, and discipline.

Comparison of JIT and Traditional System

There are a number of differences in the traditional manufacturing and JIT manufacturing systems. Some of the differences are shown in Table J.1.

Transitioning to JIT System

The companies that want to transition from traditional manufacturing to JIT system, they need to get top management commitment. Also, before starting the implementation, the management has to decide that what are the priorities and which parts need most efforts. To avoid any untoward incidence they must get support of workers.

Table J.1 Differences between traditional and JIT manufacturing system

Factor	Traditional	JIT
Inventory	To hide problems in the system	Minimal
Deliveries	Few and large	Many and small
Lot sizes	Large	Small
Setup; runs	Few, long runs	Many, short runs
Vendors	Usually small-term relationships	Partners
Workers	Necessary for work	Assets
Quality	Quality has cost	Quality is free
Workers – Engineers Relationship	Managers – engineers are experts Workers execute their orders	Workers are experts managers and engineers are facilitators
Errors	Errors are to be eliminated by inspection	Stepping stones to success. One must learn from them
Queues	Queues at work production stations lead to better machine utilization.	Small lot sizes and low inventories result in small or no queues.

To take advantage of JIT practices, firms might have to change their existing layouts. Certain workstations might have to be moved closer together, and cells of machines devoted to particular families of components. The single most important factor in successful implementation is changing product flows and layout to a cellular design. However, rearranging a plant to conform to JIT practices can be costly. For example, whereas many plants now receive raw materials and purchased parts by rail, to facilitate smaller, more frequent JIT shipments, truck deliveries would be preferable. Loading docks might have to be reconstructed or expanded and certain operations relocated to accommodate the change in transportation mode and quantities of arriving materials.

Inventory and Scheduling

Firms need to have stable master production schedules, short setups, and frequent, reliable supplies of materials and components to achieve the full potential of the JIT concept.

MPS Stability. Daily production schedules in high-volume, make-to-stock environments must be stable for extended periods. At Toyota the master production schedule is stated in fractions of days over a three-month period and is revised only once a month. The first month of the schedule is frozen to avoid disruptive changes in the daily production schedule for each workstation; that is, the workstations execute the same work schedule each day of the month. At the beginning of each month, kanbans are reissued for the new daily production rate. Stable schedules are needed so that production lines can be balanced and new assignments found for employees who otherwise would be underutilized. Just-in-time systems used in high-volume, make-to-stock environments can't respond quickly to scheduling changes because little slack inventory or capacity is available to absorb these changes.

Setups. If the inventory advantages of a JIT system are to be realized, small lot sizes must be used. However, because small lots require a large number of setups, companies must

significantly reduce setup times. Some companies haven't been able to achieve short setup times and therefore have to use large-lot production, negating some of the advantages of JIT practices. Also, JIT systems are vulnerable to lengthy changeovers to new products because the low levels of finished goods inventory will be insufficient to cover demand while the system is down. For example, Ford and GM are at a competitive disadvantage because of the time they need to change from one year's model to the next. GM required 87 days to change from the 1994 Chevrolet Lumina to the 1995 model, and Ford required 60 days to change from the 1994 Tempo to the Mystique, its 1995 replacement. In contrast, Toyota changed from the 1991 Camry to the 1992 version in 18 days, and Honda switched from the 1993 Accord to the 1994 model in only 3 days. Every month a plant is shut down costs between \$65 million and \$85 million in pretax profits.

Purchasing and Logistics. If frequent, small shipments of purchased items cannot be arranged with suppliers, large inventory savings for these items can't be realized. In the United States such arrangements may prove difficult because of the geographic dispersion of suppliers.

The shipments of raw materials and components must be reliable because of the low inventory levels in JIT systems. A plant can be shut down because of a lack of materials. For example, in 1992, a strike at the GM plant in Lordstown, Ohio, caused the Saturn plant in Spring Hill, Tennessee, to shut down, losing the production of 1000 cars per day. Lordstown supplies parts to Saturn, which doesn't stockpile the parts because of JIT practices.

Benefits of JIT

Some of the benefits of JIT are listed below:

1. Reduced inventory
2. Improved quality
3. Lower costs
4. Reduced space requirements
5. Reduced lead times
6. Increased productivity
7. Greater flexibility
8. Reduced scrap and rework
9. Better relations with suppliers
10. Simplified scheduling and control activities
11. Increased capacity
12. Increased equipment utilization
13. Better use of human resources
14. More product variety

K. Advanced Scheduling

In shop scheduling problems, resources are machines only able to execute one task – or operation – at a time. On the other hand, each job involves an indivisible physical entity, called product, or lot when several identical products are grouped. Since an entity cannot be in two places at the same time, a single job can only be executed one operation at a time on a single machine. We will discuss one-machine and two-machine problems consecutively.

After the completion of this lecture, students will be able to:

- Summarize the research findings, which is helpful in assigning jobs or labor to machines
- Apply different sequencing rules on machines for production
- Apply Johnson's rule on multiple machines for production

One-machine Case

Sequencing is determining the order in which jobs will be processed on a machine. In an intermittent manufacturing environment, a number of jobs are placed in a queue for processing on a machine. Priority of jobs to process first depends on the performance measures being used to evaluate the performance of the system.

There are a number of performance measures being used and some of them are:

- Flow time of a job: Duration of time a job enters into the system until it leaves
- Lateness of a job: Amount by which completion date exceeds due date. Could be negative.
- Tardiness: Amount by which a job is late = $\max(\text{lateness}, 0)$
- Makespan: total time needed to finish a group of jobs
- Average number of jobs until the last is finished:
 - $\text{Average number of jobs} = \text{Total flow time} / \text{Makespan}$

To determine the sequence in which jobs should be processed on a machine could be determined using different priority rules. These are simple heuristics used to select the order in which jobs should be processed. Each rule performs differently using different performance measures and in certain conditions. Figure K.1 shows processing of two jobs on a machine.

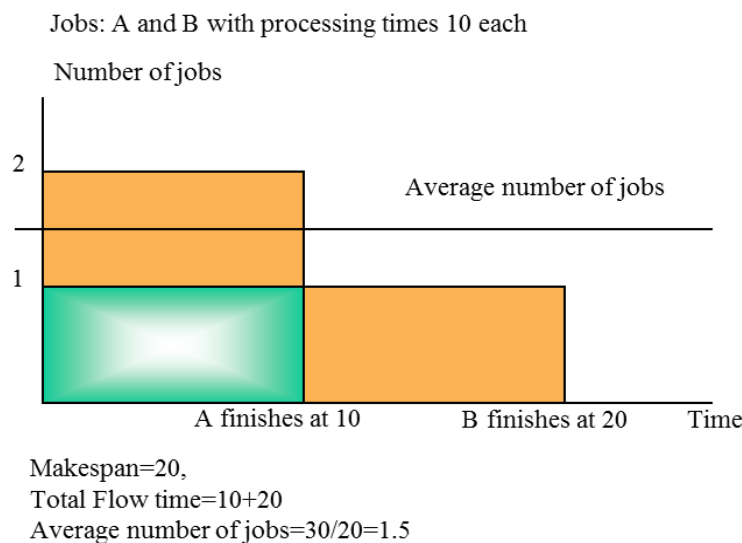


Figure K.1 Processing of two jobs on a machines

Two-machine Case

On a two machines jobs can be assigned using Johnson's Rule. It is a technique for minimizing completion time for a group of jobs to be processed on two machines. It also minimizes total idle time and the makespan. Several conditions must be satisfied to apply this technique and they are:

- Job time must be known and constant
 - Job times must be independent of sequence
 - Jobs must follow same two-step sequence
 - Job priorities cannot be used
 - All units must be completed at the first work center before moving to the second
- Johnson's rule
1. Select a job with the shortest processing time.
 2. If the processing time of the selected job is on the first work center schedule the job right after the already scheduled job at the beginning of the list.
 3. If the processing time of the selected job is on the second work center schedule the job right before the already scheduled job at the end of the list.
 4. Cross out the scheduled job and go to 1

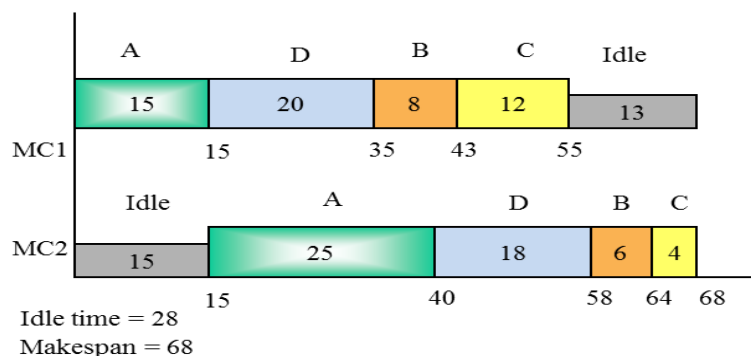
Example Problem

There are four jobs A, B, C, and D to be processed on two machines. Their processing time on each machine is given in Table K.1. Find the job sequence that will minimize the total completion time.

Table K.1 Processing time of jobs on two machines

Job	Processing time on machine 1	Processing time on machine 2
A	15	25
B	8	6
C	12	4
D	20	18

Solution:



Sequencing Rules

Some of the sequencing rules are mentioned below:

First Come, First Serve (FCFS)

The name describes the rule. This is the rule that is heavily used by service organizations such as banks and retail stores, often because they have no alternative. The underlying assumption is that the first job is also needed first. In addition, this rule implies a common perception of fairness, given that a job that enters the operation first has first priority.

Shortest Processing Time (SPT)

According to SPT rule, jobs are prioritized according to the estimated processing time it takes to do them, with the shortest processing time first. An advantage of this approach is that a lot of jobs are completed quickly. Unfortunately, there is nothing in the rule that captures when the order is needed by the customer. Often this rule will tend to leave the large jobs at the end, and will therefore frequently make them late. That is not a good condition in environments where the large jobs often represent a large and valuable customer.

Earliest Due Date (EDD)

As the name implies, this rule selects the job with the earliest due date to be done first. In case of ties, another secondary rule (from the list below) can be used to break the tie. This rule is often used in operations using MRP for planning, as the due date is inherent with MRP planning and is naturally generated from the system.

Critical Ratio (CR)

For this rule a ratio without units of measure is calculated. The ratio is time remaining until due divided by the work remaining. Work remaining is the total processing time, while time remaining is the time until the job is due to be done. If the critical ratio is greater than 1, there is slack. If equal to 1, there is no slack and work must proceed without delay. If less than 1, the job is already late. Clearly the job with the lowest critical ratio is scheduled first with this rule. Many people consider this a superior rule since it takes into account both the due date and the slack time.

Least Work Remaining (LWR)

This rule is a variant of SPT rule. Here total time of remaining processes is checked for each in the current queue. Whichever job has the least amount of total time of all the remaining jobs should be processed first.

Fewest Operations Remaining (FOR)

Again this is a variant of SPT rule. In this rule, total number of remaining operations is checked for each job and the job with the fewest operations remaining is processed first.

Slack Time (ST)

For all remaining operations on the job, the total processing time remaining is computed. Then the total time until the job is due is calculated. Subtracting total processing time from total time until due yields slack. Slack is really a buffer time, or time that can pass without danger of making the job late. The rule is to select jobs with the least total slack to be done first, since they are in the greatest danger of being late if held up.

Slack Time per Operation (ST/O)

A variant of total slack, the total slack for this rule is divided by the number of operations left. The job with the least total slack per operation is scheduled first. This gives more information than the total slack rule, in that it gives the average slack at each operation rather than the total slack for the entire job.

Next Queue (NQ)

This rule looks at the next queue. Whichever job has the smallest queue for the next process should be processed first. This rule mainly targets the machine utilization. It means that all the machines are checked where these jobs are going next for their queue size. That job will be processed first whose next queue is smallest.

Least Setup Time (LST)

As the name suggest, whichever job requires the least amount of the changeover time should be processed first. This helps in maximizing capacity utilization.

Example FCFS

The processing times (including setup time) and due dates for six jobs waiting to be processed at a work center are given in the following table. Determine the sequence of jobs, the average flow time, average tardiness, and average number of jobs at work center for FCFS rule.

Job	Processing time (days)	Due date (days from present time)
A	2	7
B	8	16
C	4	4
D	10	17
E	5	15
F	12	18

The FCFS sequence is simply A-B-C-D-E-F.

Job sequence	Processing time	Flow time	Due date	Days tardy
A	2	2	7	0
B	8	10	16	0
C	4	14	4	10
D	10	24	17	7
E	5	29	15	14
F	12	41	18	23
Sum	41	120		54

The measures of effectiveness are as follows:

Average flow time = $120/6 = 20$ days

Average tardiness = $54/6 = 9$ days

The Makespan = 41 days

Average number of jobs at the work center = $120/41 = 2.93$

Example SPT

The SPT sequence is A-C-E-B-D-F.

Job sequence	Processing time	Flow time	Due date	Days tardy
A	2	2	7	0
C	4	6	4	2
E	5	11	15	0
B	8	19	16	3
D	10	29	17	12
F	12	41	18	23
Sum	41	108		40

The measures of effectiveness are as follows:

Average flow time = $108/6 = 18$ days

Average tardiness = $40/6 = 6.67$ days

The Makespan = 41 days

Average number of jobs at the work center = $108/41 = 2.63$

Example EDD

The EDD sequence is C-A-E-B-D-F.

Job sequence	Processing time	Flow time	Due date	Days tardy
C	4	4	4	0
A	2	6	7	0
E	5	11	15	0
B	8	19	16	3
D	10	29	17	12
F	12	41	18	23
Sum	41	110		38

The measures of effectiveness are as follows:

Average flow time = $110/6 = 18.33$ days

Average tardiness = $38/6 = 6.33$ days

The Makespan = 41 days

Average number of jobs at the work center = $110/41 = 2.68$

Example CR

The CR sequence is C-F-D-B-E-A.

Job sequence	Processing time	Flow time	Due date	Days tardy
C	4	4	4	0
F	12	16	18	0
D	10	26	17	9
B	8	34	16	18
E	5	39	15	24
A	2	41	7	34
Sum	41	160		85

The measures of effectiveness are as follows:

Average flow time = $160/6 = 26.67$ days

Average tardiness = $85/6 = 14.17$ days

The Makespan = 41 days

Average number of jobs at the work center = $160/41 = 3.9$

Example ST

The ST sequence is C-A-F-D-B-E

Job sequence	Processing time	Flow time	Due date	Days tardy
C	4	4	4	0
A	2	6	7	0
F	12	18	18	0
D	10	28	17	11
B	8	36	16	20
E	5	41	15	26
Sum	41	133		57

The measures of effectiveness are as follows:

Average flow time = $133/6 = 22.17$ days

Average tardiness = $57/6 = 9.5$ days

The Makespan = 41 days

Average number of jobs at the work center = $133/41 = 3.24$

Example ST/O

The ST sequence is C-D-F-A-B-E.

Job sequence	Processing time	Flow time	Due date	Days tardy
C	4	4	4	0
D	10	14	17	0
F	12	26	18	8
A	2	28	7	21
B	8	36	16	20
E	5	41	15	26
Sum	41	149		75

The measures of effectiveness are as follows:

Average flow time = $149/6 = 24.83$ days

Average tardiness = $75/6 = 12.5$ days

The Makespan = 41 days

Average number of jobs at the work center = $149/41 = 3.63$

L. Strategy and MPC System Design

Before any critical system design issues are decided, it is very important that a fairly comprehensive operations strategy be developed. Essentially, the operations strategy is intended to support the overall strategy of the firm, and the operations structure and infrastructure must align with the market drivers for the selected product and market mix if the firm is to position itself in the most favorable competitive stance. This can be accomplished by understanding what the order winners and order qualifiers are. The design must be made by recognizing the critical nature of being able to at least meet (exceed if possible) the minimal market expectations with respect to order qualifiers, but should be able to perform at a superior level with respect to the order winner(s) in the market. Since it is virtually impossible to be the best in the market with respect to all dimensions of competition, design tradeoffs must be made in the context of the clear understanding of these market drivers.

After the completion of this lecture, students should be able to:

- *Critically evaluate different options for designing an MPC system*
- *Select the option that best support the corporate strategy*
- *Integrate MRP and JIT in a company's MPC system*
- *Extend MPC integration to suppliers & customers*

MPC Design Options

There are a number of design options available for MPC system. Also, individual modules have different options available for designing them. Here we will discuss different options available for three modules, namely:

1. Master Production Scheduling Options

For MPS, the options depend on the manufacturing environments, which are make-to-order, assemble-to-order, and make-to-stock environments.

a. Make-to-Order

Make-to-order approach is typical when product is custom-built to individual customer specifications. In this case the MPC system needs to encompass preproduction engineering design activities as well as manufacturing and supplier operations.

b. Assemble-to-Order

Assemble-to-order is used when overall manufacturing lead time exceeds customer expectations, end items are too varied and costly to invest in finished-goods inventory, and modules or options can be combined to meet customer requirements.

c. Make-to-Stock

Make-to-stock is used for standardized end items with short delivery lead times. Here the focus is to track inventory throughout the supply chain. The end product is produced based on the demand forecast to stock. The market demand is met through the inventory, which acts as a buffer for the production system.

2. Detailed Material Planning Options

There are two main options available for detailed material planning, namely: Time-phased planning and rate-based planning.

a. Time-phased planning

Time-phased planning for individual product components is typically carried out with material requirements planning approaches.

- b. Rate-based planning

Rate-based planning users include repetitive manufacturing, assembly lines, just-in-time, and other flow manufacturing systems.

3. Shop-Floor Systems

- a. MRP-based system

MRP-based approach supports batch manufacturing operations. Objective is to coordinate sequencing of orders at work centers with customer delivery requirements.

- b. JIT-based system

JIT-based approach supports repetitive type of manufacturing. It is based on minimal flow times for the entire product.

Choosing the Options

While choosing the option, the management should review firm's customers and targeted market segments. They should determine their present and future needs regarding the firm's products and services, compare them with competitor's products and services, and also should evaluate sales growth opportunities.

Market focus, customer satisfaction, and delighting the customer are common phrases - but we must redefine the manufacturing task to create the desired results. The firm must be consistent with, and support, the corporate and marketing strategy. This could be accomplished by determining target market's requirements including product variety, volume and delivery flexibility, low-cost production, critical product quality requirement, and other manufacturing-related capabilities.

Also a universal issue across all production environments, as every business needs to provide some type of measurement and control over the production activity as it is taking place. One major issue inherent with the design and selection of the scheduling system to control production activity is the existence and type of detailed planning and execution system that is also present. If, for example, an MRP (ERP) system is used to both plan and execute production, then the PAC scheduling will be due-date based. "Pull" systems commonly used for lean production (JIT), on the other hand, will essentially dictate a first come, first serve-based scheduling system. The other types of scheduling prioritization systems may be selected only in production environments where there is essentially no integrated planning/execution system, such as MRP or Kanban, present, although the trend is to integrate all types of PAC systems with the planning systems.

Once these steps are completed, the MPC system is ready to be designed. In general, the manufacturing planning and control system should be selected/designed to meet the needs and expectations of the organization, suppliers, and customers as closely as possible. While the MPC system should meet the needs, caution should be taken to not select a system that far exceeds the needs. Such a system could prove to be more costly, burdensome, and actually impair effective performance with respect to the expected needs. In any case, a complete cost-benefit analysis should be undertaken to ensure commitment from top managers and other key personnel in the organization. The steps we have discussed are shown in Figure L.1.

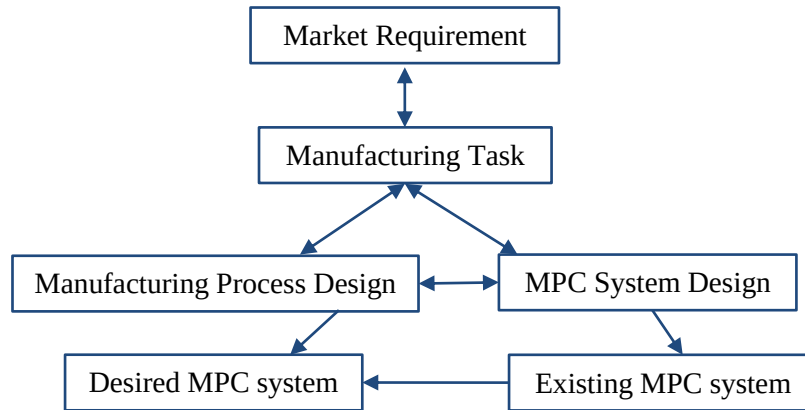


Figure L.1 Steps involved in designing the MPC system

Integrating MRP & JIT

As we start to move away from a very volatile environment-one in which MRP handles quite well-we will start to see some "easing" of the volatility. Demand patterns are starting to be more stable and design changes are less frequent or radical. In this system there is still a level of volatility to call for planning and execution by using MRP, but since some stability is evident we may be able to utilize some of the principles of lean production. Setup reductions to reduce lot sizes and inventory investments may start to make sense here, as well as some of the layout changes and supplier relationship building that can bring great benefits in time, cost, and quality. Statistical process control tools can also be used to bring additional quality benefits.

The MRP logic can be used in a way that allows for planning design changes effectively while providing some of the benefits of a pull system. It tends to be used where there is some improvement in the volatility of demand. The system works by programming the MRP system to look ahead for a set period of time (2 to 3 weeks, for example). The system will then determine total component demand during that time period to calculate the number of Kanban cards required using the Kanban calculation formula provided in Lecture J. The system will then have two major outputs for that time period printing the number of Kanban cards as calculated but also generating a standard dispatch list that is the normal output of an MRP system. Both the dispatch list and the printed Kanban cards are issued to the work center. The work center is authorized to produce a part only if there is an unattached Kanban card and the part number is listed on the dispatch list.

Extending MPC Integration

The system integration can be extended to customers and suppliers. The firm's MPC system could be integrated with the MPC system of suppliers as well as customers. Our traditional view of MPC system design needs to be expanded to consider MPC system improvements that span the operations of customers, plants, and suppliers throughout the supply chain. In this way, the development of manufacturing strategy to support market requirements can include investments in MPC system architecture within an integrated supply chain context.