Production & Inventory Control

Readings and Problems

By

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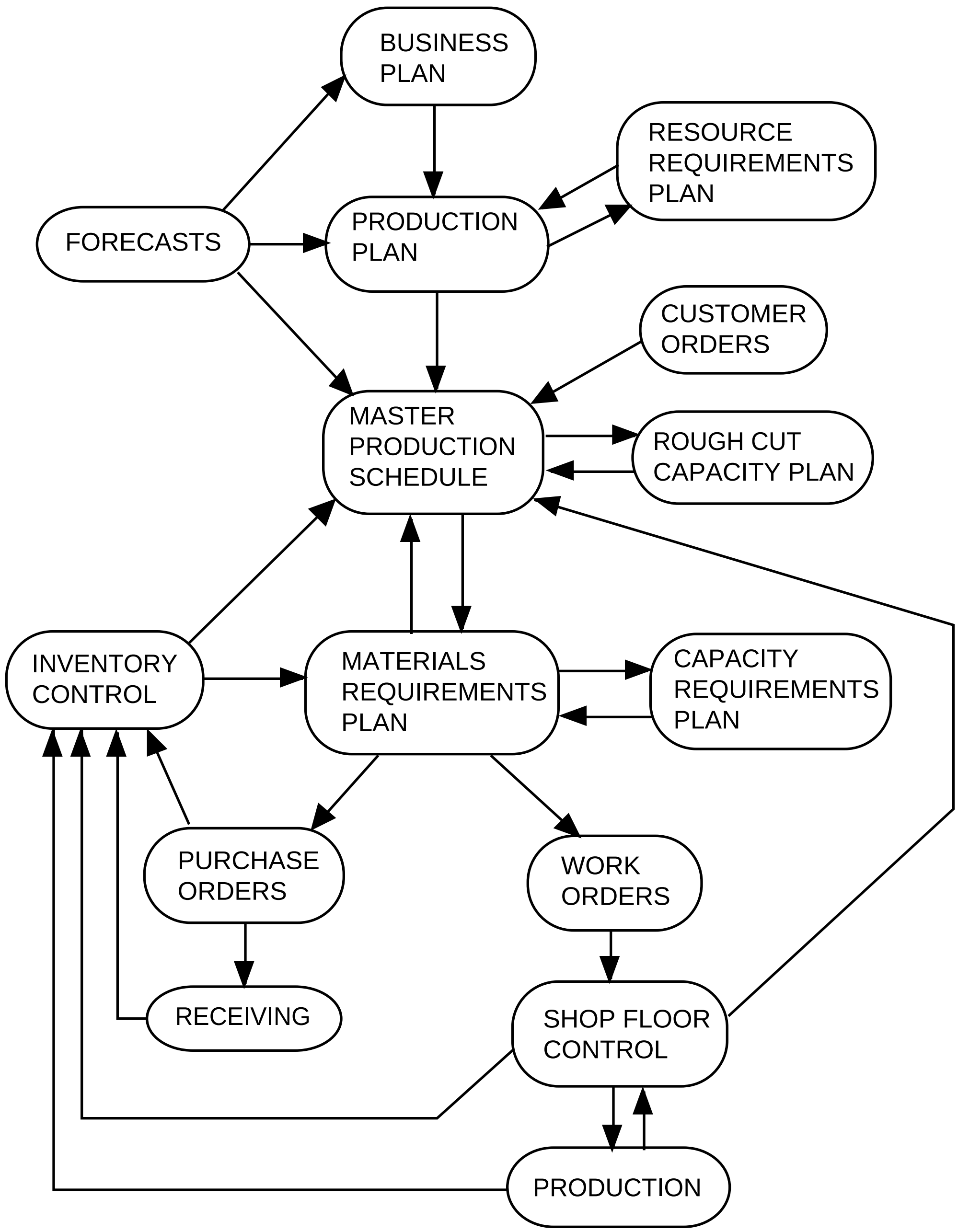
MODEL REFLECTING CONTEMPORARY PRODUCTION AND INVENTORY CONTROL USED AS THE MODEL FOR THIS COURSE



INTRODUCTION TO PRODUCTION AND INVENTORY CONTROL

Any complete understanding of production systems includes an understanding of the planning and control techniques necessary to allow those systems to function efficiently. There are many different aspects of planning and control in production systems including product design, planning plant layout, planning for equipment acquisition, planning production rates and patterns, control of quality, control of cash flow, control of inventory levels, control of production lead times, etc. Production and inventory control focuses primarily on the planning and control of the materials of production from the determination of customers' demands and the ordering of raw materials through the production sequence of component parts to the final assembly schedule and inventory of finished products.

Production and inventory control represents a true control system in the broadest sense. For our purposes control is defined as:

> The action of monitoring the operation of a system and making corrections so that the system performs within desired limits. A simple example of control is the action of a thermostat to control the temperature of a room. Control is achieved by sensing the room temperature and turning the heating unit on and off whenever the temperature falls or rises beyond the set limits. In such systems, the controlled variable (in this case heat) will oscillate between the limits. Other control situations require more accurate and variable control and thus more complex control systems. The control of machine tools, engines, and aircraft are examples of such complex systems.
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> Control is also important for much wider ranging activities such as controlling cost, quality, and production in industry; and controlling the life functions of living organisms. In these types of situations just as with mechanical devices, desired output is defined, output and system function are monitored, and corrective action is taken when the system deviates from the defined conditions.
>
> Typically, output cannot be adjusted directly itself but instead depends on other variables that can be adjusted. Those variables are called input or manipulated variables.
>
> Many sophisticated control theories, models, and systems have been developed to control the great many situations in which it is necessary.

In our discussions we will examine the actions taken to establish production objectives (desired limits) such as meeting identified levels of customer demand and due dates. We will examine the means used to monitor the variables such as inventory levels, product status, and resource utilization that determine the achievement of those goals. And we will study corrective actions such as schedule changes and material orders that keep the system progressing satisfactorily toward the overall goals of the company.

We will find that production planning and control systems are complex control systems with many levels, much data, and many feedback loops operating in constantly changing and uncertain environments. That coupled with the variations of details to match the differences between companies requires us to examine general models that illustrate the basic nature of production control systems.

The model for production planning and control systems used in this course is based on the commonly used, computer integrated system known as MRPII or Manufacturing Resources Planning. MRPII and similar systems have brought high levels of control to complex manufacturing systems through the integration of databases that can be accessed instantaneously using computers to record, track, and manipulate data with a great deal of accuracy. The illustration following the title page for these readings illustrates the basic areas of decision making necessary for production and inventory control that we will examine, and the primary relationships between those areas.

Taken from the top down, the model progresses from the most general and earliest decisions based on forecasts and master schedules to the very specific and immediate decisions of shop floor control. Also included are the closely associated areas of capacity and inventory management activities from rough cut capacity planning to the scheduling of loads on specific work centers.

Briefly, the sequence of events that take place is:

1. A business plan is prepared which identifies the nature and direction of the business, its financial goals, and the strategic plans to achieve those goals. It is many times accompanied by budgets, projected balance sheet, and a cash flow statement.

2. Production plans, which serve as a link between the business plan and manufacturing, are prepared that define the overall level of manufacturing output planned; usually as monthly rates for each product family. At this point, specific products are usually not identified, but are combined into aggregate measures that serve to identify general patterns of production capacity. Thus, another common name for these plans is aggregate plans.

3. Resource requirements plans are prepared that identify in broad terms the major classes of resources that will be needed to provide the long-range capacity to complete the production plan. Typically overall labor levels, overall facility capacities, and anticipated major changes in capacity are identified at this level.

4. Forecasts are prepared to anticipate the level of demand for the products. Forecasting information is important input both at the production plan and master schedule levels.

5. The first level at which specific end products are usually planned is the master schedule. At this level the anticipated mix of specific end products is usually planned and scheduled. The master schedule serves to provide the game plan from which more specific plans are derived. It also disconnects those plans from the unpredictable nature of the short term marketplace. That disconnection is necessary, because if the manufacturing system tries to respond directly to the short term variations in the market, its relatively long leadtime activities will be disrupted.

6. At the master schedule level, capacity requirements are checked with rough cut capacity planning. It is a means of determining whether the master schedule can be met with the existing capacity. Because it is primarily to determine feasibility and not to schedule capacity, only critical work centers are checked and it is assumed that if they are adequate the schedule can be achieved.

7. The level of planning at which individual component requirements are identified and scheduled is material requirements planning. At this level, product information in the form of bills of materials, process information in the form of routings, and inventory information about available materials are used to "explode" the master schedule into schedules for the production or purchase of individual components. It is this level of scheduling that determines the activities for most of the work centers.

8. The component schedules produced by materials requirements planning are used as the basis for capacity requirements planning. At this point, specific components are converted into standard measures of capacity requirements, such as standard hours, which are then scheduled against the capacity available at the required work centers. These schedules also serve to further check the feasibility of the master schedule.

9. The output from materials requirements planning is also used as the basis for the preparation of shop orders and purchase orders. Both of which are prepared and submitted to either vendors or the shop to be filled.

10. On the shop floor other, more immediate, levels of planning and control take place. The order in which the individual orders will be processed is determined and corrections are made as their status changes because of the inherent variables of manufacturing based on MRP and changes in due dates and material availability. Also at this level the control of manufacturing leadtimes is critical and is monitored through input-output analysis.

As is also illustrated by the diagram, information feedback loops serve to feed data back to the various levels so that the system can be kept within the desired levels of performance.

These activities, which answer questions about what should be produced, what capacity will be needed, what materials will be needed, when various activities should take place, and how well it is all going, are common to all manufacturing. The techniques used in MRP are sophisticated techniques used in many companies, but also serve well to illustrate the nature of the techniques used in less sophisticated companies to answer the same questions.

The focus of this course will be on MRP as a primary example of production and inventory control systems with an examination of a few closely related areas such as line balancing, ABC analysis, project scheduling, work cells, and just-in-time manufacturing.

The various aspects of production and inventory control will be examined in terms of their basic terminology, basic concepts, and with an example of a simple mathematical model that illustrates the nature of the data and logic involved in its processing.

FORECASTING

Forecasting is usually included in the study of production planning and control because information about future demand is needed to plan future activities. It is defined by Webster's New Collegiate Dictionary as "to calculate or predict (some future event or condition) usually as a result of rational study and analysis of available pertinent data".

The forecast of future demand for the products being produced is needed in several areas of manufacturing activity. The number and mix of products must be anticipated to allow for capacity changes that may have long lead times such as hiring and training labor, increasing floor space, and acquiring additional equipment. Materials must many times be ordered before the actual demand for the product is known. Budgets must be planned that reflect the future activity of the firm, and it is sometimes desirable to be able to tell customers in advance of production when their products will be available. These activities are not the only uses of forecasts, but illustrate its importance.

There are many approaches to forecasting ranging from quick gut feelings to complex mathematical simulations. They can be broken down into various groupings, one of which is to label them as being qualitative, causal, or time series.

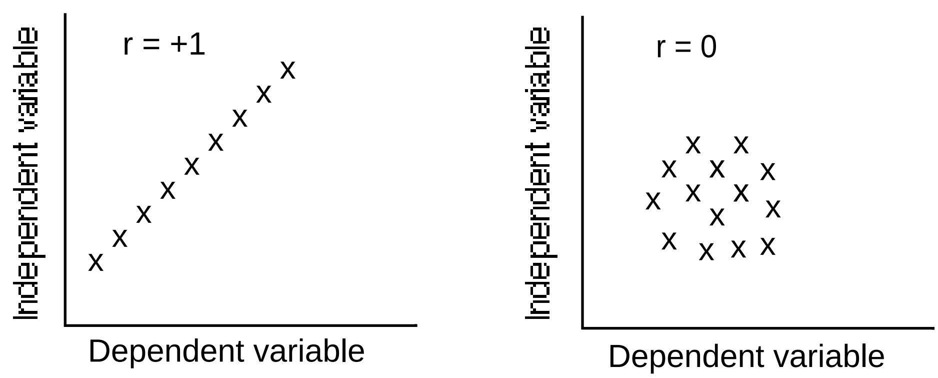
Qualitative forecasting methods are usually used when historic or predictive data is not available and includes techniques such as market surveys, Delphi techniques, sales force surveys, and scenario writing.

Delphi techniques have been developed to help control for the bias caused by the tendency for participants in groups to be influenced by members who hold authority positions, who are believed to have special expertise in the area, or who have more dominant personalities. In a typical Delphi study, a questionnaire is distributed to the group in a way that group members have no information about the other members of the group. The questionnaires are collected, the data is summarized, and the questionnaire is again distributed. However, this time the summarized data is included with the questionnaire and the members are ask to explain their answers. A summary of the new answers are then distributed to the group with another questionnaire along with the reasons why the various members answered as they did. This round is then followed with yet another round and information about the members is provided. Each time the members are given the summary of the responses and more data about the other members. The groups answers usually tend to converge to a consensus that is believed to be less effected by the group members than with other techniques.

Sales force surveys are commonly used to forecast because sales personnel communicate directly with the customer and are the first to be aware of changes in demand and industry trends.

Scenario writing is the development of alternative forecasts based on alternative visions of future conditions. For example, different forecasts might be developed that reflect different interest rates or different patterns of competition. The scenarios ask the question "what can we expect if....".

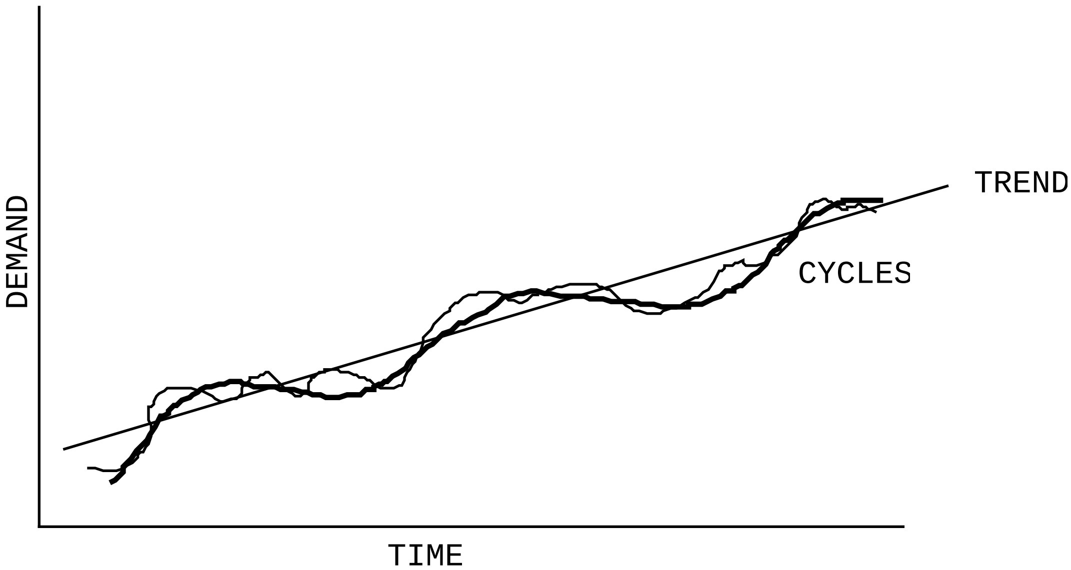
Correlational methods (many times called leading indicators) are based on the predictive nature of events such as the number of births and the future demand for baby food. The power of the leading indicator to predict is determined from historic data of the relationship using correlation techniques. Correlation coefficients used as a measure of the relationship between the independent and dependent variable range from 1 to -1. A coefficient with either a 1 or -1 represents a perfect relationship which is weaker as the coefficient approaches 0. The illustration below illustrates the relationship for a correlation of 1 and one of 0.



Mathematical techniques used to forecast using leading indicators include regression formulas. Multiple independent variables can be used using multi-regression techniques.

Time series techniques are based on the assumption that past patterns will continue, and use mathematical techniques to clarify patterns and extend them into the future. Common techniques include moving averages and regression formulas.

A great many series of events follow fairly predictable patterns over time and the demand for many products and services is no exception. When charted, the pattern for the demand of a product may be as illustrated following diagram.



In the illustration, lines have been drawn over the data to illustrate its repeating patterns. The straight line represents the general <u>trend</u> of the data and the curved line represents the repeating or cyclical pattern. The trend line may be straight or curved and there may be multiple frequencies of cycles in one pattern such as for daily, weekly, and yearly changes. Data that does not conform to patterns that can be explained or expressed mathematically are considered to be useless noise.

An example of the math used in the analysis and extension of time series is provided in the following case. In this case, sales data is known for years 1998 through 2002 and a forecast is needed for 2003. The model used is a simple <u>linear regression</u> which assumes that the trend is best represented by a straight line. Also available are monthly sales for 2000, 2001, and 2002 which are averaged to form the basis for index numbers used to predict future monthly sales.

YEAR	X	Y	X^2	XY
1998	1	400	1	400
1999	2	500	4	1000
2000	3	520	9	1560
2001	4	640	16	2560
2002	5	800	25	4000
	15	2860	55	9520

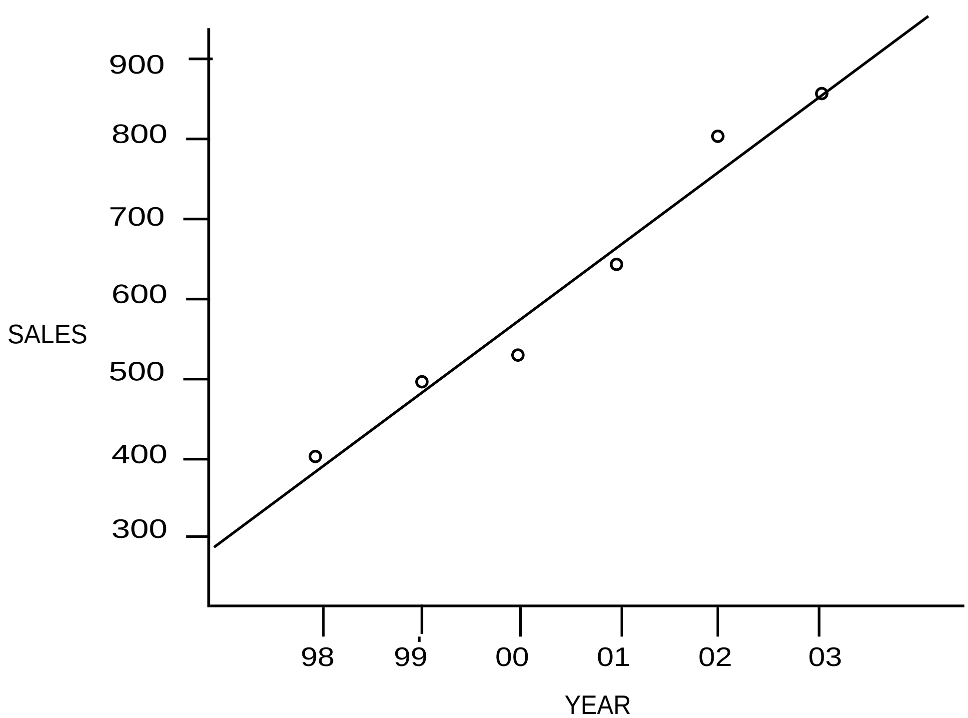
$Y = A + BX$

$$B = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2} = \frac{5(9520) - (15)(2860)}{5(55) - 225} = 94$$

$$A = \frac{\sum Y - (B * \sum X)}{N} = \frac{2860 - (94)(15)}{5} = 290$$

$$Y_6 = 290 + (94 * 6) = 854$$

The forecast for 2003 is determined by calculating the origin and slope of the regression line as shown above, and then extending the line for year 6. The line determined by the formula is illustrated below. Notice that it does not intersect any of the actual yearly data.

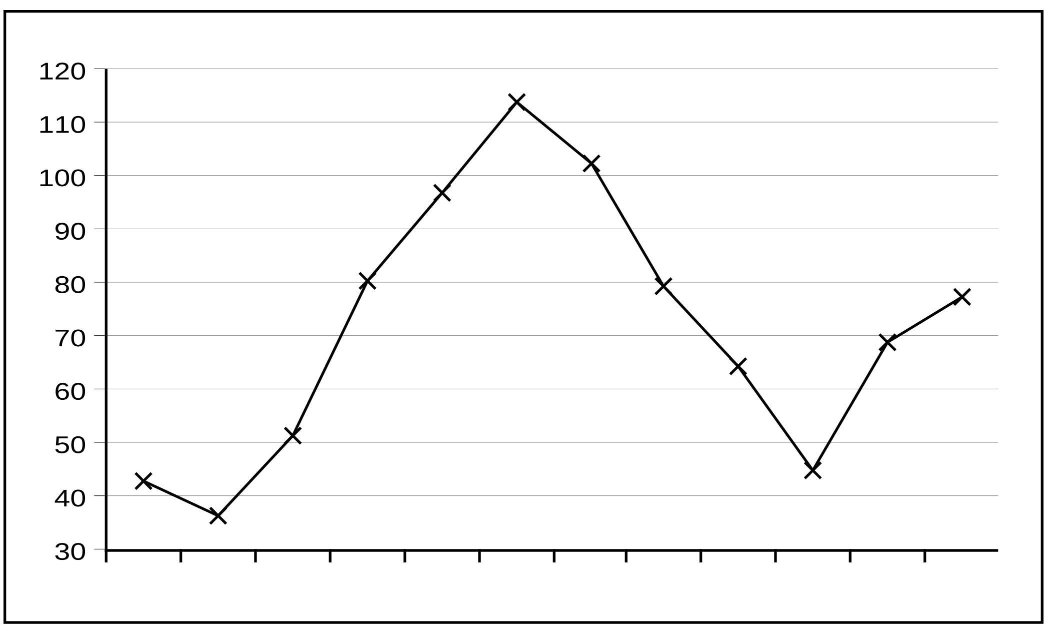


After the yearly forecast has been made by extending the trend line, index numbers (based on ratios of each month to the monthly average) can be used to extend the historic monthly data into the forecast year, as shown below.

	2000	2001	2002	Average	Ratio	Index	2003 Forecast
Jan	40	32	26	33	33/54	0.60	43
Feb.	34	27	22	28	28/54	0.51	37
Mar	48	38	31	39	39/54	0.73	52
Apr	75	60	49	61	61/54	1.13	81
May	90	72	58	74	74/54	1.36	97
Jun	106	85	69	87	87/54	1.60	114
Jul	95	76	62	78	78/54	1.44	102
Aug.	74	59	48	60	60/54	1.12	80
Sep	60	48	39	49	49/54	0.91	65
Oct.	42	34	27	34	34/54	0.64	45
Nov.	64	51	42	52	52/54	0.97	69
Dec.	72	58	47	59	59/54	1.09	77

In this case, the ratio is the average sales for each month divided by 54, which is the sum of the average monthly sales divided by 12 (months). The index number is the ratio expressed as a decimal. It is then multiplied by the average monthly sales for 2003 (71.17) to produce the monthly forecast for 2003.

The graph below of the forecast monthly sales shows the seasonal nature of this product.



When doing forecasting, the limitations of the techniques must be considered. Forecasts are less accurate as the time into the future increases. Also, the assumptions of correlations and the continuation of patterns may not hold.

Because of these limitations, those doing and using forecasts need to understand the specific techniques used, need to match it to their needs and data, need to track the accuracy of their forecasts, and need to design production systems that can respond to changes when the forecasts are wrong. It is also common to use both qualitative and mathematical methods at the same time. It is usually important to evaluate mathematical results with the judgment of people who have a perspective on the market.

FORECASTING TERMINOLOGY

Causal Techniques - Forecasting Techniques that are based on an examination of the relationship between factors that at least mathematically appear to have a cause and effect relationship. An example of this type of situation is the relationship between the number of building permits issued and the number of bathtubs sold.

Correlational Techniques - Another name for causal techniques.

Correlation Coefficient - A mathematical measure of the degree of relationship between two groups of data. In forecasting it is a measure of the degree to which measures of one factor can be expected to predict measures of another. Correlation coefficients typically range between -1 and +1, with 0 meaning no predictive relationship and either -1 or +1 being a perfect predictive relationship.

Cycles - Repeating patterns of data that in forecasting are usually expected to continue into the future. Common types of cycles used in forecasting are seasonal, weekly, daily, and hourly.

Delphi Techniques - Qualitative forecasting techniques that use the opinions of experts to predict the future. In the technique the opinions of the group are refined through a series of discussions and opinionaires to arrive at a consensus.

Environmental Scanning - a forecasting technique in which the tracking of a wide range of cultural, environmental, economic, demographic, etc., factors is used to detect changes that may predict changes in patterns of demand.

Forecasting - The estimating of future conditions. In business and industry it is used to anticipate the future demand for products and services before actual demand is known so planning can take place.

Index Numbers - In time series forecasting they are used as a measure of the point in a cycle in relation to the baseline which is commonly the mean of data points in the cycle. In other situations they may relate to other types of baselines such as base years in the case of inflation.

Leading Indicators - In causal or correlational forecasting it is the independent variable that relates to and leads the variable to be predicted. To be useful it must lead by enough time for the planned action to take place.

Market Surveys - Forecasting techniques that survey customers and potential customers about their future buying patterns.

Moving Average Techniques - Forecasting techniques that reduce the effect of "noise" in the data by basing forecasts on the average of past data. For example, in a four point moving average new forecasts are calculated by averaging the last four data points. Each time a new data point is added a new average is calculated using it and drops off the oldest data point from the last calculation.

Qualitative Techniques - Forecasting techniques based upon the opinions of individuals rather than historical data. Common types of qualitative studies are Delphi techniques and market surveys.

Linear Regression - Mathematical techniques used in forecasting that fit data to a straight line to allow for the extension of that line (and thus the data) into future time periods.

Seasonal Variation - Cyclical variation of data that reflects the yearly cycles of the annual seasons.

Trend - The long-term direction of data patterns used in forecasting. The slope of the line determined by linear regression in time series analysis.

DOUGH BOX FORECASTING PROBLEM

The USMIT Furniture Company produces a line of wood furniture including a reproduction dough box. They use time series techniques to forecast demand for the dough box in the future. Given the following data from past years, compute the expected yearly and monthly sales for next year. Use the regression technique demonstrated in class and all the data below in your calculations. Graph the regression line, monthly sales, and projected monthly sales.

Yearly sales for past years:

1995	200
1996	320
1997	435
1998	550
1999	560
2000	600
2001	620
2002	660

Average monthly sales for the last three years were:

Jan -	17	May -	106	Sept. -	30
Feb. -	25	June -	114	Oct. -	19
Mar -	47	July -	85	Nov. -	38
April-	65	Aug. -	53	Dec. -	27

MASTER SCHEDULING

Master scheduling is the highest level of production planning at which individual products are usually identified. It is a disaggregation of the production plan that identifies completion dates and quantities for the products the company plans to make. It is the plan by which the company plans how they will respond to anticipated independent demand for their products.

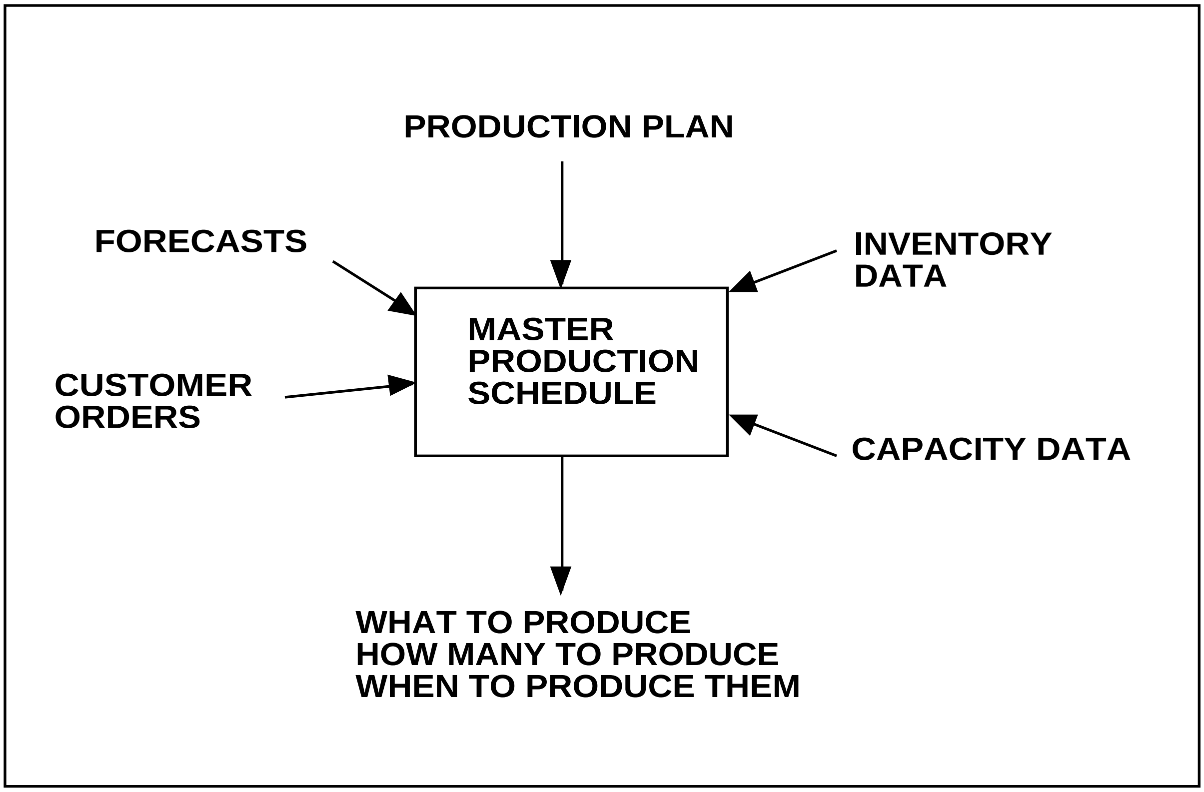
The master schedule is a plan that is used by several segments of the company to plan their detailed activities. To sales it is a schedule of final product completion dates that can be used to promise products to customers. To inventory control and finance it anticipates inventory levels of finished products, and to manufacturing it is the schedule of finished products that "drives" the materials requirements planning for component (dependent demand) production and assembly.

It is easy to imagine what may happen if there were no master production schedule. Sales would not know which products are going to be available and could sell more or different products than will be produced, or if manufacturing tried to respond directly to sales they would be trying to respond to constantly changing demand that would not allow for the leadtimes usually necessary to procure materials and produce products in economical lot sizes. One possible solution would be to carry enough inventory of finished products to always meet demand, a solution that would however require high levels of expensive inventories. A well developed master schedule can greatly reduce those problems.

Master production scheduling requires effective communication and agreement between marketing and manufacturing. Marketing must provide demand information and must agree that the master schedule does allow for anticipated sales. Manufacturing must provide critical capacity information and must agree that the products scheduled can be produced by the dates specified. And inventory control must agree that the inventory levels that will result from the plan will be acceptable.

Developing and maintaining the master schedule is a very important task which requires constant information from manufacturing, purchasing, sales, and management. Even though it is important that the master schedule be as stable as possible, it is subject to change as demand patterns change, material availability changes, or production capability varies. For example, if forecasts are revised upward, more products may be scheduled; or if components are delayed, the master schedule may be changed to prevent other components from being processed early.

The following diagram illustrates the inputs and outputs of a typical master schedule.



The following example illustrates the basic components of a master schedule. It contains basic information about the part, critical resource information, and leadtime information.

Part # CT23	Description	Trestle Chair Table				
Critical Resources	Planer		Finishing			Level LT 1
	.25	-5	2.25	-0		Total LT 7

Week	Past	5/19	5/26	DTF 6/2	6/9	6/16	6/23	6/30	7/7
Orig Forecast		20	22	25	27	25	25	20	20
Rem Forecast		0	3	7	15	25	24	20	20
Actual Demand		20	19	18	12	0	1	0	0
Master Schedule		45		50		50		40	
Proj Avail Bal	3	28	9	34	7	32	7	27	7
Avail to Prom	3	9		20		49		40	

Demand information is shown as the original forecast, remaining forecast, and actual demand. The remaining forecast is the difference between the actual demand and the forecast except in cases where the actual demand was not included in the forecast. It is useful to track the accuracy of the forecast.

The master scheduled amounts are the amounts of finished products that are planned for the time periods shown.

The projected available balance (PAB) is the amount of the product expected to be remaining in inventory at the end of the periods shown. It is calculated by adding any remaining balance from the previous period to any master scheduled amount and subtracting any amount to be delivered that period. Within the demand time fence (DTF) the amount to be delivered is the actual demand. Beyond the DTF the forecast is used because it is assumed that more orders will come in and that the forecast is the best indicator of those orders.

The available to promise (ATP) amounts are the number of products that are available to sell. In this example, available to promise is indicated for each master scheduled amount. ATP is calculated for the first period by adding any remaining ATP from previous periods (past) to the master scheduled amount and then subtracting all actual demand that will come from that amount. In this case, both the 20 to be delivered during the week of 5/19 and the 19 to be delivered during the week of 5/26 will come from the lot of 45 scheduled for the week of 5/19 plus the 3 remaining from the past period. The resulting ATP is 9 units. In subsequent periods just the master scheduled amounts are used minus the amounts that will have to come from them.

The demand time fence (DTF) is a point in time at which master schedule review procedures and projected available balance (PAB) formulas change. In this case it is assumed that no further orders will be received and that the PAB calculated from the actual demand will be the most accurate. As indicated above, in this case, beyond the DTF the forecasts are used to calculate the PAB because it is assumed that the forecasts are the best measure of what the demand will be.

This example only shows one time fence but in some cases several are used and are given other names such as planning time fence. In those cases they represent points when policies (usually master schedule review policies) change. They are based on the fact that as the scheduled date gets closer to the current date, the cost of making changes in the master schedule increases. In the case above the cost is considered to be so high that the master schedule is frozen within the DTF and no changes are allowed except under extraordinary circumstances.

An activity closely associated with master production scheduling is rough cut capacity planning (RCCP). Rough cut capacity planning checks the feasibility of meeting the master schedule from manufacturing's point of view. It is a procedure in which critical resources are identified for the products scheduled and the availability of those resources in the necessary time periods are confirmed.

In the example above, the planer and finishing operation are identified as the critical resources. If we can get the scheduled number of products through those areas we assume that we can get them through the others, those are the bottleneck operations. The .25 listed under planer is the standard time that each unit takes at that resource, and the -5 is the number of weeks before the master schedule date that those products normally need those resources. Therefore we can examine the load on the planer five weeks before the master schedule date to see if those resources will be available. The same procedure is used for the finishing area, and if both resources are available, we assume that the number of units master scheduled can be produced.

Master production planning is a critical stage in the planning of production activities. It is the level at which the overall "game plan" is developed which serves as the basis for more detailed planning. The example discussed here is for the manufacture of discrete products, but master schedules are equally important for continuous production and in service industries.

MASTER SCHEDULING TERMINOLOGY

Aggregate Planning - An older term for production planning (see production plan below).

Available to Promise - the unsold or otherwise uncommitted portion of master scheduled production. It is available to be promised to customers.

Critical Resource - Selected resources used in rough cut capacity planning to predict if the master schedule can be accomplished. They are resources that are thought to be the bottlenecks when those products are produced.

Lead Time - The time expected between the time a decision is made and when the activity is completed. In master scheduling it is usually the time necessary for all activities between the master scheduling of products and when they are available for delivery to customers.

Make-to-Order - Manufacturing situation in which the products are produced based on known customer orders. In some cases, some long lead time activities are completed prior to the orders to reduce delivery times.

Make-to-Stock - Manufacturing situation in which products are produced for inventory based on forecasts, and are available to be shipped from stock when customer orders are received.

Master Schedule - The anticipated build schedule of end products or selected sub-assemblies which is the basis of detailed component scheduling done by materials requirements planning. It is what the company expects to produce expressed in specific products, dates and quantities. Its primary purpose is to balance the ability to produce products with the expected demand for those products.

Planning Horizon - The time between when plans are made and the events planned take place. Adequate planning horizons must include enough time to complete all required activities.

Production Plan - The level of manufacturing planning above master scheduling that specifies the overall level of output. It usually states output in product families of other aggregate measures such as tons, gallons, etc. It is used to plan strategies of overall resource use and budgets to meet company goals. An older term for the production plan is aggregate plan.

Projected Available Balance - In master scheduling it is the inventory balance projected out into the future. It is the running sum of on-hand inventory plus planned receipts minus expected demand.
Rough Cut Capacity Planning - Capacity planning done at the master

scheduling level to determine the feasibility of completing the master schedule. It examines critical resources and assumes that if they are adequate the master schedule can be achieved as planned.

Time Fences - Points in time established by policy at which restrictions or changes in procedures go into effect. In master scheduling as time fences nearer to the delivery date are reached, higher levels of authority are usually required to change the schedule because of the increased impact of changes.

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MASTER PRODUCTION SCHEDULE

Problem #4

Using the format and data shown below, calculate the remaining forecast, the projected available balance, and the available to promise amounts for the dough box.

Part # DB12	Description	Dough Box					
Critical Resources	Jointer		Finishing				Level LT 2
	.10	-5	.75	-0			Total LT 6

Week	Past	5/5	5/12	5/19	5/26 (DTF)	6/3	6/10	6/17	6/24
Orig Forecast		32	32	33	34	35	35	35	36
Rem Forecast									
Actual Demand		31	33	24	8	4	0	0	
Master Schedule		64		68		70		75	
Proj Avail Bal	4								
Avail to Prom	4								

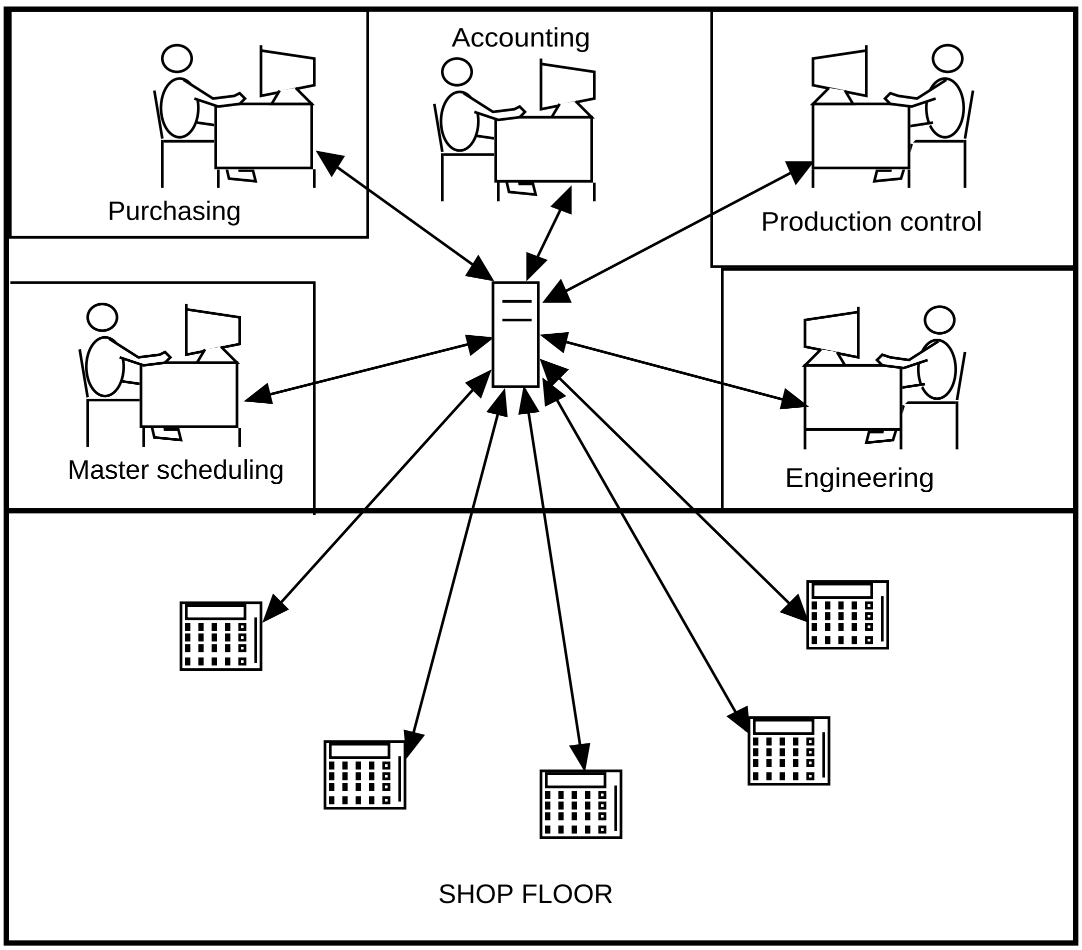
FORECASTING AND MASTER SCHEDULING REVIEW QUESTIONS

1. Why is forecasting necessary in industry?
2. What are the basic assumptions associated with the three general types of forecasting methods we discussed in class?
3. What are the two primary requirements of leading indicators that make them useful to a given situation?
4. In time series analysis, the pattern of past data is broken down into what components to allow its examination?
5. If families of products are forecast, such as the tables in the USMIT Furniture Co., how are they commonly broken down into individual product forecasts?
6. What are index numbers as used in forecasting?
7. What is the output of the master production schedule?
8. What does the statement "To plan and control the impact of independent demand on company resources" mean when referring to the MPS?
9. What are time fences and why are they needed in MPS?
10. What is the minimum length of the MPS planning horizon?
11. Independent demand in the MPS comes from (is in the form of)?
12. What is the procedure used by production to evaluate the MPS?
13. What questions does marketing and finance ask about the MPS to evaluate it?
14. What is the production plan (aggregate plan)?
15. What types of decisions are based on the production plan?
16. What is the relationship between the production plan and the MPS?
17. What is the resource requirements plan that is associated with the production plan?
18. How does the MPS serve production, marketing, and finance?

THE MRP DATABASE

The creation of and maintenance of an accurate database is an essential part of a formal production control system such as MRP. In fact, the lack of the data necessary to create the database is one reason for the slow implementation of formal systems by many companies, and the lack of accuracy is a primary reason for the poor performance some companies experience when using formal systems.

The diagram below illustrates a multi user MRP system in which different functional areas have access to the common database. Because of the common database, changes are available to everyone on the system as soon as they are made, and everyone has access to the same data. The terminals on the shop floor provide a feedback loop that updates the files on the status of work in process.



The database necessary for MRP varies somewhat between systems, but basically contains information about the production system and the products produced that is necessary to perform materials requirements, capacity requirements, and cost accounting calculations. This information is maintained as related computer databases which are accessed as necessary for MRP calculations and information inquiries. The databases used for MRP calculations (there are other databases needed for other functions such as payroll, accounting, maintenance, etc.) typically include parts master, bill of materials, routing, and work center information. The following lists contain the types of data contained in those databases.

Parts Master: The parts master file contains the primary descriptive data for all the parts included in the MRP system. It commonly includes items such as:

A unique part number for each part.

A description (name) of the part.

The common unit of measurement for the part such as each, gallon, pound, etc.

ABC classification (how important an item is the part).

Inventory cycle code (how frequently is it to be counted).

Quantity on hand.

Quantity on order.

Last physical inventory date (when was it last counted).

Reorder point (at what point should it be reordered).

The lot size or order quantity (what is the standard quantity of an order).

Safety stock (how much extra do we carry to be safe from stock outs).

Shrinkage factor (% expected loss during manufacturing due to all causes).

Lead time (the mount of time it takes to get the part).

Make or buy code (do we make or buy the part).

Supplier identification.

Stock location.

Master schedule code (is it a master scheduled item).

Material cost.

Labor cost.

Overhead cost (costs not directly associated with individual parts).

Selling cost.

Bill of Materials: The bill of materials file contains information about the components and structure of the products. It commonly includes:

The unique part number for each part.

A description (name) of the part.

The part number of the next higher level part in the product structure.

The quantity needed for that next higher level structure.

Routing Database: The routing file contains the information necessary to describe the process used to produce the products. It normally contains data such as:

The unique part number for each part.

A routing identification number (identifies the specific sequence of operations to produce the part).

An identification number for each operation.

A description of each operation.

A sequence number (at what point in the process does the operation take place) of each operation.

The work center where each operation is performed (work center ID number).

Reference to the documentation about each operation.

Tooling required for each operation.

The standard set-up time for each operation.

The standard processing time for each operation.

Transport time for the part at each operation.

The operation lead time for each operation.

Work Center Database: The work center file contains information that describes the work centers used to produce the parts. It typically includes such information as:

The work center identification number.

A description of the work center.

The number of hours the center is normally used per day.

The number of days per week it is normally used.

Its percent standard efficiency.

Its percent standard utilization.

The number of operators.

The number of machines at the center.

The standard queue at the center.

The labor rate (cost per hour).

The overhead rate (many times a % of labor or machine rate).

The machine rate (cost per hour).

The types of data listed above is typical of MRP databases. In our course we will be using examples of that data to perform simple simulated MRP and capacity planning calculations.

MATERIALS REQUIREMENTS PLANNING

One of the most significant developments in production and inventory control in the last two decades has been that of MRP and MRP II. MRP or Materials Requirements Planning is the older of the two and is a subfunction of MRP II or Manufacturing Resources Planning. MRP in the remainder of this section refers to the narrower materials requirements planning.

MRP is a powerful, almost always computer-based, technique that uses inventory and product structure information to translate master schedules into time phased order dates for component parts. The programs are almost always computerized, not because the logic is complex, but because in most manufacturing environments the volume of data prohibits manual manipulation.

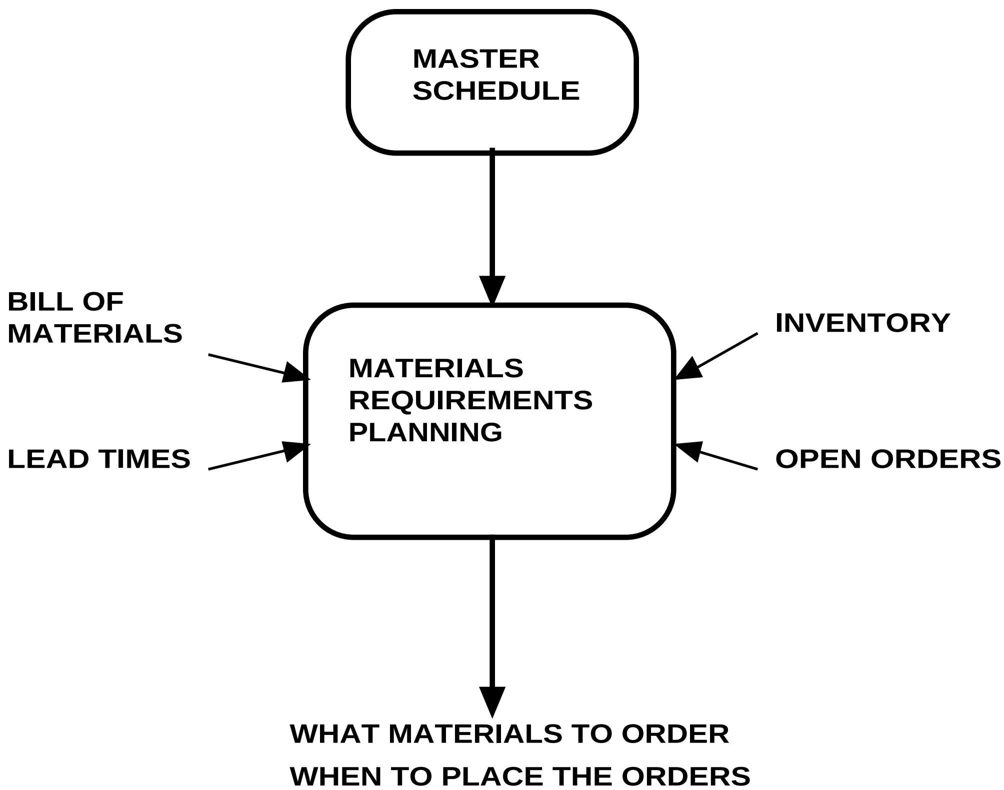
Before the development of MRP techniques, many materials and parts used in manufacturing were ordered when their inventories reached levels below order points calculated based on assumptions of constant or historic usage. That resulted in materials being ordered because of past demand and not future planned demand. In cases of fairly constant usage the system may work well, but because it does not take specific plans for future production into account it usually results in excessive inventories being available during periods of no demand inherent in intermittent batch production.

MRP has allowed a transition from simpler, non-integrated, order point techniques to an integrated ordering system based on production plans instead of production history. MRP is therefore pro-active instead of reactive in terms of order generation. MRP also has the advantages of integrating the demand for component parts so as to better assure the correct combination relative to the final products.

Before discussing the logic of MRP, a few terms must be defined. MRP schedules the ordering of dependent demand items, whereas master scheduling usually deals with independent demand items. Independent demand items are usually finished products such as automobiles, toasters, etc. The demand for those items is, for the most part, determined by forces external to, or independent of the manufacturing organization. The demand for those items is based primarily on forecasts and customers orders.

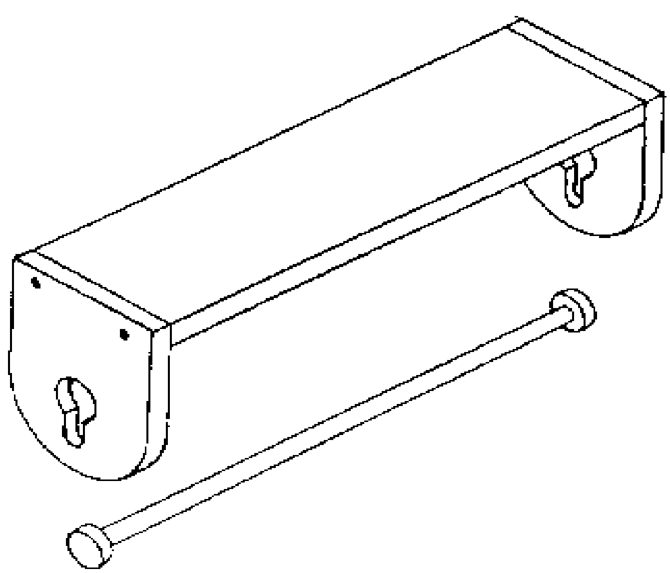
Dependent demand items are the component parts of those end products, and their requirements depend on the number of independent demand items master scheduled. After the number of toasters to be produced has been determined, it is a fairly simple process to determine how many toaster components will be required for their manufacture except for scrap factors and safety stocks.

The figure below illustrates the relationship of MRP to its primary inputs and outputs. As can be seen, the three primary inputs are the master schedule which indicates what final products are to be produced and when they are to be finished; the bill of material and product structure that identifies component parts and lead times; and inventory information that indicates materials available to fulfill requirements. The output from MRP includes reports on what to order and when, what must be expedited to meet scheduled due dates, what can be canceled because of changes, and provides data that can be used to examine the feasibility of the master schedule.

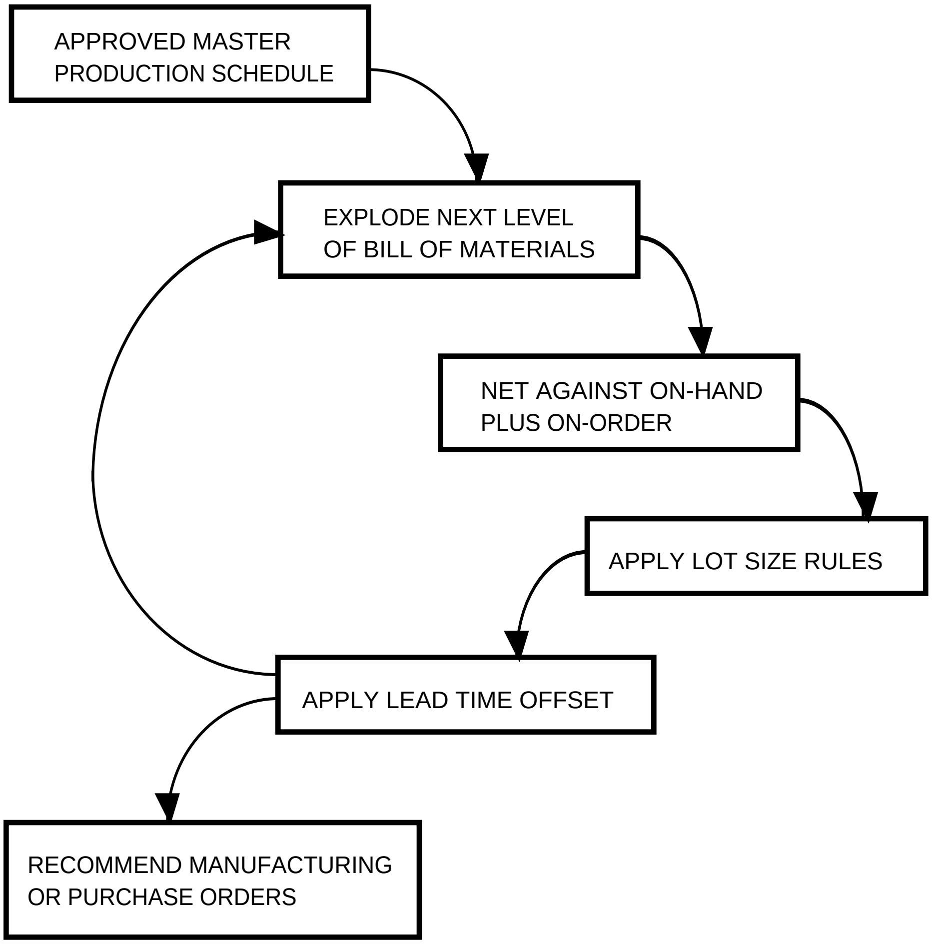


The bill of materials (BOM) used in MRP is structured to contain the necessary information about the relationship of parts and their time phasing or place in the production schedule. As can be seen in the following example, which is a partial BOM for a towel rack, the components are identified by subassembly level as they relate to the next higher level. For example, the back (level 2) is shown as a component of the hanger (level 1) which is shown as a component of the towel rack (level 0). Notice that not only are the individual beginning components listed but all higher level subassemblies are also listed. Also provided is data on the number required for the next level and the lead time to produce the components.

LEVEL	PART	QUANTITY	LEAD TIME	ON HAND	LOT SIZE
0	TOWEL RACK	1	1	28	100
1	HANGER	1	1	20	100
2	BACK	1	1	50	100
2	END	2	2	40	400
2	SCREWS	4	3	140	1000
1	ROLL BAR	1	2	75	200
2	DOWEL	1	2	0	500
2	END CAPS	2	1	100	1000



The following diagram illustrates the basic logic of MRP. Before MRP can schedule dependent items, the final products must be scheduled on the master schedule. The master schedule then drives MRP which determines component part demand. Each level on the BOM is computed in turn using the steps shown.



The first step is to "explode" the BOM to identify the lower level component being scheduled. After the part is identified, its gross requirements are determined by multiplying the previous levels' requirements by the number of those components that go into that level. For example, on our towel rack the number of ends required is determined by multiplying the required number of hangers by two. Each level must be taken in turn, and no levels may be skipped.

The gross requirements may however not be what we must actually produce, because we may have some in inventory. Next then, the gross requirements are adjusted by any uncommitted items in inventory to provide actual net requirements. The new quantity may additionally be adjusted by any lot size rules to determine actual order quantities.

After the order quantity is determined, it is scheduled by subtracting the lead time of the component from its due date. Its due date is the date it is required to produce its next higher level subassembly. Thus all dependent component orders can be scheduled in turn by cycling each level through the MRP logic.

For example the MRP data and calculations for a few of our towel rack components could be as illustrated below. Notice that the towel rack (master scheduled item) is offset for the leadtime needed for its assembly, but it is not adjusted for any inventory on hand because it is the actual amount to be built.

PART TOWEL RACK LEADTIME 1

WEEK	1	2	3	4	5	6	7	8	9	10
MPS AMOUNT						400		550		900
ORDER					400		550		900	

PART ROLL BAR LEADTIME 2 ON HAND 75 LOT SIZE 200

WEEK	1	2	3	4	5	6	7	8	9	10
GROSS REQ.					400		550		900	
INVENTORY					75		75		125	
NET REQ.					325		475		775	
ORDER			400		600		800			

PART DOWEL LEADTIME 2 ON HAND 0 LOT SIZE 500

WEEK	1	2	3	4	5	6	7	8	9	10
GROSS REQ.			400		600		800			
INVENTORY			0		100		0			
NET REQ.			400		500		800			
ORDER	500		500		1000					

PART END CAP LEADTIME 1 ON HAND 100 LOT SIZE 1000

WEEK	1	2	3	4	5	6	7	8	9	10
GROSS REQ.			800		1200		1600			
INVENTORY			100		300		100			
NET REQ.			700		900		1500			
ORDER		1000		1000		2000				

MRP TERMINOLOGY

Dependent Demand - In MRP logic, dependent demand items are components the demand for which is determined by the quantities of independent demand items that are master scheduled. The independent demand items are items for which the demand is usually generated external to the organization.

Gozinto Chart - A chart that can be used to illustrate the hierarchy of components that are needed to produce a product. It is useful to determine the total lead time necessary for production considering the dependent relationships between components and various bill-of-materials levels.

Gross Requirements - In MRP, the gross requirements for individual components is the number needed to supply the quantity to be built at the next higher level. It does not consider any that may be available in inventory or lot size restrictions.

Independent Demand - Independent demand items are master scheduled items the demand for which is usually generated outside the company. It is the quantity of independent demand items that determines the demand for dependent demand items and which are said to "drive" MRP.

Lead Time - In MRP, lead time is the time it takes to produce a component or product from the time production can begin to when the component or product is finished and available for the next activity. It usually consists of order processing time, move time, queue time, set-up time, processing time, and wait time components.

Lot Size - Quantities of items manufactured together (in lots) usually to offset the costs of set-ups or because of the economic capacities of equipment such as heat treating furnaces.

Materials Requirements Planning - The term referring to the computer-based process used to generate order schedules for dependent demand components based on the bill of materials breakdown of master scheduled items, product structure, leadtimes, and inventory.

Net Requirements - In MRP, net requirements refers to the requirements (quantity) of parts after inventory on hand and scheduled receipts are subtracted from gross requirements.

Planned Orders - The suggested order quantity and order release date for dependent demand items created by MRP.

Structured Bill of Materials - A listing of the component parts of a product that includes data about the hierarchy of those parts in the product assembly. The hierarchy of a part is the point in the production process at which it exists.

MRP REVIEW QUESTIONS

1. What questions are answered by MRP?
2. What does independent and dependent demand mean in MRP?
3. How does MRP relate to master scheduling?
4. What input data is necessary for MRP?
5. What is product structure as it relates to MRP?
6. What are the steps of MRP logic?
7. What are the components of MRP lead time?
8. How is total product lead time calculated?
9. In MRP, what is meant by gross requirements, inventory, net requirements, and order amounts?
10. In MRP, why must each level of the BOM be exploded one level at a time?

MATERIALS REQUIREMENTS PLANNING

Problem #3

Using the following data from the master production schedule, bill of materials, and inventory records; construct an MRP schedule for the dough box, its base, legs, long rails, and corner blocks.

Master scheduled dough boxes:

Week of:	5/4	5/18	6/1	6/15	6/29
MPS	64	68	70	75	80

Structured bill of materials: Numbers in () represent the number required for the next level in the BOM.

- Dough box (1)
  - wood screws (6)
  - box (1)
    - bottom (1)
    - wood screws (10)
    - top (1)
      - stationary lid (1)
      - moving lid (1)
      - hinges (2)
      - hinge screws (6)
    - tray (1)
      - sides (2)
      - ends (2)
  - base (1)
    - legs (4)
    - long rails (2)
    - short rails (2)
    - corner blocks (4)
    - wood screws (8)
    - lag screws (4)
    - wing nuts (4)

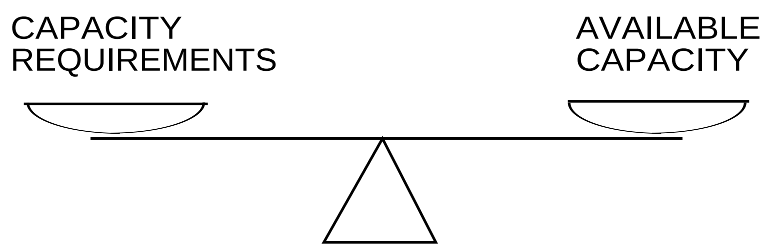
Inventory and lot size information:

At the beginning there are no dough boxes or bases available, there are 50 legs available; 100 short rails, 85 long rails, and 100 corner blocks available. The manufacturing lot size for dough boxes and bases is 1, for legs it is 50, for long rails it is 50, and for corner blocks it is 100. The lead times for the parts are 1 week for the dough box, 1 week for the base, 2 weeks for the legs, 1 week for the long rails, and 1 week for the corner blocks.

CAPACITY REQUIREMENTS PLANNING

After the material requirements necessary to complete the master scheduled products have been identified, the production capacity necessary to carry out the materials plan can be identified and scheduled. The procedure used for that identification and scheduling is called capacity requirements planning (CRP). It is a time phased technique that identifies and schedules the expected load on identified work centers.

The management goal of CRP is to balance the capacity required to produce products with the capacity available. If balance is not achieved, either the production cannot be accomplished on time or excess resources drive up costs. The balancing act done at the CRP planning level can be viewed as the balancing act illustrated below.



As is suggested by the illustration, balance can be achieved and maintained by making adjustments to either the requirements side or the capacity side or both. Changes on the requirements side take the form of changes in the production schedule or through changes in routings. On the capacity side, the balance is changed through the use of overtime, redeployment of the work force, subcontracting, increasing or decreasing the number of workers, adding or reducing shifts, adding or reducing equipment, increasing efficiency, or changing utilization.

Before the planning of the work load can take place however, the available and required capacity must be determined. Available capacity is a function of the number of workers available, the number of machines, the time available, the amount of available time used (utilization), and the efficiency of work centers. The formula for determining available capacity for individual work centers is:

> # shifts X # operators (for labor dependent centers) X time per shift X utilization X efficiency X days in the planning period.

For example, if a work center operated for one shift with 2 operators for 8 hours each shift at an average of 90% utilization and 98% efficiency for 5 days, the available capacity would be 70.56 standard hours.

1 X 2 X 8 X .90 X .98 X 5 = 70.56

Required capacity is a function of the number of products to be processed, the time necessary to process each one, and the time necessary to set-up the work center. The formula for determining the required capacity is:

units X std. hr. per unit + set-up

For example, if there are 60 units to process and each one takes .05 hours and it takes 2 hours to set-up the work center, the required capacity is 5 standard hours.

60 X .05 + 2 = 5

After the available capacity of work centers is known, the required capacity of each lot of components to be produced (as scheduled by MRP) is associated with its work centers, is offset by the expected leadtime, and the load is scheduled against the work center in the appropriate time period. The following example using data generated in the MRP example of the towel rack illustrates the procedure.

The available capacity of the two work centers in question is calculated first using the formula for available capacity. The calculations indicate that there are 79.2 standard hours available at work center #6 and 97.2 at work center #2.

After the work center capacity is determined, the loads to be scheduled on the centers is calculated using the formulas for required capacity. The quantities of components calculated by MRP are multiplied by the run time per unit and added to the set-up time for each operation. That time is then added to any other jobs scheduled to be run on the work center during the same time period.

The load to be scheduled for the towel rack on work center 6 in period 7 is calculated by multiplying the 400 units determined by MRP for that period by the run time per unit of .08 hours plus the .2 hours set-up time to produce the 32.2 hours shown. That requirement is then added to the 25 hours of work required by the table to generate a total requirement of 57.2 hours for that time period. The percent of the total load is then calculated by dividing the 57.2 hours by the 79.2 hours available. The calculations for the other parts and time periods follows the same procedure and produces the results shown.

The loads scheduled are also commonly displayed in chart form as shown in the bar charts following the example calculations.

ROUTING INFORMATION

	Operation	Work Center		Run Time		Set-up Time
Towel Rack	70	6		0.08		0.2
Roll Bar	30	2		0.06		0.2
Dowel	20	2		0.02		0.1

WORK CENTER INFORMATION

Work Center	Shifts	Operators	Utilization %	Efficiency %
6	1	2	90	110
2	1	3	90	90

INPUT FROM MRP

	Period	3	4	5	6	7	8	9
Towel Rack	Wk. Cntr #6					400	600	900
Roll Bar	Wk. Cntr #2			400	600	1000		
Dowel	Wk. Cntr #2	500	500	1000				

WORK CENTER # 6

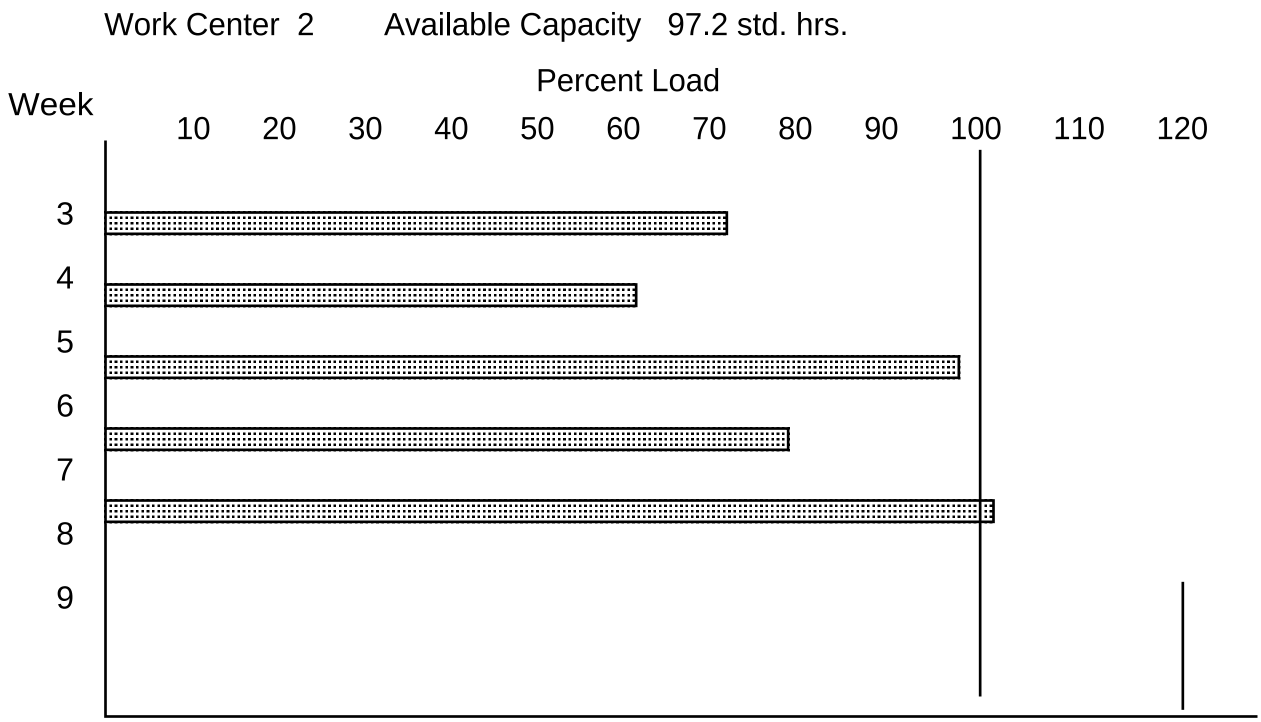
1 Shift * 8 Hrs * 2 Operators * .9 Utl * 1.1 Eff * 5 Days = 79.2 Std Hrs

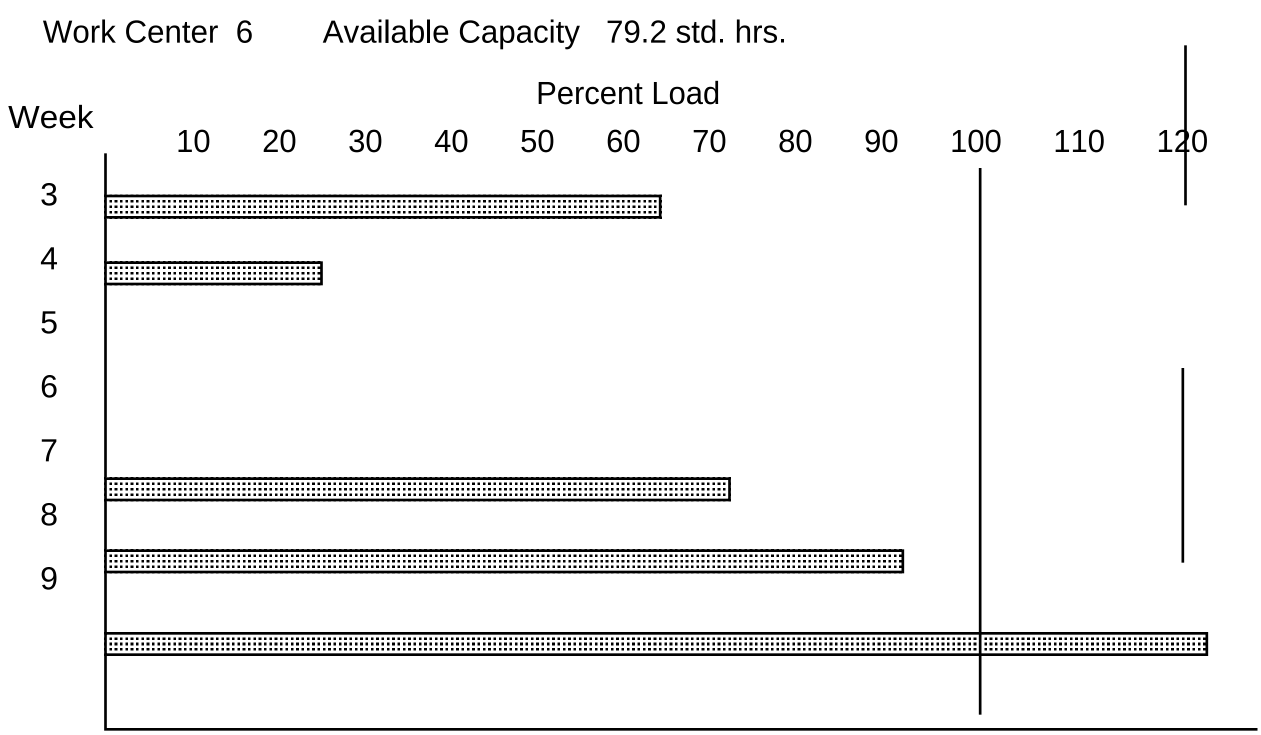
Period	3	4	5	6	7	8	9
Table	50	20			25	25	25
Towel Rack					32.2	48.2	72.2
Total	50	20			57.2	73.2	97.2
% Load	63.1%	25.3%			72.2%	92.4%	122.7%

WORK CENTER # 2

1 Shift * 8 Hrs * 3 Operators * .9 Utl * .9 Eff * 5 Days = 97.2 Std Hrs

Period	3	4	5	6	7	8	9
Table	60	50	50	40	40		
Roll Bar			24.2	36.2	60.2		
Dowel	10.1	10.1	20.1				
Total	70.1	60.1	94.3	76.2	100.2		
% Load	72.1%	61.8%	97.0%	78.4%	103.1%		


Work Center 2
Available Capacity 97.2 std. hrs.
Percent Load
Week
10 20 30 40 50 60 70 80 90 100 110 120
3
4
5
6
7
8
9


Work Center 6
Available Capacity 79.2 std. hrs.
Percent Load
Week
10 20 30 40 50 60 70 80 90 100 110 120
3
4
5
6
7
8
9

CAPACITY PLANNING TERMINOLOGY

Bill of Capacity - similar to a bill of materials, except that it lists the production resources needed to produce the product.

Capacity Requirements Planning - The function that plans the capacity (labor and machines) required to produce scheduled products.

Demonstrated Capacity - Proven capacity based on previous actual output.

Efficiency - A measure used to compare the degree to which actual output compares to predetermined capacity standards for a production resource such as a work center, employee, or machine. It is the standard hours of required work produced divided by the actual hours worked.

Load Profile - A display of future capacity requirements based on planned and released orders over a given time span. (APICS Dictionary.)

Maximum Capacity - The theoretical capacity if the plant worked 24 hours a day, 7 days a week.

Nominal Capacity - The maximum available capacity under normal conditions. For example, the nominal capacity of a plant that works 8 hours per day for 5 days, using one operator would be 40 hours.

Required Capacity - The capacity (resources) needed to produce the scheduled products.

Standard Hours - The mean time to do tasks determined from historical data or motion and time study. Used as the base measure for required capacity, available capacity, and efficiency measures.

Utilization - The actual time a resource is used compared to the hours it is normally available for use. Utilization accounts for factors such as breakdowns and absenteeism.

Work Center - A specific unit of production resources consisting of one or more people and/or machines. It is counted as one unit for the purposes of capacity requirements planning.

CRP Practice Problem

The USMIT Furniture Company that uses MRP to order the production of the components of it's dough box, also uses capacity requirements planning to schedule the use of its capacity. Using the following data, determine the total required capacity and the % of available capacity scheduled for work centers 4, 8, and 9. Assume 5 working days per week, 8 hours per shift.

Work Center Data

Work Center	Shifts	Operators	Utilization	Efficiency
4	1	1	90%	100%
8	1	4	92%	95%
9	1	2	80%	102%

Routing Information

Part	Operation	Work Center	Run Tme/Unit	Set-up Time
Dough Box	PreAssem	9	.15	.50
Dough Box	Assembly	8	.25	2.00
Base	Assembly	8	.40	1.25
Legs	Turning	4	.04	2.00

Currently Scheduled Load in Standard Hours

Work Cnter	Part	Week 5/7	5/14	5/21	5/28	6/4	6/11	6/18	6/25	7/1
4	Bench Legs	30	0	0	10	18	12			
8	Bench			60	0	0	0			
9	Table				40	30	30	30	30	40

MRP Output

	5/7	5/14	5/21	5/28	6/4	6/11	6/18	6/25	7/1
Dough box				150	300	200	200	0	200
Base			200	250	200	200	0	200	
legs	200	600	800	800	0	600			

CRP REVIEW QUESTIONS

1. What is the management goal of capacity requirements planning?
2. What is meant by available capacity?
3. What is meant by required capacity?
4. How can available and required capacity be changed?
5. What does utilization mean as it relates to work centers?
6. What does efficiency mean as it relates to work centers?
7. How does the utilization and efficiency of a work center relate to its capacity?
8. What are standard hours?
9. How is work center capacity calculated?
10. How is required capacity calculated?
11. How is the total load for a work center calculated?

LEAD TIME CONTROL

An important aspect of production control that has received little attention in the literature and particularly in production control texts is lead time control. Also, common problems in industry of excessive expediting and high backlogs of orders suggest that it is little appreciated there.

Lead time is the total amount of time between when it is determined that an item is needed and when it is available for its intended purpose. It usually includes order preparation as well as the manufacturing sequences of queue, set-up, run, wait, and move for each operation. Of that sequence, the actual run times are usually less than 10% of the lead time for lots, and much less for individual items. Commonly, queue (waiting in line before an operation) makes up most of the lead time, in many cases over 80%. Queue times also tend to be highly variable and difficult to predict and become increasingly so as the number of jobs increase.

Lead times exist for a combination of reasons. The actual time necessary to perform operations on the parts is central, although usually a minor time component. The need for available work to maximize the utilization of resources is a major justification. The variability in arrival rates at work centers requires that some backlog of jobs is available if the center is to be kept busy. Another reason is to allow for a degree of job order adjustment at work centers to respond to variation in lead times relative to due dates and to reduce set-ups.

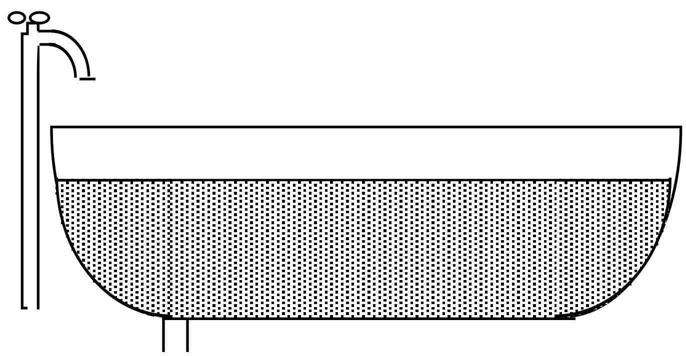
Lead times are commonly much longer than those reasons warrant and add cost to the firm through excessive work-in-process inventories, low customer service, excessive floor space requirements, poor forecasts, high lead time variability, excessive expediting, and excessive finished, but unneeded part inventories.

High lead time variability is particularly serious as more sophisticated scheduling procedures such as MRP are used because of their heavy dependence on standard lead times. No matter how precisely the computer can track levels in a bill of materials, if the lead times cannot be trusted, the resulting schedule cannot be trusted.

What then are desirable lead times, and how can they be controlled? Desirable lead times are a trade-off between the costs and benefits involved, but because of the difficulty of quantifying many of those costs and benefits, cannot be precisely identified. Many firms however have long lead times and unless they have significantly low utilization and are unable to fill their orders, should try to reduce them. Goals of 100% utilization for all work centers probably result in excessive lead times without increasing plant output (which is determined by bottlenecks) and should be questioned.

Lead times are controlled by controlling the amount of work in process, which is determined primarily by the relationship between the input and output of the manufacturing system. If work is input faster than it is output, work in process inventories (WIP) and lead times will increase; if output is greater than input, WIP and lead times will decrease. If they remain the same, WIP and lead time will remain the same.

The water level in a bath tub can be used to illustrate the effects of inputs and output on inventory levels. In the tub illustrated below, the water level will be determined by the relative amount of water added through the tap and drained through the drain. If the drain is closed or restricted below the flow of the tap the water level will rise. If the tap adds less water than is drained the level will fall. The same relationship exists in a factory or at individual work stations when the rates of work being added does not match the amounts being completed.

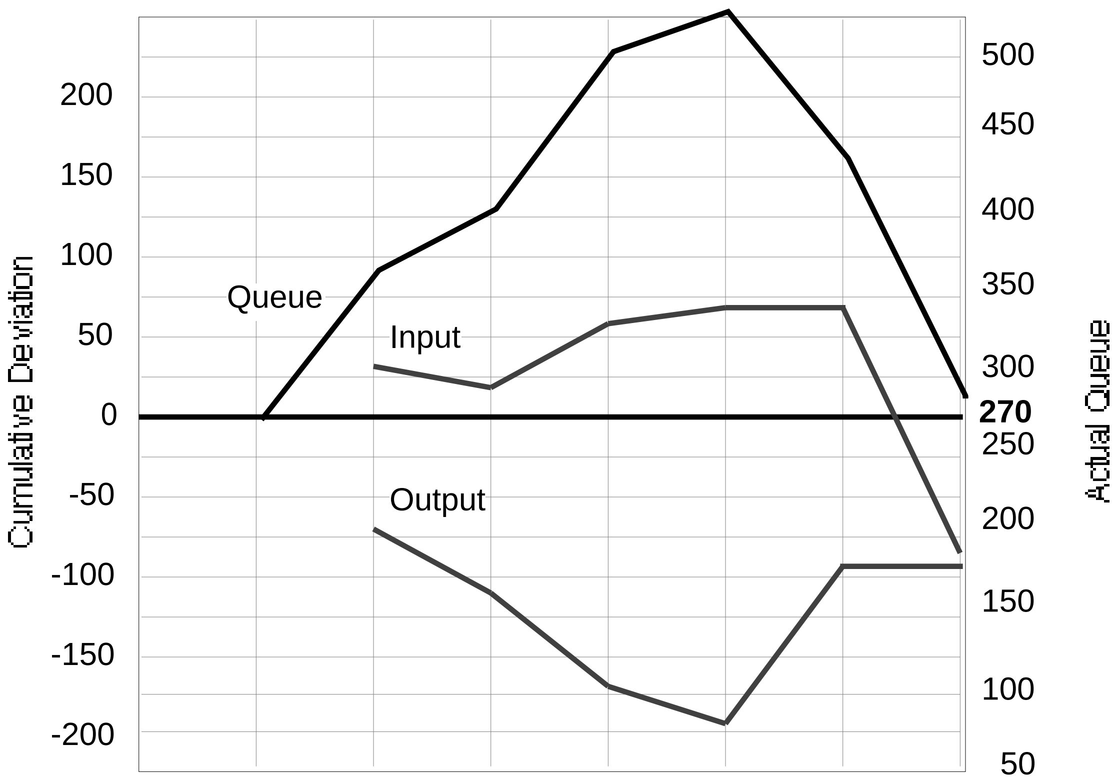


In many situations, it is impossible to perfectly match input and output on a daily basis, but if it is monitored and adjusted for variability, the fluctuations will cancel out and WIP and lead times can be controlled over time.

A useful aid in monitoring input and output is the input/output report. It is a technique that can be applied to the firm as a whole as well as to individual work stations. When applied to work stations (see example), it can be used to detect situations in which WIP and lead times are changing and to adjust to minimize those changes.

The following example illustrates and graphs the content of an input/output report.

Planned Input		450	450	450	450	450	450
Actual Input		480	440	490	460	450	300
Deviation		30	-10	40	10	0	-150
Cum. deviation		30	20	60	70	70	-80
Planned Output		450	450	450	450	450	450
Actual Output		380	410	390	430	550	450
Deviation		-70	-40	-60	-20	100	0
Cum Deviation		-70	-110	-170	-190	-90	-90
Planned Q	270	270	270	270	270	270	270
Actual Q	270	370	400	500	530	430	280



As can be seen on the report; the queue, which is directly related to lead time, increases and decreases as the difference between the input and output is either positive or negative. If input is greater than output, there will be more work on the shop floor and queues and lead time will increase; if output is greater than input, they will decrease. The graphs illustrate cumulative deviation from planned input and output because it is the cumulative effects that create the resulting queues.

In practice, the response that will control lead times as opposed to reacting to changes in lead times is often not understood. It is not uncommon for schedulers to assume that lead times are "given" and that if the actual lead times increase, the correct response is to increase planned lead times to match. In most cases, that response will only produce orders that are past due to begin, which are then dispatched and thus increase lead time even more. The response to increased lead times that will reduce them and thus represents control is to reduce planned lead times which means that the last orders were dispatched early, no more are released for the period of the reduction, and therefore the amount of work will decrease and lead times will fall.

Q CONTROL PRACTICE PROBLEM

In an attempt to increase the accuracy of their schedules, the USMIT Furniture Company is in the initial phases of using input-output analysis to monitor the impact of dispatching on the queues of their input work stations. Using the data provided below, determine the input and output deviations, cumulative deviations, and actual queue. Graph the cumulative deviations and queue.

Week	Planned Input Std. Hrs.	Actual Input Std. Hrs.	Planned Output Std. Hrs.	Actual Output Std.Hrs
1	76	84	76	74
2	76	80	76	76
3	76	74	76	68
4	114	100	114	112
5	114	80	114	114
6	76	76	90	98

The planned queue is 50 std. hrs., and there is 85 hours of queue at the beginning of the analysis.

PRIORITY CONTROL

After MRP generates a schedule of order dates for component parts, and capacity requirements planning schedules the resulting load to various work centers, there is still a level of fine tuning and changing of the system that is necessary if due dates are to be met. Schedules and loads produced by MRP and capacity requirements planning are based on average historic data and are planned for time periods of a week or more, and thus do not accurately anticipate the actual conditions that will exist during the production run. Also, changes in the master schedule, because of changes in demand or because of material or parts delays, create changes in component demand that need to be adjusted for.

To deal with those factors, techniques are used to make adjustments at individual work centers that modify the time jobs spend waiting to be processed. This practice is usually called priority control because it establishes the relative priority that the various jobs will be given in the processing sequence. It is the technique used by the scheduler, foreman, and worker to see that the necessary adjustments are made to the schedule so that the orders get out on time and to avoid production of components before they are needed.

There are a variety of techniques used to establish job priority such as earliest due date, slack time remaining, shortest processing time, and critical ratio. Earliest due date is one of the simplest, but also makes little contribution to solving the problem in many situations. It does not consider the amount of work remaining to be done, and therefore does not consider the opportunity to make corrections. For example, a job that is due in 3 days but which has 12 days worth of work to be done is in much more trouble than one that is due out in 2 days but which has only 2 days worth of work remaining; even though a rule of earliest due date would have us do the job due in 2 days first. It is however a very simple technique that can be used when little leadtime data is available or when products follow the same processing sequence.

Shortest processing time is also a simple technique that has some of the same disadvantages as earliest due date, but in practice usually maximizes the number of jobs processed and minimizes the number of jobs in the queue. It however has the disadvantage that long jobs tend to not get done or tend to be late. That problem is dealt with by having a rule that long jobs will be run regardless of the other jobs when they reach a certain level of lateness.

Slack time remaining is a technique that subtracts the amount of set-up and processing time remaining from the amount of time available and calls the difference slack time. Slack time remaining is a significant improvement over earliest due date in that it considers the amount of actual work remaining compared to the time available. The jobs are then processed according to the amount of slack time they have.

Critical ratio is one of the most sophisticated and potentially accurate techniques available because it takes more factors into consideration. It compares the total lead time remaining including queue, wait, move, set-up, and processing; with the time until the product is due. The resulting ratio is an indication of the degree the job is apparently overdue or early. For example, if a job is due in 12 days and the total amount of lead time remaining is 16 days, the ratio is .75 which indicates that based on the information given, it appears that there is only 75 percent of the necessary time available. In this model of critical ratio, the smaller the number the higher the priority of the job.

$$\text{Critical Ratio} = \frac{\text{Time Remaining}}{\text{Work Remaining}} = \frac{12}{16} = .75$$

In cases like the one given above however, most of the time in the leadtime remaining is usually queue time and can be adjusted; and if the system is not overloaded the job may very well get out on time. Even though critical ratio is one the potentially most accurate techniques available, like MRP it depends on the accuracy of the data available and also on accurate and timely status reporting.

Critical Ratio
Practice Problem

The USMIT Furniture Co. uses critical ratios to determine the order of the jobs at its various work centers. A report is generated each day for each work center and is used by the work center operator. Using the data given below, calculate the critical ratios for each job.

Days till	Order	Work Remaining						Critical
due date	#	Op#1	Op#2	Op#3	Op#4	Op#5	Op#6	Ratio
16	W132	2	4	3	2	2	1	
12	W432		3	4	4	3	1	
23	W765	5	4	4	6	2	2	
6	W123				4	3	2	
16	W089		4	6	4	3	1	
4	W654					2	1	

What order would the jobs be processed in based on the critical ratios?

What order would the jobs be processed in if earliest due date was used? (In the case of duplicate due dates take the jobs in the order given)

SHOP FLOOR CONTROL TERMINOLOGY

Critical Ratio - Priority rule that calculates the ratio of the time available until the due date and expected work time (total lead time) remaining. Items with the lowest critical ratio are in the most danger of being late and are usually given the highest priority.

$$\frac{\text{Time remaining}}{\text{Work remaining}} = \text{Critical ratio}$$

Earliest Due Date - Priority rule that gives the highest priority to the jobs that have the earliest due date. Because it does not consider the amount of work remaining it is usually not as good at avoiding late jobs as critical ratio.

First-Come-First-Served - Priority rule that gives the job first in line priority. It is usually no better than random selection at meeting due dates.

Input-Output Control - A capacity control technique that controls the amount of work dispatched to work centers based on the amount of work completed. For MRP the most important result is probably the control of leadtimes that are critical for the generation of accurate schedules.

Priority Control - The practice of using the relative urgency of jobs to decide the order in which they will be processed. It is important in MRP to adjust the leadtimes of individual jobs that were scheduled based on average leadtimes. Various rules are used such as earliest due date, shortest processing time, and critical ratio.

Queue - The mount of work waiting to be processed at work centers.

Shop Floor Control - The use of information from production activities to monitor and control shop orders and work centers. It includes priority control, work-in-process tracking, input-output control, and data collection for utilization and efficiency calculations.

Shortest Processing Time - Priority rule that gives priority to the jobs that will take the shortest time to complete. In the absence of more suitable techniques it has the advantage of getting the most jobs out in the shortest time.

Slack Time Remaining - Priority rule that gives priority to the jobs with the least amount of slack time remaining. Slack time is defined as being the difference between the number of standard hours of production remaining and the amount of time until the due date. Its primary disadvantage is that it does not consider queue time remaining.

Work-In-Process Inventory (WIP) - The inventory made up of products in their various stages of production. Levels of WIP are usually a primary factor in determining the length and variability of leadtimes. Commonly most WIP is held as buffers against set-up costs, unplanned down time, quality problems, and schedule variations.

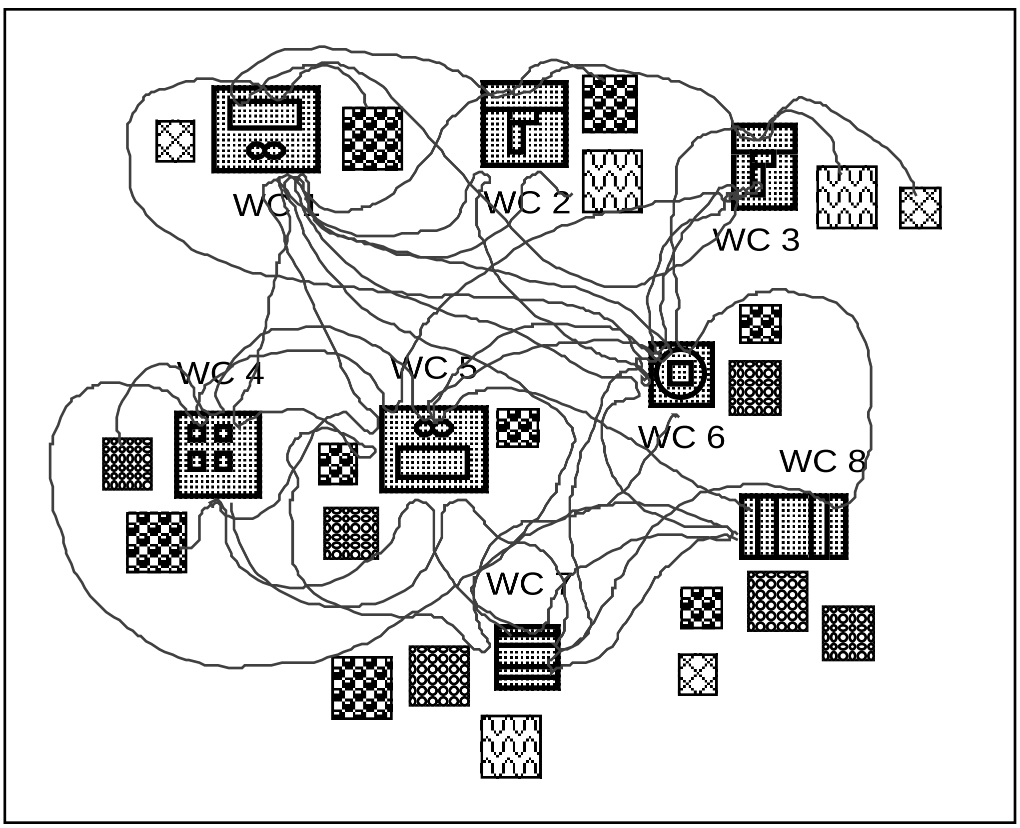
SHOP FLOOR CONTROL REVIEW QUESTIONS

1. Why is shop floor control necessary?
2. What is priority control?
3. What is leadtime control?
4. How is leadtime usually controlled in intermittent production?
5. Why do queues exist at work centers?
6. What are the costs of queues?
7. How does input/output control work?
8. How does priority control help meet product due dates?
9. What are some common examples of priority rules?
10. How does the critical ratio technique work?

WORK CELLS

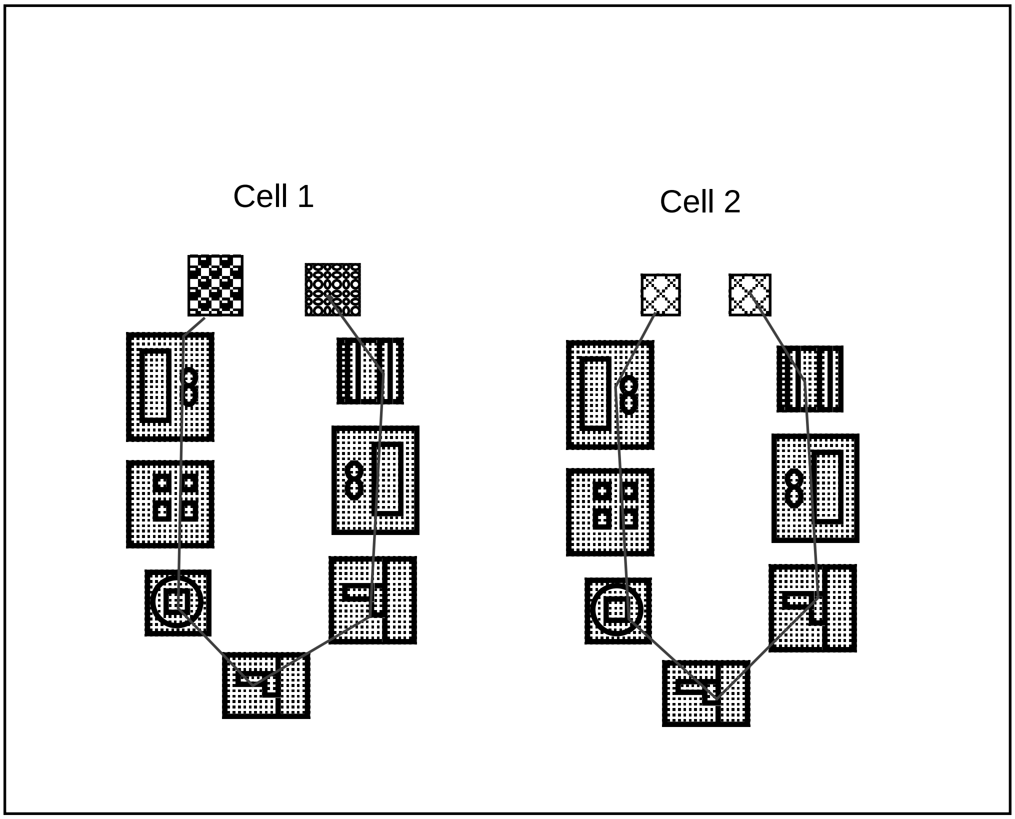
One of the most important changes taking place in many manufacturing companies is the development of work cells. Work cells are made up of closely arranged work centers or machines which operate together as continuous manufacturing lines. Their adoption usually results in dramatic reductions of lead time, work in process inventories, and floor space requirements.

To understand the impact of work cells it is useful to compare them with the traditional intermittent batch manufacturing they are replacing. In intermittent batch manufacturing, relatively large batches (lots) are manufactured according to a master schedule that separates them with batches of other parts or products. The large batches are justified to reduce the per part impact of high set-up costs. The facility usually used for intermittent batch production is arranged into departments of similar machines and processes. Machines usually have several different jobs (batches) in a queue to assure that they will never be idle due to lack of work. A typical intermittent batch system is illustrated below.



In a functionally laid out facility such as the one above, each batch of parts moves a relatively long distance between work centers and waits at each work center while all the batches in front of it are processed. Each part waits for all the batches in front of it to be processed, plus waits for all the parts in its own batch to be processed. The time at each work center is many times longer than the time necessary to process an individual part. A great deal of floor space is also necessary for the queues

The illustration below represents a cellular layout to produce the same parts as above. The machines have been moved very close together and there is only a queue at the end of the cell. Individual parts are processed at each machine, then are passed to the next machine. Inventory is not allowed to accumulate between machines.



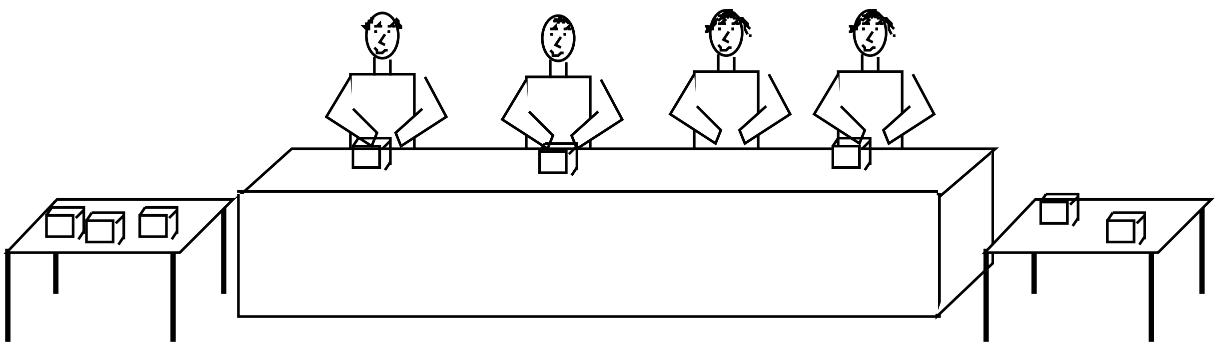
Parts move through the work cell much faster than through the functional layout. They only have to wait for the single part at the next machine to be finished before they can be processed at that machine. Lead time for individual parts can many times be reduced by over 90% when cells are established. Floor space requirements are also much lower because there are no queues between machines.

Establishing work cells requires much more than just moving machines together. The large batches and queues in intermittent batch manufacturing serve a purpose. The large batches reduce the per part cost of set-ups, and the queues maximize utilization by providing a buffer against breakdowns, quality problems, differences in processing times, differences in routings, unpredictable schedules, unreliable workers, etc. To be able to economically change to work cells, those and other problems must be solved.

LINE BALANCING

Line balancing is a production system planning activity which attempts to assign tasks to sequential work centers in a way that efficiency is maximized. Such planning has been important in assembly line continuous production, and is being increasingly used in intermittent production situations as flexible manufacturing systems, work cells, and just-in-time procedures are implemented. All these situations are increasingly characterized by small lots or individual items moving continuously between work centers.

The situation is illustrated in the figure below.



	WS#1	WS#2	WS#3	WS#4
WC Content	20 sec	30 sec	18 sec	40 sec
Cycle Time	40 sec	40 sec	40 sec	40 sec
Idle Time	20 sec	10 sec	22 sec	0 sec

In this situation, the product progresses from left to right along the line, with each work station's required work taking the different amounts of time shown as work station content. Because no build-up of materials is allowed between the work stations, all work stations must hold their part for the 40 seconds required by the station (WS#4) with the longest content time. The time the part is at each station is called the cycle time. The difference between the time the part is held and the actual amount of work time required is idle time which adds cost to the product but which produces no added value. The goal of line balancing is to minimize that wasted time.

As in any area, there are specific terms that relate to line balancing. The following list of terms and definitions are

necessary for a basic understanding:
Production line balancing - dividing the work necessary to produce a product between work stations in a way to minimize the idle time spent in production.

Work station (work center) - the assigned area or operator where a designated amount of work is done. It is commonly identified by major equipment used or the process step performed and may use one or more people.

Work station content - the amount of work (measured in time) performed at a given work station. It is the sum of all the work elements assigned to that station.

Work elements - the smallest reasonable tasks that the job can be broken down into.

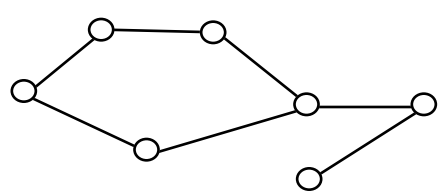
Total work content - the total amount of work necessary to produce the product on the line. It is the sum of all the work elements.

Cycle time - the time the product spends at each work center, also the frequency at which the products exit the line.

Line balancing efficiency - the ratio of the total work content to the actual time the product spends on the line. The sum of the work elements, divided by the cycle time multiplied by the number of stations.

Balancing restraints - any factors in the situation that limit the balancing and therefore limit the possibility of a perfect balance. Restraining factors include such things as the required order of tasks (precedence), required locations at which certain tasks must be done, facility restrictions, and personnel requirements.

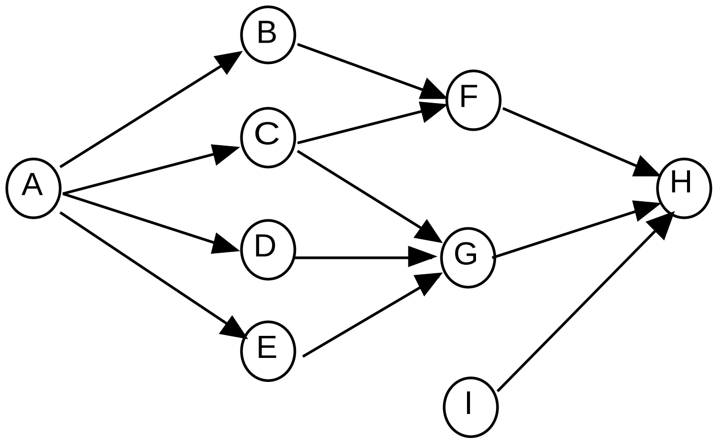
Precedence diagram - a network diagram that illustrates the required order of the tasks.



There are several procedures that are used in line balancing but they are all similar in that they break the problem into a set of less complex decisions that consider only a few work elements at one time. This simplification of the problem is necessary because the lines can contain hundreds of elements that otherwise cannot be systematically considered.

The technique in the following illustration is perhaps the simplest and is called the largest candidate method. The steps in the process are to:

1. Determine the work elements and their times.
2. Determine the required precedence and draw a precedence diagram.
3. Determine the production time available.
4. Determine the required output to meet the production schedule.
5. Determine the theoretical minimum number of work stations.
6. Determine the cycle time to balance that number of stations (this provides a target for station assignments).
7. Determine the maximum allowable cycle time.
8. List the work elements in descending order based on their times.
9. Assign tasks to the work stations by assigning the longest feasible tasks without exceeding the maximum allowable cycle time.
10. Calculate the line balancing efficiency. (The sum of the work elements, divided by the cycle time multiplied by the number of stations.)
11. Attempt to improve the balance by either reducing cycle time or the number of stations.



Element	TIME
A	8
B	19
C	14
D	12
E	8
F	4
G	8
H	10
I	10

Element	Time	Prec
B	19	A
C	14	A
D	12	A
H	10	F,G,I
I	10	-
A	8	-
E	8	A
G	8	C,D,E
F	4	B,C

Req. Output = 20
Time Avail = 480 min
Total Wk Time = 93 min

Min stations = (93 *20) / 480 = 3.88

4 center cycle time = 93/4 = 23.25

Max cycle time = 480/20 = 24

Efficiency = 93/110 = 84.5

Center	Element	Time	Center time
1	I	10	
	A	8	18
2	B	19	19
3	C	14	
	E	8	22
4	D	12	
	G	8	20
5	F	4	
	H	10	14

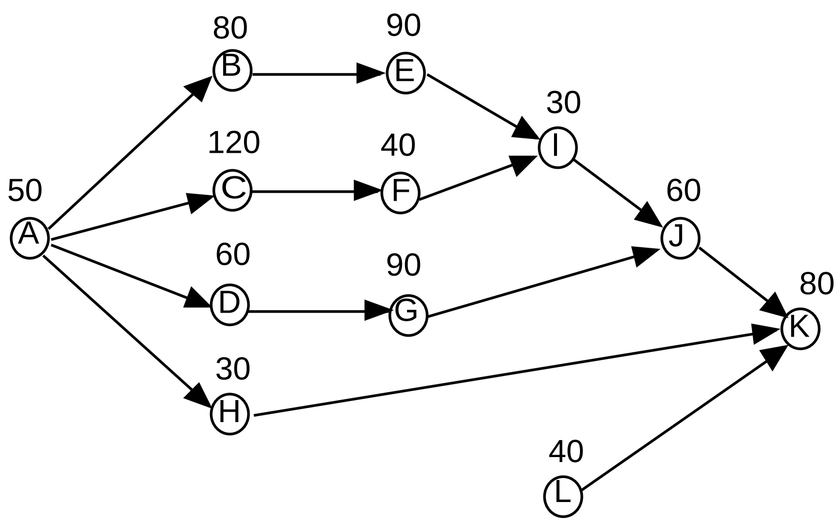
LINE BALANCING REVIEW QUESTIONS

1. What is the goal of line balancing?
2. How does the largest candidate method work to balance lines? (What is the procedure?)
3. What are the data inputs for line balancing?
4. How are the minimum number of stations and maximum cycle time calculated, and what is that information used for?
5. What measure is used to evaluate how well the line is balanced, and how is it calculated?
6. Why is line balancing becoming more important than it has been in the past?
7. What do the line balancing terms in the reading mean?

LINE BALANCING PRACTICE PROBLEM

The USMIT Furniture Company is setting up an assembly line for a new table. They have determined the element times (in seconds) and sequence of elements as shown in the diagram below. Production planning has the task of designing the line to assemble 200 tables in each 8 hour shift.

Your problem is to assign the elements in a way that will achieve the most efficient balance using the largest candidate rule method. Also, determine the minimum number of stations possible, the cycle time to balance that number of stations, the maximum allowable cycle time, and the efficiency of the final line.



INVENTORY CONTROL

In contemporary industry, inventories represent a sizable proportion of assets. It is not uncommon for 50% to 70% or more of current assets to be tied up as inventory. Because of this worth and because of the potential disruptions to production if appropriate materials are not available, the control of inventories is very important. This reading will briefly define inventory, examine its functions, and present a typical control data format.

Inventory is defined by the American Production Control Society as:

> "Items which are a in stock point or work-in-process and which serve to decouple successive operations in the process of manufacturing a product and distributing it to the consumer. Inventories may consist of finished goods ready for sale, they may be parts or intermediate items, they may be work-in-process, or they may be raw materials".

Other definitions of inventories may include supplies which are materials such as cutting oils, repair parts, and cleaning materials that although needed to produce the product do not become part of the product itself.

We can examine the function of inventories further than the "decoupling" of operations, which are commonly called buffer inventories, to include several other functions which suggest approaches to better control and inventory reduction. First of all, <u>buffer inventories</u> are materials stored for varying periods between stages of production to minimize the effects on production of such things as different processing times, set-up times, machine down times, and different production sequences. Even in industries considered to be continuous such as paper making, buffer inventories exist between stages and can be made up of significant amounts of the materials in process.

Another type is <u>order quantity inventory</u> which results from the purchasing or production of more materials than can be used immediately but which lowers the per item procurement or set-up cost. Order quantity inventory may also result when standard quantities are available which do not match immediate production needs. For order quantity inventory, reduction of procurement or set-up costs can lead to lower inventories.

Additional inventories are carried as <u>safety inventory</u>. Safety inventory is inventory carried to protect production from running out of materials because of longer lead times or higher usage rates than expected. They are a particularly expensive type of inventory because on the average they are never used up. Since they exist to protect against variations in usage and procurement lead times, actions to reduce those variations can lead to reduced stocks.

Production leveling inventories serve to permit the constant production of items not in constant demand. Clear examples are highly seasonable items such as snow blowers that must be stock piled prior to winter if they are to meet the demands without major changes in production rates. Reductions in inventories such as these can be made by overall increases in capacity that can be justified by the production of complimentary products such as lawn mowers.

Hedge inventories are carried as a hedge against price increases or interruptions in supply. These factors are many times external to the firm in question, but any action to reduce inflation or supply interruptions can reduce the need for hedge inventories.

In-transit inventories are materials held while being moved from one location to another. They can be reduced by reducing times, quantities, and distances traveled.

A final type is finished goods inventories that are held so that customer demands can be met immediately. These inventories can be reduced by producing to order, reducing lead times, and by better forecasting.

Further functions of inventory could be examined but these are common and serve to demonstrate that an examination of the specific functions of inventories can lead to inventory reduction.

Among the most basic requirements of inventory control is the tracking of inventory to assure adequate but not excessive supplies. An examination of a typical inventory record form serves well to illustrate the basic process and the nature of the data maintained.

As can be seen in the following example, to know what materials are and will be available, it is necessary to track orders when they are placed, when they are received, and when the materials are released to production or sold. Additionally, basic information about the item itself is necessary and can be seen at the top of the form.

When we examine the data entered on this form we see the part both as description and number, the name and address of its supplier, the units its supplied in, the normal time it takes to receive it, and the reorder point which in this case is when our supply drops to or below 36.

The entries below the basic part data track the parts activity. The upper space in the balance column indicates that 64 units have been carried over from the previous record for this item. The first activity was on 6/16 when 18 items were supplied to work order 369 which reduced the balance to 46. Similar activity continued until 6/17 when an order was placed because the balance dropped below 36. That order is shown being received on 6/27 and the balance has been increased to 131. One later action is shown on 7/2 which is a work order for 20, which again dropped the balance toward the 36 that will trigger another order.

This example represents a very simple manual system. Many systems are more complex and in many cases computerized. They all serve the same purpose and require the same basic information.

INVENTORY RECORD

VENDOR *Anco Inc.*
313 N. 48 St
New York, NY

PART NO. 286PD12
UNITS EA
MIN 36
ORDR 100

DES. Small dry top

LD TIME DAYS 10

	ORDERED			RECEIVED			DISBURSED		BAL
DATE	ORDER #	QNTY	DATE	ORDER #	QNTY	DATE	ORDER #	QNTY	
									64
						6/16	WO369	18	46
6/17	PO372	100				6/17	WO258	13	33
						6/20	WO789	2	31
			6/27	PO8765	100				131
						7/2	WO922	20	111

INVENTORY SYSTEM MAINTENANCE

Even though the central function of inventory control is to carry out the materials control cycle of determining material needs, determining what, how many and when to order; preparing requisitions; receiving materials; issuing materials; and keeping records; there are other activities that are important to maintain the inventory system. The list below identifies and briefly describes some of those activities.

Physical inventories - One of the most complex and expensive inventory activities is to physically count the items to maintain the accuracy of inventory records for control, planning, accounting, and tax purposes. These physical counts are often annual events that require that the entire operation be shut down and employees trained to complete the count. The normal activities of the business must be stopped to "freeze" the activities to allow for an accurate count of items that under normal conditions are scattered throughout the physical and information system.

There has however been significant adoption of "**Cycle Counting**" techniques that reduce the disruption of the physical count, reduce costs and improve accuracy. In cycle counting, relatively small groups of items are counted at regular intervals to maintain record accuracy without requiring the shut down of the entire enterprise. The cycle counting frequency differs between items depending on factors such as value, difficulty of maintaining accurate records, and importance to the manufacturing activity. Some items may be counted every week while others are counted every six months or yearly, or any other frequency that serves the need for accuracy.

In addition to reducing the need to shut down the operation, cycle counting also introduces the opportunity to reduce the cost of physical inventories by allowing the count to be done by a small specifically trained team and items to be counted when they are at their minimum numbers, or counted when other "normal" inventory activities such as replenishment takes place.

Another type of cycle counting is the use of **cycle-counting control groups.** These control groups are a <u>sample</u> of representative items that are counted frequently, commonly every week, to monitor the overall accuracy of inventory records and to allow for efficient identification of the causes of record inaccuracies. For example, if a significant inaccuracy is found, only one week's activity for that item usually needs to be examined to determine its cause.

Simplification - Over time as new products are introduced and engineering changes are made, inventories become more complex because of the various versions of current and obsolete products and components on hand. Simplification is the elimination of obsolete and marginal products and components. That reduction of the number of items in the inventory system simplifies the system and reduces cost.

Standardization - As product lines evolve and new products are added, the variety of components increases which adds to the number of different items that must be obtained, controlled, and stored. Standardization of products and components can greatly reduce that variety and therefore reduce cost and confusion. Inventory control usually cannot directly increase standardization, but "design for standardization", clearly specified standards, and part classification and coding systems can.

Part numbering and classification systems - The use of part numbering systems is important to accurately identify and sort parts and products. In the simplest and probably least useful systems the numbers are sequentially assigned as parts are added to the system and are used only as unique identification numbers. More sophisticated systems use numbering systems that classify the parts into families based on characteristics and/or describe important features of the items. These "intelligent" numbering systems appear in several forms such as:

Block codes, in which blocks of numbers are reserved for certain families of items such as where all numbers starting with 1 through 5 are for gears and all numbers starting with 6 through 8 are for bearings.

Significant-digit codes, in which part of the number describes characteristics of the item such as weight, size, or power ratings such as 120/100 being used for 120 volt 100 watt light bulbs.

Mnemonic codes, in which letters and numbers are used to describe features of the item such as LB120V100W for 102 volt 100 watt light bulbs.

Consonant codes, in which the vowels are dropped such as VLV for valves and GRS for gears.

Geometric classification systems, in which the coding system identifies the shapes and sometimes materials of the items.

For a good source of further information on these topics and a detailed listing of physical inventory procedures, see the <u>Production and Inventory Control Handbook</u>, Second Edition, edited by James H. Green, 1987.

ABC ANALYSIS

ABC analysis is a common technique used to prioritize inventories. It has been adapted from work done in Italy around the turn of the century by an Italian economist named Vilfredo Pareto. The technique is sometimes called Pareto analysis in his honor. Pareto conducted a study for his government describing the economic patterns in communities in Italy. As part of his study he observed that much of the wealth was controlled by a small portion of the population while the remaining small portion was controlled by the much larger middle and lower classes. He later published his findings in a journal and generalized the pattern into a theory that states that in many systems there will be a relatively small group of significant items and the majority of items will be of minor significance

In the early 1950’s Pareto’s principle was applied to inventory control and developed into the concept commonly known as ABC analysis. In inventory control, ABC analysis is used to prioritize items by identifying their relative significance (usually financial). The items are many times broken down into three groups which are designated as being A, B, or C.

The classification of items by their value can then be used to designate different control practices for each group that better matches their value and thus the return on control resources used. More control is used for the A items because changes there will have more of an impact on the system then improvements in the the other groups will. Control practices that may differ according to ABC ranking include the frequency of cycle counting, the type of inventory tracking system, ordering procedures, and the status of the person responsible for tracking and ordering the items.

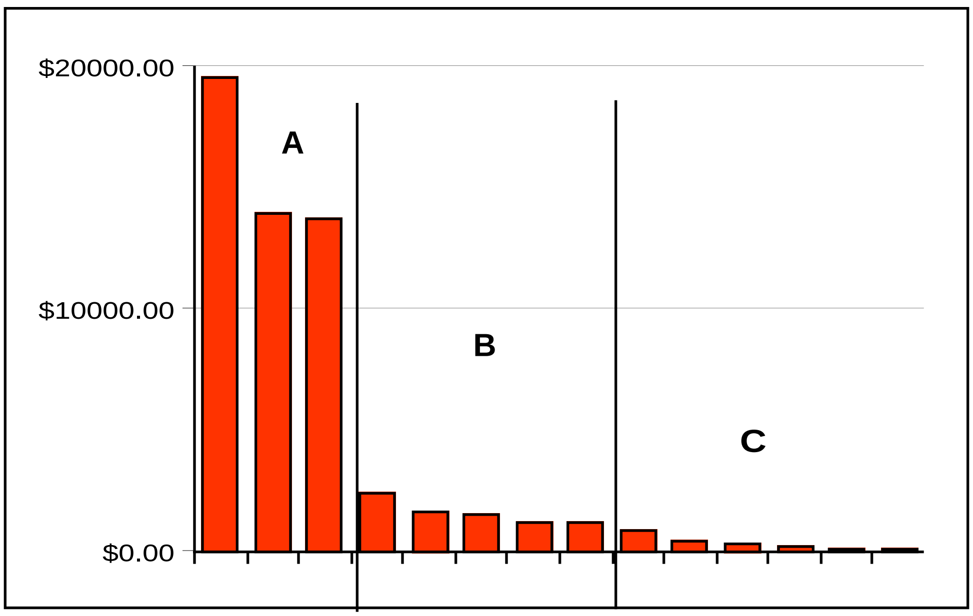
ABC analysis is a generalized concept that can be applied to other situations in industry. It can be used to identify the products that make the greatest contribution to profits, the critical maintenance issues that will be most disruptive to production, the few materials that are most costly to store and dispose of, or the few employees that need the most support. When used in these types of situations it allows for more appropriately concentrated actions to maintain and improve the system.

The following example illustrates the calculations commonly used to determine ABC classification of inventory items. Their classification is based on a ranking of their annual usage value, which is their cost or value multiplied by their frequency of usage. This illustration also shows the percent of the total annual usage value for each class and the percent of part numbers represented by each class.

ABC ANALYSIS

PART	UNITS	UNIT VALUE	ANNUAL USAGE VALUE	% TOTAL VALUE		% PART NUMBERS	% ANNUAL USAGE VALUE
P23	8000	$2.45	$19600.00	34.09%			
G34	682	$20.50	$13981.00	24.32%	**A**	21.43	82.38%
G24	7450	$1.85	$13782.50	23.97%			
K58	1002	$2.36	$2364.72	4.11%			
F34	204	$8.00	$1632.00	2.84%			
G12	634	$2.50	$1585.00	2.76%	**B**	35.71	13.99%
G13	620	$2.00	$1240.00	2.16%			
G23	102	$12.00	$1224.00	2.13%			
H45	256	$3.32	$849.92	1.48%			
P62	324	$1.25	$405.00	0.70%			
F45	234	$1.45	$339.30	0.59%		42.86	3.62%
G56	123	$2.22	$273.06	0.47%	**C**		
G36	30	$4.00	$120.00	0.21%			
P62	48	$2.00	$96.00	0.17%			
		TOTAL VALU	$57492.50				

The graph below illustrates the annual usage value and class of each item.



The designation of A B or C status to the items does not usually follow a rigid percentage, even though the technique is sometimes called the 80/20 rule. There are sometimes natural breaks in the pattern of values that are convenient division points, or sometimes logical breaks by amount, such as at $1,000 and $10,000 are used. In some situations breaks are made based on other logic that fits the situation.

A B C status is not always based on the value of the items. Other measures of the importance of the items to the system may be used. For example, if an item is particularly difficult to obtain it may be classified as an A item even though it is of low cost or infrequent usage. Or if running out of an item is particularly costly it may be classified as an A item.

In some situations more than the three A B C classifications are used to enable a finer degree of distinction. Their may be additional levels such as D and E or there may be classifications within the A B or C categories.

ABC ANALYSIS PRACTICE PROBLEM

As part of their efforts to improve their inventory control procedures, the USMIT Furniture Company is classifying their inventory of parts using ABC analysis. The classifications will then be used to match parts with inventory control and purchasing policies more suited to their financial importance. Using the following data; calculate the annual usage value and the percent annual usage value for each of the items listed. Select A, B, and C classifications, then determine the percent of part numbers and percent annual usage value for each classification.

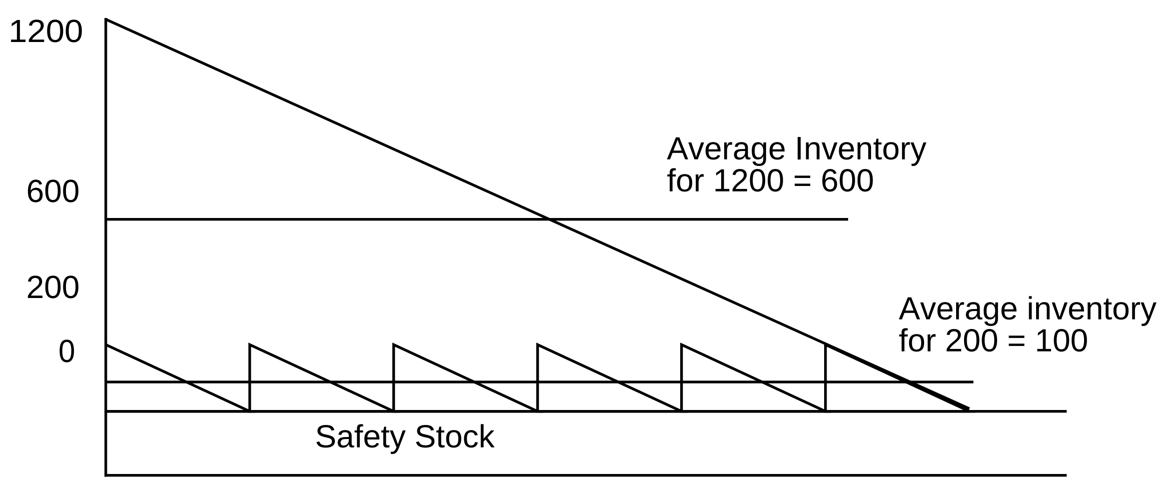
Part #	Item	Units Used	Unit Value
1	Varnish	408 gal	$12.00
2	Caning	2100 sq ft	$0.75
3	Nails	800 lb	$3.45
4	Glue	37 gal	$11.50
5	P.S. Sheet	88 sq ft	$0.30
6	Base Cloth	4800 sq yd	$0.89
7	Clips	5800	$0.08
8	1/4" Board	528 sq ft	$0.48
9	1/8" Board	2600 sq ft	$0.16
10	Stain	220 gal	$6.20
11	Pine	3000 bd ft	$0.89
12	Oak	6500 bd ft	$1.95
13	Walnut	2900 bd ft	$3.20
14	Mahogany	1800 bd ft	$2.20
15	Ash	5200 bd ft	$2.10
16	Birch	12000 bd ft	$1.80
17	Birch Plywood	1480 shts	$22.00
18	Oak Plywood	800 shts	$34.00
19	Pine Plywood	450 shts	$18.00
20	Walnut Plywood	250 shts	$40.00
21	Ash Plywood	700 shts	$30.00
22	#6 Screws	50 boxes	$12.00
23	#8 Screws	62 boxes	$18.00
24	#10 Screws	74 boxes	$22.00
25	#12 Screws	84 boxes	$30.00

ECONOMIC ORDER QUANTITIES

An old concept that is gaining new importance as more efficient (particularly JIT) techniques are being adopted is that of economic lot sizes and economic order quantities. As the new techniques put more emphasis on the reduction of inventory, the understanding and control of the factors that lead to large lot sizes and order quantities have become critical. This discussion will not examine the techniques being used to reduce lot and order sizes, but will examine the classic model used to determine the most economical lot sizes. The move to reduce lot sizes and some of the techniques used to make that reduction economically feasible will be examined later in the course when JIT is discussed.

The economic determination of lot sizes is based on a balance between the procurement or set-up cost of the item and its carrying cost which results in the lowest total cost over time. The classical model discussed here does not consider all currently recognized associated costs or complications that arise when MRP logic is used to generate orders. It is however the basic conceptual model and good discussions are available in the literature that can be used to develop an understanding of modifications to the model to take those situations into consideration .

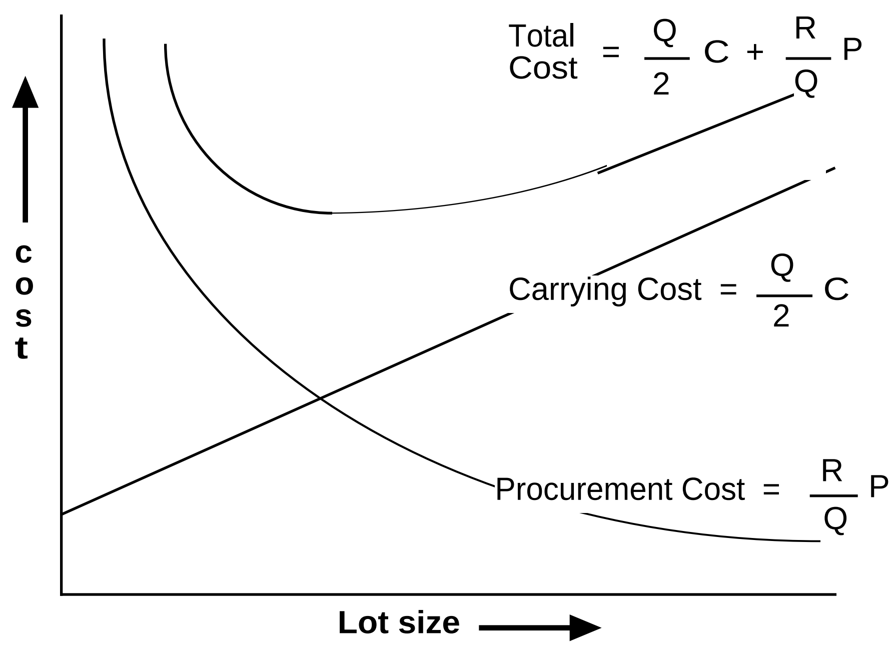
The basic trade-off is illustrated in the diagram below which represents the placing of orders and the amount of inventory carried over time.



In the case illustrated, annual requirements for a component is 1200. The two ordering strategies shown are to order all 1200 at one time or to place 6 orders of 200. Both the placing of orders and the carrying of inventory cost money. It is not uncommon for ordering costs to average $100.00 or more and for carrying costs to average 35% of the value of the inventory. In the case above, it can be seen that if only one order is placed the ordering cost will be minimized, but that a large quantity of inventory will need to be carried - an average of 600 units for the year, if we assume constant usage. If on the other hand we place 6 orders, our carrying costs will be much lower - based on an average of 100 units, but our ordering costs will be 6 times as great as for one order.

The economic order quantity model is a technique that is used to determine the optimum balance between ordering and carrying costs which will result in the lowest total cost (considering the limitations of the model assumptions and data used).

The relationship of procurement and carrying cost to lot size is illustrated in the diagram below. Where R = the annual requirements, Q = lot size, P = procurement cost per order, and C = carrying cost per unit per year. As can be seen, as the lot size increases, the procurement costs go down because fewer orders are placed, but the carrying costs increase because the amount of inventory carried increases. The total cost is the sum of the carrying and procurement cost for each lot size. In this model, the lowest total cost is at the point where the carrying and procurement costs are equal.



There are several methods that can be used to determine the economic order quantity when the annual requirements, carrying cost, and procurement costs are known. It can be determined by calculating the total costs for the feasible lot sizes and then selecting the lowest, the data can be graphed as in the illustration on the previous page, and it can be determined mathematically using the formula:

$$EOQ = \sqrt{\frac{2RP}{C}}$$

For example, if we have an annual requirement of 1000 items, a carrying cost of $.16 per item per year, and a procurement cost of $20.00, we would compute an EOQ of 500 units.

The same answer could be found by calculating the total costs for each possible lot size. The calculations below are of selected lot sizes to illustrate the technique and to show the relationship between carrying and procurement costs as the lot size varies.

Q Lot Size	Q/2 x C Carrying Cost	R/Q x P Procurement	Total Cost
100	8.00	200.00	208.00
300	24.00	66.67	90.67
500	40.00	40.00	80.00
700	56.00	28.58	84.58
900	72.00	22.27	94.92
1000	80.00	20.00	100.00

The same technique is used to determine the economic lot size for manufacturing. In that case the procurement cost is replaced with set-up costs.

In contemporary practice there are several factors that limit the accuracy of this EOQ technique. The model assumes a constant rate of usage, it assumes that the procurement costs will be constant regardless of the number of times the orders are placed, and it does not assure that the EOQs for various components will add up to the number of parts needed for complete assemblies. It also usually uses data that does not consider factors such as the increased exposure to engineering changes, greater variance of leadtimes, greater space needed, poorer forecast performance, and higher expediting costs associated with high levels of work-in-process inventory.

Because of those limitations, several expansions of the classical formula have been developed that take other factors into consideration. It is also assumed by some managers that whatever number the formula gives is too high, and that the reduction of lot sizes should be given high priority such as it is in Just-In-Time.

ECONOMIC ORDER QUANTITIES

PRACTICE PROBLEM

Our USMIT Furniture Company uses approximately 9,000 gallons of mineral spirits at $2.50 per gallon each year. We have traditionally ordered all 9,000 gallons at once. In our attempts to reduce procurement and inventory costs, we would like to use EOQ techniques to examine our current practices. Data available from purchasing and inventory records indicate the following:

1. The mineral spirits are available in lots of 300, 600, 1000, 2000, 3000, 6000, or 9000 gallons. The cost per gallon is the same regardless of lot size.

2. The inventory carrying cost per year is 20% of the direct material cost.

3. The procurement costs are $100 per order.

The Problem:

Determine the EOQ by both the graphical and mathematical methods.

REORDER POINT ANALYSIS

In the area of inventory management, one of the important decisions to be made is when to place orders for parts and materials. The decision is based on the leadtime required to obtain the materials, because the goal is to have the materials on hand when they are needed. A somewhat conflicting goal, however, is to not have too much inventory on hand because it increases carrying costs.

The problem of determining reorder points can be broken down into two separate problems. The first is the determination of the amount of inventory that is expected to be used under normal or average conditions, and the second is the determination of safety stock to provide protection if the rate of usage is higher than expected or if the delivery is delayed.

If historical data is available and if it is assumed that conditions have not changed, the determination of the normal usage during the leadtime is straightforward. The past usages are just averaged. If conditions have changed however, those changes would have to be considered.

The determination of safety stock is somewhat more complex as it deals with the uncertainty of leadtime variability, and the difficult to determine costs of either carrying excessive inventories or not being able to meet production schedules or customer demands.

Several methods have been used historically to determine safety stocks. Standard amounts based either on percentages or time are easy to use and are common. For example if 10% safety stocks are used for all products, we would compute a safety stock of 24 for a product that we expect to use 240 of during normal leadtimes and 50 for a product we expect to use 500 of. If based on time, an additional 24 would be added for two weeks of safety stock if we used the product at a rate of 12 each week and 50 for a product we use at a rate of 25 each week.

Although these methods are simple and do provide some protection from stock outs, they have major weaknesses. Because they attempt to treat all products equally, they don't take into consideration that different products are of different importance and should have different levels of protection. They also don't recognize that the degree of uncertainty in delivery and usage differs between suppliers and products, and therefore actually offer different amounts of protection. These techniques many times result in higher than necessary inventory costs for some products and lower than desired service for others.

Another simple technique is to set order points at levels that assume the worst case and therefore appear to provide total protection. In cases where a stock out of inexpensive items would result in very high costs, this technique might be warranted but in many cases the extra inventory costs will exceed the costs of stock outs, and overall costs will be higher.

Statistical order point techniques applied to individual products are usually better in that they consider various degrees of uncertainty and can be used to determine safety stock levels that provide levels of protection appropriate for individual items. They are however more complex and therefore are more costly to compute and manage.

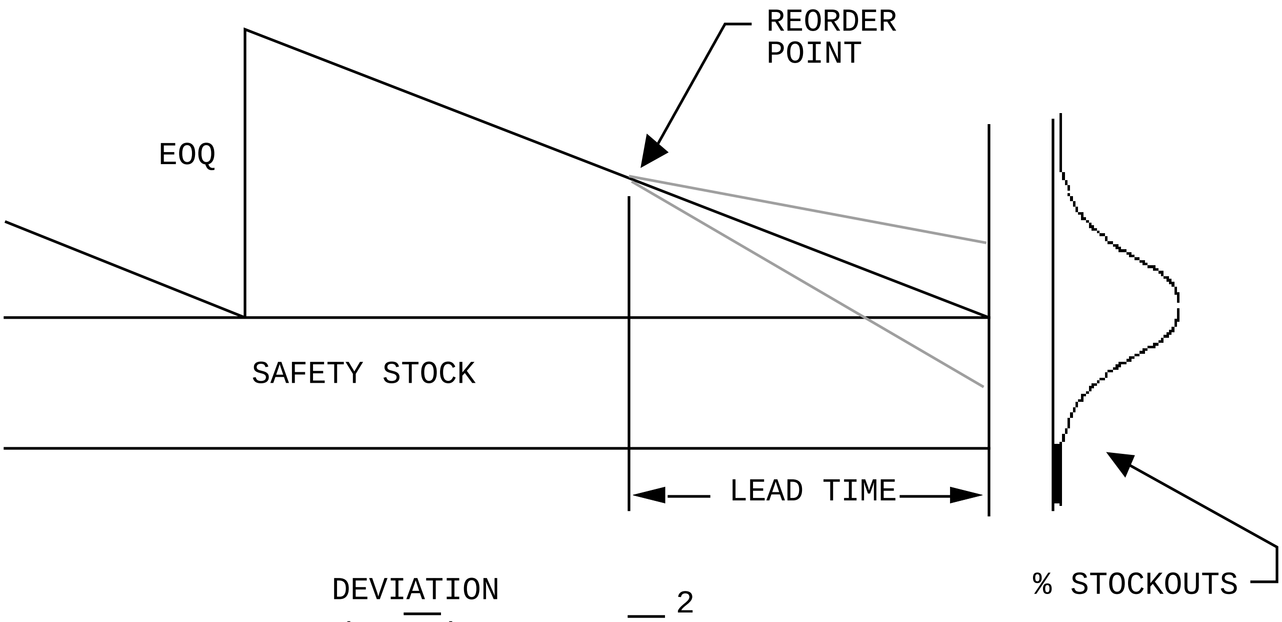
A basic question associated with statistical safety stock techniques is how much protection is desirable? It can perhaps be best considered by realizing that safety stock is insurance against stocking out, and as with all insurance, the balance is between the probability and cost of the loss and the cost of the insurance. In the case of safety stocks it is a trade off between the probability and cost of production losses and reduced customer service and the cost of carrying the extra inventory. The actual dollar amounts may be difficult to determine in many cases, but they can be estimated and can provide a basis for selecting levels of protection.

The following model illustrates a basic statistical technique used to determine safety stocks that takes into consideration the variation in lead time usage and various levels of protection. It assumes that the number of items used during all possible combinations of usage rates and leadtimes form a normal frequency distribution. Because of that assumption, the probabilities of any specific number being required can be determined.

In order to use the probabilities of the normal distribution, the standard deviation (sometimes mean absolute deviations are used) of the number used during leadtimes must be calculated, the degree of protection decided upon, the area under the curve that represents that probability determined, and that distance in standard deviations converted back into the units in question.

In the illustration, the level of protection has been set at 95% (we only want to risk a 5% chance of a stock out). The standard deviation of the number of items used during leadtimes is 111.64, and it has been determined (from a normal curve table) that the area under the curve that represents a probability of 95% is 1.65 standard deviations from the mean. The safety stock is then determined by multiplying the standard deviation of 111.64 by the distance from the mean of 1.65 standard deviations resulting in 184.21 items to be carried as safety stock. The order point is then determined to be 1373.21 by adding that to the 1189 that are expected to be used under average conditions.

For more detailed discussions of using the normal curve to determine probabilities refer to a basic statistics text.



DEMAND	DEVIATION $(X-\bar{X})$	$(X-\bar{X})^2$
1250	61	3721
1200	11	121
1000	-189	35721
1225	36	1296
1150	-39	1521
1170	-19	361
1270	81	6561
1200	11	121
1405	216	46656
1020	-169	28561
11890		124640

$$\sigma = \sqrt{\frac{\sum (X-\bar{X})^2}{N}}$$

$$\sigma = \sqrt{\frac{124640}{10}}$$

$$\sigma = 111.64$$

To achieve a 95% customer service level:

$95\% = 1.65\,\sigma$

$$
\begin{aligned}
(1.65)(111.64) &= 184.21\\
&\,+1189.00\\
\hline
&\ \ 1373.21
\end{aligned}
$$

Safety stock = 184.21

Reorder point = 1373.21

REORDER POINT
PRACTICE PROBLEM

As part of our efforts to cut the costs of our USMIT Furniture Company we are determining the best reorder points of our "A" inventory items. Given the following data on demand for drawer guides for the past 12 lead times, compute the reorder point that will prevent stock-outs 99% of the time.

Demand

810
785
798
804
812
772
794
797
806
800
782
778

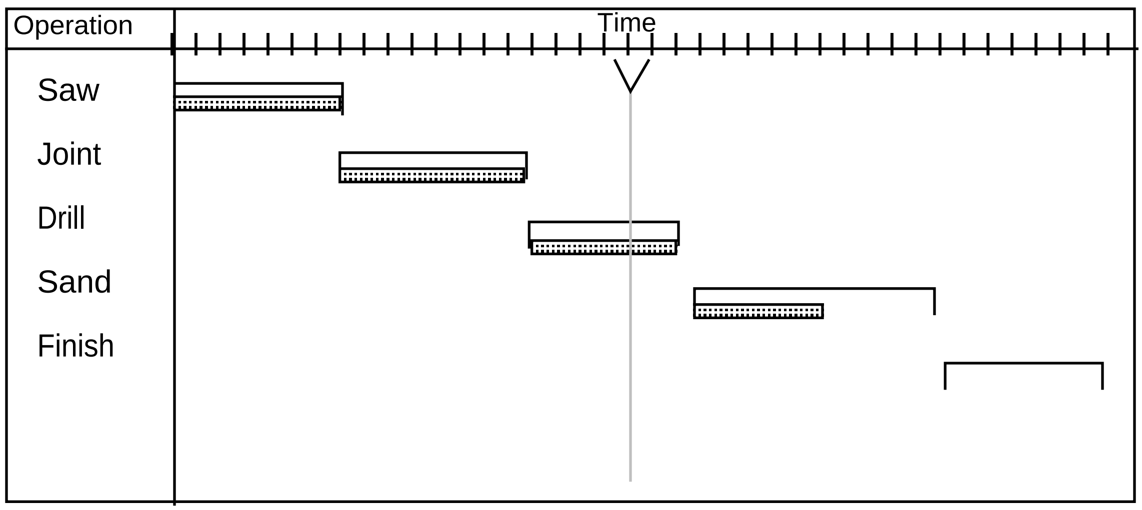
EOQ AND ORDER POINT REVIEW QUESTIONS

1. Economic order quantities are a balance between what factors?
2. Economic lot sizes are a balance between what factors?
3. What are some of the weaknesses of the classical EOQ model?
4. What are typical ordering and carrying costs?
5. Explain the formula (Q/2*C) + (R/Q*P) = Total Cost.
6. What is an order point?
7. What factors go into the calculation of order points?
8. What is the function of safety stock?
9. Why is safety stock necessary?
10. What methods are used to determine safety stocks?
11. What are some of the weaknesses of older "rule of thumb" safety stock methods?
12. How much safety stock protection is best?
13. What is the "normal distribution"?
14. What is a standard deviation?
15. How do areas under the normal curve relate to safety stocks?

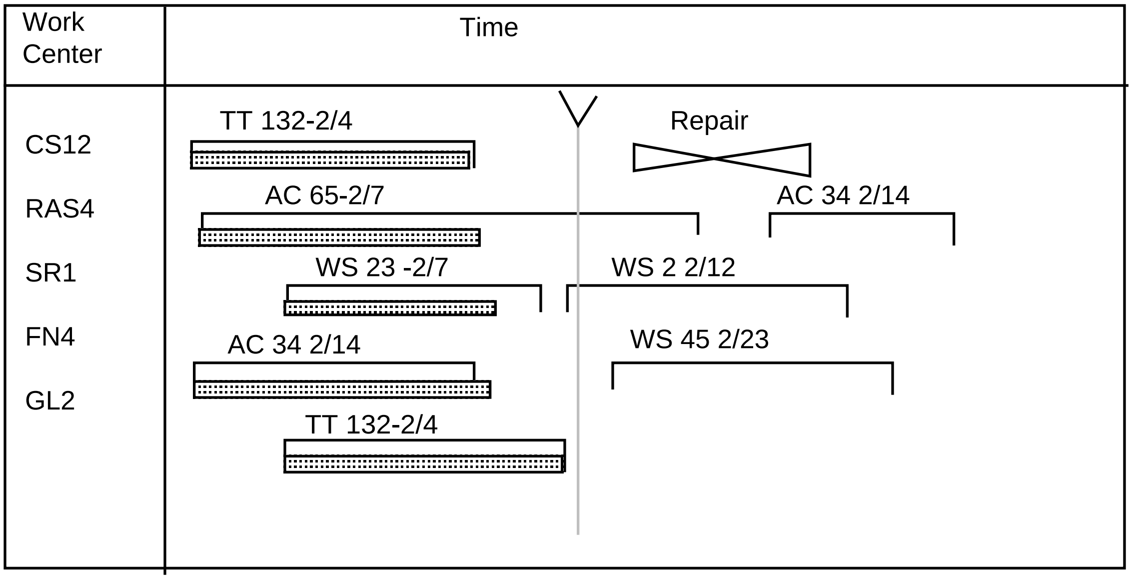
GANTT CHARTS

Gantt charts are perhaps the most commonly used scheduling and loading aids available. They are named after Henry L. Gantt who is given the credit for their development in the early 1900's at the Frankford Arsenal and are considered to be one of the scientific management advances of that time.

Gantt charts are produced using a variety of symbols and are used both for scheduling sequences of activities and loads placed on resources. They are used for a wide variety of loading and scheduling tasks from scheduling manufacturing production and loading work centers to scheduling school buses and research projects. The following examples illustrate scheduling a simple sequence of production operations and the loading of work centers.



In the example above, each operation is shown as scheduled by the empty bracket and the operation as completed is shown as the filled rectangle in the bracket. The dotted vertical line indicates the current day and allows the schedule to be monitored. In the example the sanding operation is in process and the sequence of operations is ahead of schedule.



The loading chart above indicates the load on the work centers listed by time period as well as the order number and the completed work. The double triangle symbol is used to indicate times when the work center is scheduled to be out of service, in this case for repair.

There are several advantages to Gantt charts that make them popular. Their use forces that a plan is made, they can show several features of the situation such as planned times and loads as well as completed activities, they are easily understood with little instruction, they are easily constructed if the data is available, and they lend themselves to both manual and computerized techniques.

PROJECT SCHEDULING USING PERT

As manufacturing and construction activities have become more complex, more sophisticated techniques have been developed to schedule them. For one general class called projects, one of the more powerful techniques available is Program Evaluation Review Technique or PERT.

Project is a term used to refer to activities in which there are relatively few, but complex jobs to be done which are scheduled as being one time efforts. Examples are the construction of buildings, ship building, major overhauls of complex systems, research and development efforts, etc.

PERT as a technique was created for use in the development of the Polaris submarine system in the 1950s and 60s. It has gained much use in a wide variety of industries and other organizations since that time and remains a commonly used and powerful tool. A simple example of the PERT technique is shown later in this section. As can be seen, PERT is a network technique that diagrams activities in a way such that their relationship to each other is shown.

Before examining the calculations necessary, the following terms must be defined:

Activities are the actual tasks that need to be accomplished to complete the project. They take time and use resources. Examples would be erecting a wall or installing wiring. In the network shown, activities are represented by arrows.

Events are the points in time that indicate that given tasks have been completed. In the example, they are represented by small circles.

The **Network** is a diagram of the interrelated activities that shows precedence and which when calculated manually forms the basis for the calculation sequence.

The **Critical path** is the longest sequential path or paths through the network who's accumulated times represent the earliest that the project can be completed. Another way to define the critical path is that it is the sequences of activities that have no slack. Any delay along the critical path can be expected to delay the completion of the entire project.

Slack (Ts) is the extra time associated with non-critical activities, that is, the time between when they can be completed and when they must be completed without delaying the project.

Earliest time (TE) is the earliest time that an activity can be expected to begin or end if all preceding activities have been completed as early as possible.

Latest time (TL) is the latest time an activity must begin or end if it is not to delay the project.

Optimistic time (To) is the time estimate used in PERT calculations that represents the most optimistic time of an activity or the time required if everything goes as well as possible.

Pessimistic time (Tp) is the time estimate used in PERT calculations that represents the most pessimistic time of an activity or the time required if unexpected delays are encountered.

Most likely time (Tm) is the time estimate used in PERT calculations that represents the time the activity is expected to take.

Expected time (Te) is the activity time estimate used in calculating the expected duration of the project. It is a weighted mean time derived by using the formula

$$Te = \frac{To + 4Tm + Tp}{6}$$

The basic procedure for using PERT is illustrated in the following example and consists of:

1. Listing the activities that must be accomplished to complete the project. In the example, letters A-F represent the activities.

2. Listing all immediately preceding activities to identify precedence.

3. Drawing the network, which although not necessary for the following calculations, clearly illustrates precedence and facilitates manual calculations. PERT networks begin with a single event and end with a single event. If there are multiple activities without preceding activities or multiple activities without following activities, their arrows are brought together into single events.

4. Establishing the three times (To, Tm, Tp) by requesting optimistic, pessimistic, and most likely time estimates from those best qualified to provide accurate estimates.

5. Determining the expected time for each activity using the formula

$$Te = \frac{To + 4Tm + Tp}{6}$$

6. Calculating the earliest time (TE) for each event in the network by adding the expected time of each activity to the preceding (TE) and picking the largest (TE) in cases where multiple activities come together. The (TE) of the first event is zero. The (TE) of the final event is the expected duration of the project and has a 50% probability of being met.

7. Calculating the latest time (TL) for each event by working backward (from the end) through the network, subtracting the duration of each activity from the preceding (TL) and selecting the smallest (TL) when multiple activities emanate from the event. The latest time of the final event is equal to the projects (TE).

8. Calculating slack (Ts) for each event by subtracting (TE) from (TL). All activities with (Ts) of zero are critical and are part of a critical path.

At this point, the expected duration of the project has been determined, as has the critical path and expected activity times. Its final date, even though the most likely, does however have only a 50% probability of being met. Further calculations can be made to determine either the probability of meeting other dates or to establish dates with higher or lower probabilities of being met. The example shown illustrates that procedure, with the following steps:

9. Determining the variance σ^2 estimate for each activity on the critical path using the formula

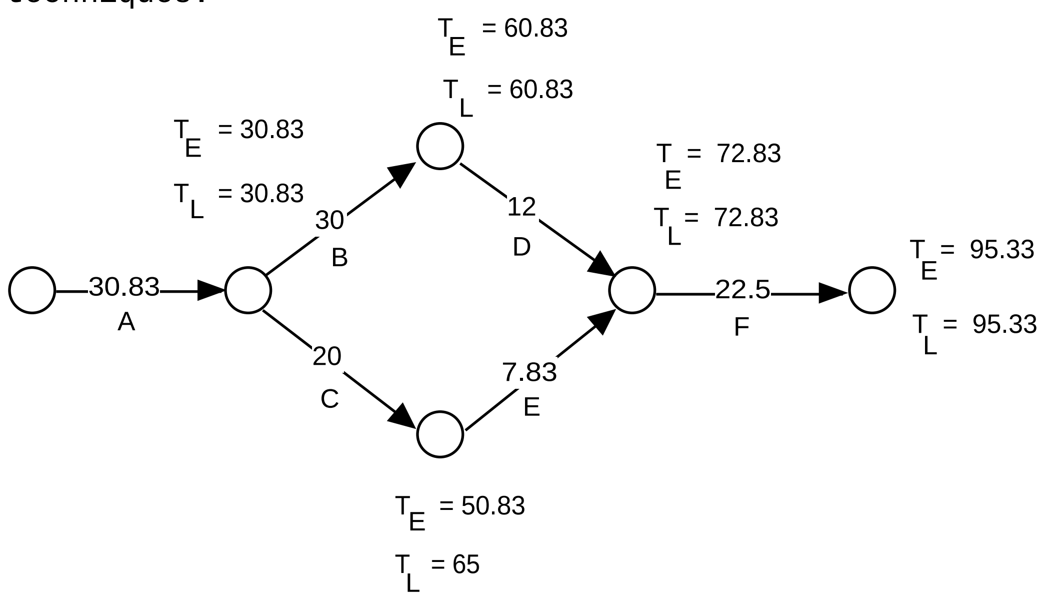
$$\sigma^2 = \left(\frac{To - Tp}{6}\right)^2$$

10. Determining the estimate of the standard deviation of possible ending times for the project by adding the estimated variances for the activities on the critical path, and then taking the square root of that sum.

11. Determining the probability of meeting alternate project completion dates by dividing the difference between the alternate and the expected (TE) completion date by the standard deviation and using the normal curve table to establish probability. In the example, the probability of completing by day 90 is determined by converting the 5.33 day difference to standard deviation units (.899) by dividing by the standard deviation of 5.93. Examination of a normal curve

table (the one included in your readings) indicated that the area represented by .899 standard deviations from the mean is 31.59% of the total area under the curve. The probability of meeting that date is then determined by subtracting the 31.59% from 50% (because areas in the table are given from the mean) and is 18.41%.

As can be seen in the example, PERT is well suited for project scheduling when exact time standards are not available. There are extensions of PERT such as "PERT cost" that consider the cost of each activity and the cost to expedite the activities. Those techniques are useful in calculating the most economical ways to reduce or "crash" the project schedule. The many discussions of PERT in the literature can be used to develop an understanding of those techniques.



Activity	Prec. By	T_o	T_m	T_p	T_e	σ^2
A	-	25	30	40	30.83	6.25
B	A	20	30	40	30	11.11
C	A	15	20	25	20	2.78
D	B	10	12	14	12	0.44
E	C	5	8	10	7.83	0.69
F	D,E	15	20	40	22.5	17.39

$\Sigma \sigma^2 = 35.19$

$\sigma = 5.93$

What are the chances of being done in 90 days?

$$\frac{90 - 95.33}{5.93} = .899\ \sigma \text{ from the mean}$$

$.899\ \sigma$ = .3159 % of the area under the curve

$$\begin{array}{r} 50.00 \\ -\ 31.59 \\ \hline \end{array}$$

18.41 % chance of completion

PERT PRACTICE PROBLEM #1

The USMIT Furniture Company needs to schedule the building and set-up a new machine area. The major tasks are listed below with preceding activities and time estimates. Draw the resulting network, show TL, TE, the critical path, the variance, and determine the probability of completing the project five (5) days earlier than expected. Also determine the date that has a 95% chance of being met.

		Producer Act.	To	Tm	Tp
A	Design facility	-	20	40	50
B	Build walls	A	20	30	60
C	Install equipment	B	18	25	40
D	Order supplies	-	40	60	80
E	Recruit workers	-	20	30	60
F	Train workers	E	20	40	50
G	Evaluate program	C, D, F,	5	7	10

PERT PROBLEM #2

The USMIT Furniture Company is planning to build a new facility to manufacture its expanded line of early American furniture. At this point, the following data has been collected. Using the data, draw a PERT network, determine TL, TE, TS, the critical path, variance, and the completion time with a 90% probability of being met. Also determine the probability of meeting a date 5 days later than the completion date determined through the network analysis.

	ACTIVITY	PREC. BY	To	TM	Tp
A	Layout foundation	-	1	2	4
B	Excavate	A	2	3	6
D	Foundation	B	2	3	5
E	Grading	D	1	1	3
F	Concrete floor	D	1	1	3
G	Deck	D	3	5	6
H	Wall framing	G	5	7	9
I	Ceiling framing	H	2	3	6
J	Roof framing	I	3	4	6
K	Wall enclosure	H	2	3	5
L	Roof enclosure	J	2	3	5
M	Windows & doors	K	5	7	10
N	Utilities	I	6	9	12
O	Interior finish	M	12	16	20
P	Landscaping	E	4	8	10

PERT REVIEW QUESTIONS

1. What are projects?

2. What are the advantages of PERT over earlier Gantt chart techniques?

3. What do the terms earliest time, latest time, and slack time mean?

4. What is the function of the optimistic and pessimistic time estimates?

5. What is the expected time for the project, and what is the probability that it will be met?

6. How does PERT produce schedules under uncertain conditions?

7. What does the variance estimate tell us in PERT?

8. How is a PERT precedence diagram drawn?

JUST-IN-TIME MANUFACTURING

The more Just-In-Time manufacturing (JIT) is examined, the clearer it is that it is not just the arrival of materials at the point they are needed, at the time they are needed. JIT is a philosophy - a reflection of what the Japanese believe manufacturing should be like - that has risen from the fact that Japan is a resource poor nation facing strong competition. It is also a response to strong competition that requires that profits be maintained and increased primarily through cost reductions and not price increases.

JIT philosophy and practice is based on the elimination of all kinds of waste in manufacturing: wasted time, wasted human resources, wasted space, wasted materials, wasted energy, etc. In fact, anything that does not directly add value to the product is seen as waste and is to be eliminated or reduced to the extent possible.

Many elements of JIT have been around for a long time but until fairly recently have not been seen as significant, or have not been integrated into the system in formal ways. The spread of JIT, much of which has been developed at Toyota since World War II, took place during the 1970s after the Arab oil embargo which caused the world economy to turn down sharply. At that time more efficient manufacturing was very important to Japan to retain its international sales levels. From that time the concepts of JIT spread, at first slowly, and then rapidly as its successes were recognized to a point where today it is one of the fastest growing developments in manufacturing.

Before JIT is examined however, it should be pointed out that JIT is not a replacement for MRP, EOQ, order points, or any other topic we have discussed. It is a different way of viewing manufacturing that makes use of those concepts but with different assumptions and priorities.

So then, what is JIT and what are the components that make it so powerful?

JIT is a general approach to repetitive manufacturing that tries to make the best use of resources, eliminate as much waste as possible, and benefit as much as possible from the inherent efficiency of continuous production (assembly line techniques). Its definition of waste, that is anything that does not directly add value to the product, is very powerful because it focuses on eliminating such activities as material storage, material movement, rework, layers of management, equipment set-ups, machine downtime, etc.

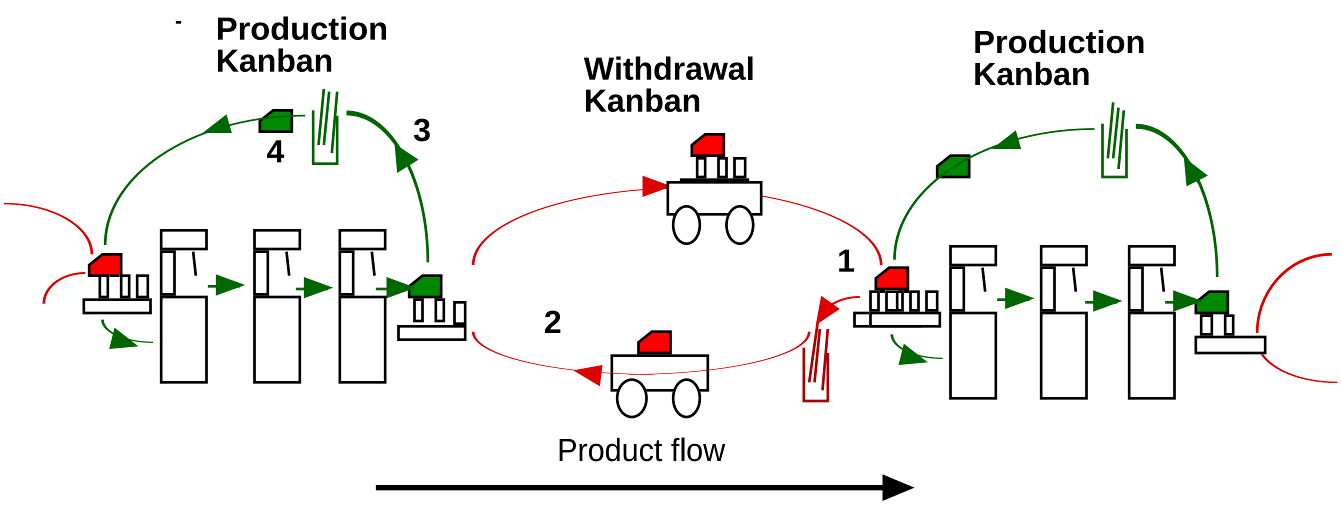
JIT Delivery:

One of the most visible components of JIT, and the one from which it gets its name, is the just-in-time delivery of materials to the factory, to all work centers, and to customers. Instead of materials being delivered to storage and then to work centers in batches of many components, they are delivered one at a time at just the time they are needed which eliminates storage and waiting in the factory.

Kanban:

Another highly visible feature of JIT is the use of kanban. Kanban is the Japanese word for a card or sign, and is used as part of a manual communication system to control the movement of materials through the manufacturing sequence and to rigidly control the level of work-in-process inventory. Instead of schedules, due dates, and traditional priority rules being used to indicate what is to be produced at each work center, a card or kanban space is used to indicate which product is to be produced and to give the authority to produce it.

Kanban is a pull system which means that components are manufactured when the center that receives the component indicates that it has used the previous component and therefore needs another to be produced. If that center does not need components they are not produced, and thus overproduction and waiting lines of components between centers are eliminated. The diagram below illustrates a two card Kanban system used in situations where work centers can not see each other. There are single card systems and systems that use spaces such as shelves to indicate if parts are to be made.



1. When a part is withdrawn from the incoming materials pile for production in the cell, the withdrawal kanban is placed in the withdrawal kanban box.

2. The transporter picks up the withdrawal kanban and takes it to the supplying cell and withdraws the part identified on the withdrawal kanban which is placed on the part withdrawn.

3. At the withdrawal of the parts, the production kanban for the part is placed in the production kanban box.

4. The kanbans in the production kanban box are used to indicate which parts are to be produced, at which time they are placed on the parts.

Stable Master Schedule:

For kanban to work efficiently there are many other system components that must work well. One is the master schedule. It is critical that work centers know what mix of products are to be produced so they can be ready in terms of tools, labor, etc. In JIT, master schedules are rigidly held to and are communicated to work centers. There should be no surprises.

Smooth production:

The mix of products that are scheduled at the master schedule level is also an important factor. In JIT the goal is to produce each product in a one day supply every day. That pattern reduces the need to hold end product inventory and smooths the demand on feeding work centers and suppliers.

Vendor Participation:

JIT is extended out of the factory to vendors so that they deliver components and materials to the plant just in time. To allow just in-time delivery from vendors, they must be considered to be part of the manufacturing process, have access to production schedule information, be able to produce acceptable products, and be treated as partners and not competitors. JIT delivery by suppliers many times also requires the rerouting and redesign of delivery trucks, vendor certification so quality is assured, and life-of-part contracts.

Total Quality Assurance:

Total quality assurance at all stages of production is necessary if JIT is to work. If a part is defective the entire sequence is thrown off. To assure total quality, each work center is responsible for the quality of the parts it produces. If a part is found to be defective, the line is stopped and the problem is fixed. Needless to say, there is a great deal of incentive to produce good parts if a single defect will stop the entire line and the operator who made the mistake is clearly visible. Total quality assurance also eliminates the need for rework, scrap factors, and quality inspectors.

Reduced Set-up Times:

Another factor, the one that allows for the very small lot sizes of JIT, is short set-up times. To allow for the production of mixed products in lots approaching one, the cost of setting up for the production of those parts must be very low (EOQ logic). In many cases lot sizes of one have not been reached, but remarkable progress has been made. For example, at Toyota the pressing department reduced their average set-up times from three hours to three minutes, and in an injection molding department they reduced the time to switch from one fan blade design to another to forty seconds.

Some of the techniques used to reduce set-up times are the separation of internal and external activities, the reduction of the internal ones as much as possible; the elimination of adjustments due to standard tooling sizes and snap-in settings; the elimination of the need for set-ups by the use of standard components and dedicated machines; and the development and use of simplified set-up procedures.

Productivity Groups:

Productivity groups are groups of employees through which workers are trained to identify and solve problems and to take responsibility for continuous improvement. It represents a high level of trust and communication within the factory. As part of the process, suggestions are expected and rewards are given. In Japan these activities take place at a level that is unexpected to the western observer. For example at the Seiki Corporation in 1982, 4900 suggestions were made which was 256 per employee. At another firm suggestions are posted on the bulletin board; all employees are expected to read them and tear them down if they disagree, and if they are up for five days they are implemented. A term used to refer to these types of suggestion and improvement systems is **Kaizen.**

Multi-function Workers:

Japanese workers are trained to higher levels than are many western workers and are trained in several production areas. They are then able to and are expected to meet differing production demands by moving to different work centers as needed. The broad training is also a significant factor in the effectiveness of the productivity groups. Much of the training is done through the productivity groups during production.

Housekeeping:

Good housekeeping organizes the workplace for efficient production and related activities, contributes to worker morale, reduces maintenance requirements, and allows traditionally dirty processes to be located near clean ones and thus allows for more flexibility in the layout of the plant.

Visual Controls:

An activity closely associated with housekeeping is the use of visual controls. Visual controls take many forms such as signs, indicator lights, labels, color codes, instruction sheets, status boards, flow charts, etc. Their purpose is to avoid confusion and delays by clearly indicating what is going on, what is to be done, where things are, etc.

Total Productive Maintenance:

Similar to total quality assurance, total productive maintenance is critical to JIT. If buffer stocks are to be eliminated, unplanned machine downtime must be eliminated and machines must be able to produce quality products. Total productive maintenance goes beyond total preventative maintenance by including activities to increase the service life and dependability of equipment beyond its design capabilities.

Equipment Layout:

In JIT, flow lines are established by using work cells. They are many times set up in a "U" configuration to allow workers to work several stations with a minimum of distance between the stations, and to allow capacity to be changed by adding or reducing workers.

Automation:

Automation is not as important a factor in JIT as is sometimes assumed. Automatic machines are used less in some cases than in western factories. They are used only when a strong need exists, not just because they are available. They can actually increase costs if they don't reduce the total number of workers, increase quality, or increase the efficiency of bottleneck operations.

Autonomation:

Autonomation is an extension of traditional automation that allows the machine to automatically shut down if it detects an abnormality. It allows automatic equipment to run unattended, or attended only as needed to change parts or perform set-ups.

Conclusion:

JIT is an approach to manufacturing that reduces wasteful practices in a wide variety of areas. It was developed in Japan, but is rapidly being implemented in the United States. Japanese culture may have been a factor in it's development, but the many successful implementations in the US demonstrate its much wider applicability.

There are many good books available on JIT and many are worth reading.

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Normal Curve Area From the Mean to Sigma

σ	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	00.00	00.40	00.80	01.20	01.60	01.99	02.39	02.79	03.19	03.59
0.1	03.98	04.38	04.78	05.17	05.57	05.96	06.36	06.75	07.14	07.53
0.2	07.93	08.32	08.71	09.10	09.48	09.87	10.26	10.64	11.03	11.41
0.3	11.79	12.17	12.55	12.93	13.31	13.68	14.06	14.43	14.80	15.17
0.4	15.54	15.91	16.28	16.64	17.00	17.36	17.72	18.08	18.44	18.79
0.5	19.15	19.50	19.85	20.19	20.54	20.88	21.23	21.57	21.90	22.24
0.6	22.57	22.91	23.24	23.57	23.89	24.22	24.54	24.86	25.17	25.49
0.7	25.80	26.11	26.42	26.73	27.04	27.34	27.64	27.94	28.23	28.52
0.8	28.81	29.10	29.39	29.67	29.95	30.23	30.51	30.78	31.06	31.33
0.9	31.59	31.86	32.12	32.38	32.64	32.89	33.15	33.40	33.65	33.89
1.0	34.13	34.38	34.61	34.85	35.08	35.31	35.54	35.77	35.99	36.21
1.1	36.43	36.65	36.86	37.08	37.29	37.49	37.70	37.90	38.10	38.30
1.2	38.49	38.69	38.88	39.07	39.25	39.44	39.62	39.80	39.97	40.15
1.3	40.32	40.49	40.66	40.82	40.99	41.15	41.31	41.47	41.62	41.77
1.4	41.92	42.07	42.22	42.36	42.51	42.65	42.79	42.92	43.06	43.19
1.5	43.32	43.45	43.57	43.70	43.82	43.94	44.06	44.18	44.29	44.41
1.6	44.52	44.63	44.74	44.84	44.95	45.05	45.15	45.25	45.35	45.45
1.7	45.54	45.64	45.73	45.82	45.91	45.99	46.08	46.16	46.25	46.33
1.8	46.41	46.49	46.56	46.64	46.71	46.78	46.86	46.93	46.99	47.06
1.9	47.13	47.19	47.26	47.32	47.38	47.44	47.50	47.56	47.61	47.67
2.0	47.72	47.78	47.83	47.88	47.93	47.98	48.03	48.08	48.12	48.17
2.1	48.21	48.26	48.30	48.34	48.38	48.42	48.46	48.50	48.54	48.57
2.2	48.61	48.64	48.68	48.71	48.75	48.78	48.81	48.84	48.87	48.90
2.3	48.93	48.96	48.98	49.01	49.04	49.06	49.09	49.11	49.13	49.16
2.4	49.18	49.20	49.22	49.25	49.27	49.29	49.31	49.32	49.34	49.36
2.5	49.38	49.40	49.41	49.43	49.45	49.46	49.48	49.49	49.51	49.52
2.6	49.53	49.55	49.56	49.57	49.59	49.60	49.61	49.62	49.63	49.64
2.7	49.65	49.66	49.67	49.68	49.69	49.70	49.71	49.72	49.73	49.74
2.8	49.74	49.75	49.76	49.77	49.77	49.78	49.79	49.79	49.80	49.81
2.9	49.81	49.82	49.83	49.83	49.84	49.84	49.85	49.85	49.86	49.86
3.0	49.87	49.87	49.87	49.88	49.88	49.89	49.89	49.89	49.90	49.90
3.1	49.90	49.91	49.91	49.91	49.92	49.92	49.92	49.92	49.93	49.93
3.2	49.93	49.93	49.94	49.94	49.94	49.94	49.94	49.95	49.95	49.95
3.3	49.95	49.95	49.95	49.96	49.96	49.96	49.96	49.96	49.96	49.97
3.4	49.97	49.97	49.97	49.97	49.97	49.97	49.97	49.97	49.98	49.98
3.5	49.98	49.98	49.98	49.98	49.98	49.98	49.98	49.98	49.98	49.98
3.6	49.98	49.99	49.99	49.99	49.99	49.99	49.99	49.99	49.99	49.99

$$f(x) = 100 \int_0^z \frac{1}{\sqrt{2\pi}} e^{\frac{(x-0)^2}{2}} dx$$