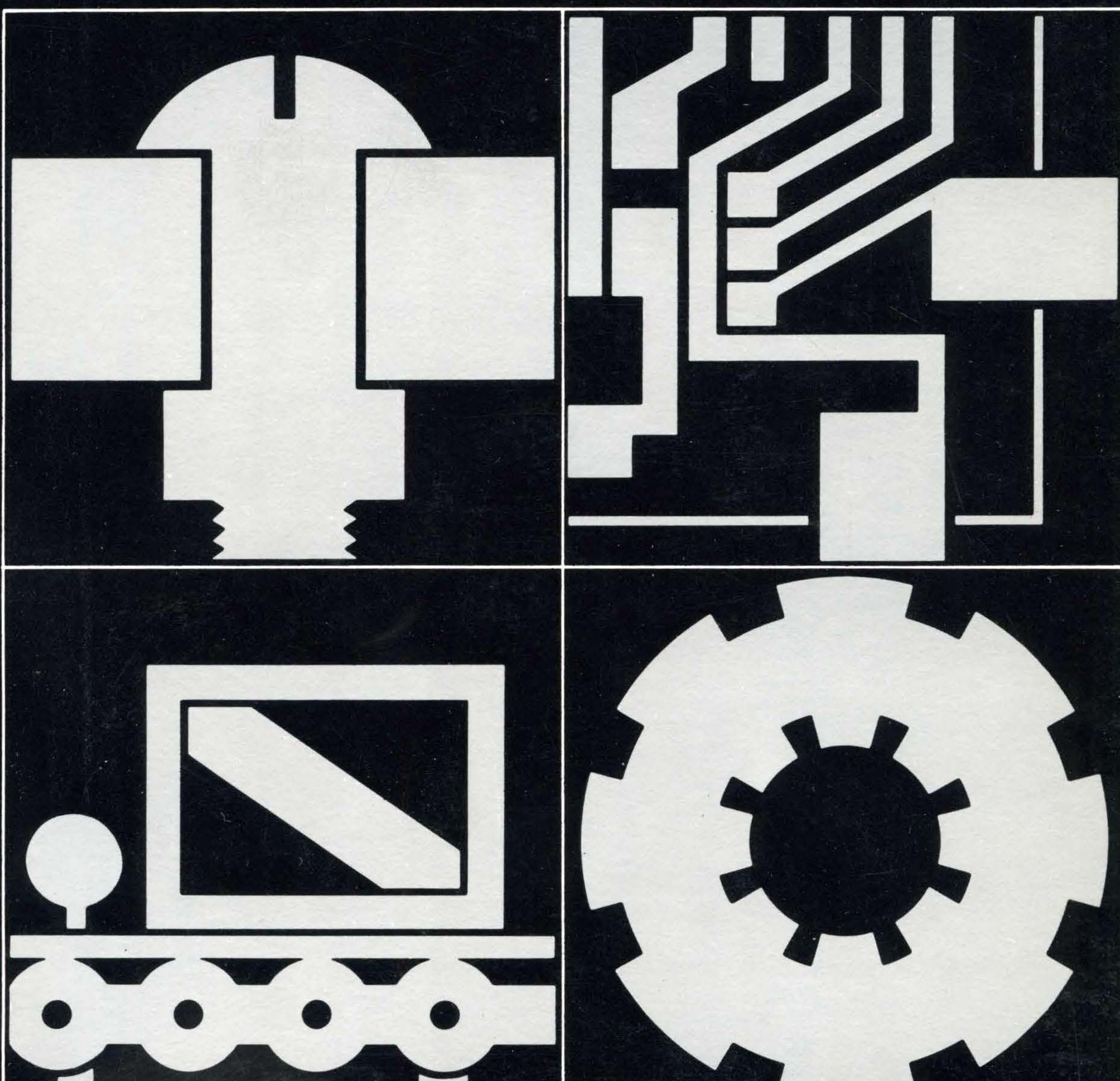
IBM

Communications Oriented Production Information and Control System

Volume III

Chapter 3 Forecasting
Chapter 4 Master Production Schedule Planning



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Foreword

COPICS (Communications Oriented Production Information and Control System) is a series of concepts that outline an approach to an integrated computer-based manufacturing control system. The concepts deal with problems common to most companies, from a forecast of customer orders, through development of the master production schedule, to production and shipment of the product. COPICS is involved, therefore, with allocation and control of most of the major resources of a company – plant, equipment, manpower, and materials.

COPICS evolved from the approach to manufacturing applications presented in the IBM publication *The Production Information and Control System* (GE20-0280). In COPICS those applications are defined from a communications point of view and have been expanded in scope.

The twelve COPICS chapters provide management with a guide for development of a dynamic online manufacturing control system that is terminal and communications oriented and event responsive. The chapters present the system's concepts in a manner designed to help develop a system that can truly respond to the requirements of all levels of operating personnel and management. Little knowledge of computers is assumed, although some prior exposure to computer concepts and familiarity with such terms as "program", "files", etc., is helpful. Emphasis is on what the problems are and *why* their solution is valuable. How specific problems are solved is discussed only at that level of detail required to assure managers that the solution is feasible. The computer is not, itself, the system, but is, rather, a tool to be used by the manager.

The COPICS concepts are oriented to production and related manufacturing applications. They are not concerned directly with other major areas, such as finance, marketing, and personnel, although the COPICS approach collects data that will be helpful to these areas.

Throughout the COPICS publications, distinction is made between a given COPICS concept, the corresponding chapter, and the corresponding plant department by the use of small capital letters, italics, and initial capital letters, respectively. For example, reference may be made to the COPICS concept PURCHASING AND RECEIVING, or to material in *Chapter 10, Purchasing and Receiving*, or to the plant departments called Purchasing and Receiving.

The complete system is presented in eight volumes containing, in all, 17 sections. The Management Overview section is also available as a separate publication, G320-1230. The contents and IBM order numbers of the eight volumes are as follows:

Volume I	G320-1974	Management Overview, System Requirements, Index, Glossary
Volume II	G320-1975	Chapter 1 Engineering and Production Data Control
		Chapter 2 Customer Order Servicing
Volume III	G320-1976	Chapter 3 Forecasting
		Chapter 4 Master Production Schedule Planning
Volume IV	G320-1977	Chapter 5 Inventory Management
Volume V	G320-1978	Chapter 6 Manufacturing Activity Planning
		Chapter 7 Order Release
Volume VI	G320-1979	Chapter 8 Plant Monitoring and Control
		Chapter 9 Plant Maintenance
Volume VII	G320-1980	Chapter 10 Purchasing and Receiving
		Chapter 11 Stores Control
		Chapter 12 Cost Planning and Control
Volume VIII	G320-1981	System Data Base

To obtain the complete set of eight volumes please order the IBM Bill of Forms number GBOF-4115.

Chapter 3. Forecasting

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Introduction

Any business decision involves some kind of forecast. Most business forecasting, however, has not been formalized. It is an educated guess, or "prediction", based on personal experience, as to what will happen in the future. A decision to hire extra employees, for example, may result from an estimate that production will continue to increase; a decision not to replenish stock may be based on an assumption that the current inventory level is sufficient for several periods.

Forecasting, as presented here, is a formalized projection of the pattern of actual past events into the future; that is, it involves some historical data as a basis for future projection. This projection may be modified by forecasts of general economic conditions, competitive activity, and so forth. The purpose of this chapter is to demonstrate how use of computers and their ability to utilize mathematical techniques can improve the accuracy of forecasting.

The role of the computer

No machine, of course, can replace the judgment, capability, and experience of the human planner. When only a small number of items are concerned and where only a limited number of factors have to be taken into account, a human forecast tends to be more accurate. When a large number of forecasts are to be made, however, as in manufacturing planning, computer forecasts are significantly more accurate.

This improved accuracy results from the computer's ability to analyze a vast amount of data, to make the large number of calculations required, and to recognize trends and seasonal patterns, all especially difficult tasks for the human forecaster. Nor can a human forecaster attempt to retain and effectively weigh the large volume of past data that must be taken into consideration in making even reasonably accurate forecasts. He tends to go with his more recent experience; that is, if his last forecast was too high, the next will tend to be too low. Computer forecasting systems do not overreact to the unusual or novel event. They balance the need to reduce wide fluctuations in demand on production facilities with the need to meet real changes in demand from changing customer requirements, and they can process these frequent changes in demand patterns that normally make manual reanalysis too costly.

The more advanced mathematical techniques, sometimes applied to improve accuracy on very important items, are generally too time-consuming to be calculated manually. Many of these techniques have become practical only because of the computer's speed.

Changing economic conditions require that forecasting models be frequently revised. In most companies this means revising thousands of forecasts each month. The forecasts are used on a daily basis by all sections of the system. For example, alterations to end product forecasts are immediately passed to the planning system responsible for ordering material and planning changes to capacity. Computer systems can process the forecast changes fast enough to avoid many of the material shortages and late order situations resulting from the delays imposed by manual forecasting systems.

One possible danger with computer forecasting systems is the tendency to accept the forecast without question. The role of judgment in forecasting cannot be overlooked. Therefore, the system is used to modify its own projections, easily and quickly, on the basis of a human judgment factor.

Scope of forecasting

A large number of forecasting methods have been published. While many of these can be valuable in particular situations, none is foolproof in all situations. This chapter presents some basic forecasting techniques that apply in most of the situations in manufacturing control. No attempt is made to list all forecasting approaches applicable to manufacturing control.

The objective is to remove some of the mystery surrounding the basic techniques of forecasting. The discussion is intended for the managers of the various manufacturing systems who utilize forecasts, rather than the professional forecaster or technician who helps in forecast development. The approach presented may oversimplify for reasons of clarity. The techniques presented, however, are those in common use today or those presenting understandable solutions to specific manufacturing problems.

Approaches to forecasting

There are three approaches to forecasting:

- Composite of expert opinion
- Intrinsic forecasting
- Extrinsic forecasting

In practice, a final forecast may be a combination of all three types.

composite of expert opinion

Developing a composite of expert opinion entails asking the people closest to the market for their estimate of future demand. People polled are usually top executives, salesmen, or customers.

The primary advantages of using the opinion of experts are simplicity, speed, and their knowledge of such special conditions as competitive activity, pricing changes, etc. When a new product line is being introduced, this may be the only reasonable method, since past performance data is not available. However, the approach has several drawbacks:

- It costs valuable executive time – provided the executives take the time in the first place.
- Opinions may change. (If asked at different times, one executive may give two different estimates.)
- Because some executives are more expert than others, there is the problem of weighing and averaging opinions. This is apparent to companies who have obtained forecasts simultaneously from top management and salesmen or customers and have tried to reconcile them.

  Salesmen, although close to the market, have historically been inadequate forecasters. Generally, they tend to be too optimistic, or, if paid according to performance, too pessimistic. A vast difference also has been found between what customers say they will buy and what they actually order.
- Because it takes time to obtain data from salesmen or customers, the results are often out of date. If the number of items is large, opinion forecasts are difficult to make and the experts cannot afford the time required to do a good job.

Because of these problems, forecasting exclusively by "expert opinion" is normally not satisfactory. It can be measurably assisted by statistical techniques. The problem of modifying computer forecasts for conditions that can be effectively estimated only by knowledgable executives is addressed in "Applying Judgment Modifications to Statistical Forecasts".

intrinsic forecasting

The intrinsic forecasting approach can be used to forecast both individual items and groups of items. It assumes that the best way to tell how an item will behave in the future is to look at its past behavior. Figure 1 represents the four basic steps in making an intrinsic forecast:

- Obtain a sufficient quantity of high-quality, historical demand data.
- Using statistical methods, determine a forecast model (in the example, a straight line) that best fits past demand data. This method is called regression analysis.

- Project (or extrapolate) the line into the future.
- Revise the forecast as new demand data becomes available.

extrinsic forecasting

Extrinsic forecasting assumes that the relationship between demand and some external factor (say, housing starts) will hold into the future and that a forecast of the external factor can therefore be used as a basis for a demand forecast. This approach is more appropriate for larger groups, that is, product lines, than for individual products – for example, all children's clothes, all investment castings, all small motors, all drilling machines. It can, however, be applied to individual major products. The higher expense of developing extrinsic forecasting models normally limits its use to a few groups.

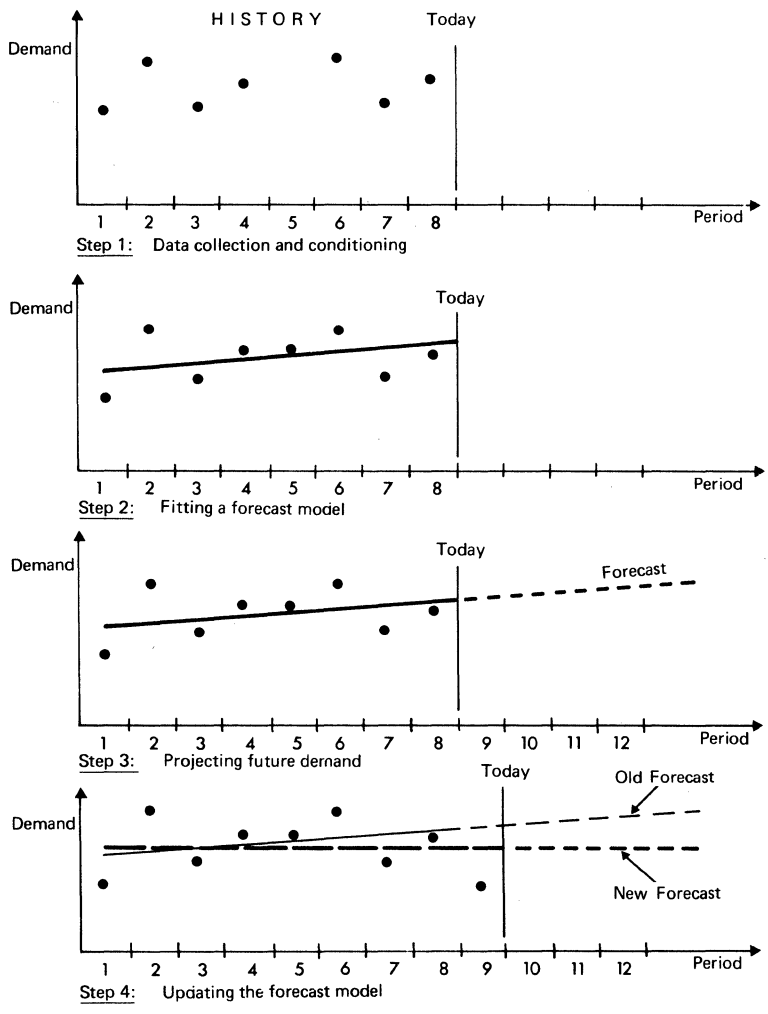


Figure 1. The four basic steps of intrinsic forecasting

Figure 2 represents a plot of the relationship between the number of housing starts and the demand for carpeting. The assumption is that the number of housing starts affects, or "causes", demand for the product group. Each point represents past demand for one period for that number of housing starts.

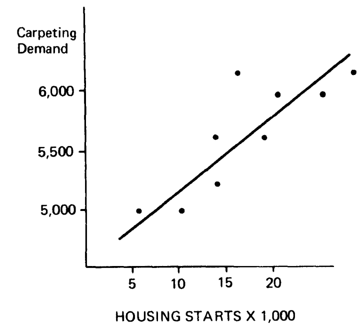


Figure 2. An example of extrinsic forecasting model

Extrinsic forecasting methods are similar to those used in intrinsic forecasting, in that the following steps are involved:

- Obtain a sufficient quantity of high-quality past demand data and associate it with one or more economic indicators for the same period.
- Using regression analysis, fit a line through the data. The output of the analysis will reveal whether there is a significant association between the indicator and demand.
- Make a forecast of the economic indicators or use those supplied by the responsible authority. Then, using the relationship established in the above step, convert the forecast of the indicator to a demand forecast.
- Monitor and revise the model to reflect changes in the relationship.

Objectives of Forecasting

Forecasts are never perfect. The only thing certain about a forecast is that it will be less than 100% accurate. Despite the progress in developing forecasting techniques, there is still no infallible way to predict the future. However, the system does improve forecast accuracy and there are significant economic savings in being more accurate. More important, the system measures how accurate past forecasts have been. The measure of forecast error is used in making effective planning decisions.

The economic impact of an inaccurate forecast is significant. If resources are allocated on the basis of forecast of future demand that is consistently too high:

- Inventories of finished goods will increase. This may deplete the company cash resource and force a reduction of inventory at unfavorable prices.
- Excess physical capacity may be acquired, thus increasing the overhead rate and reducing profit margins.
- The labor force may ultimately have to be reduced. This would disrupt company-employee relations and could result in increased labor rates in later wage negotiations.

If the forecast is consistently too low, and resources are not obtained to meet demand:

- Customer demand will not be satisfied. As a result, customers will change to other suppliers. If this change becomes permanent, it will result in a loss of profit.
- Production facilities will be severely overloaded in an attempt to catch up with demand. The result is increased expediting costs and overtime expenses. Some work may have to be sent outside, increasing subcontract costs and material handling costs, and increasing production lead times.

plans business buffers on the basis of forecast error

The output of forecasting is a projection of what will happen in the future – that is, an estimated quantity of demand for some future time period. When actual demand becomes known, it can be compared with the forecast. The difference between the forecast and actual demand is called "forecast error". In most cases, the amount of forecast error is distributed around an average value of "zero" error, in a pattern known as a "normal frequency distribution" (see Figure 3).

Figure 3 shows that the most frequent error was zero (no error). The next most frequent errors fell between plus and minus one MAD unit. Large errors appeared very infrequently.

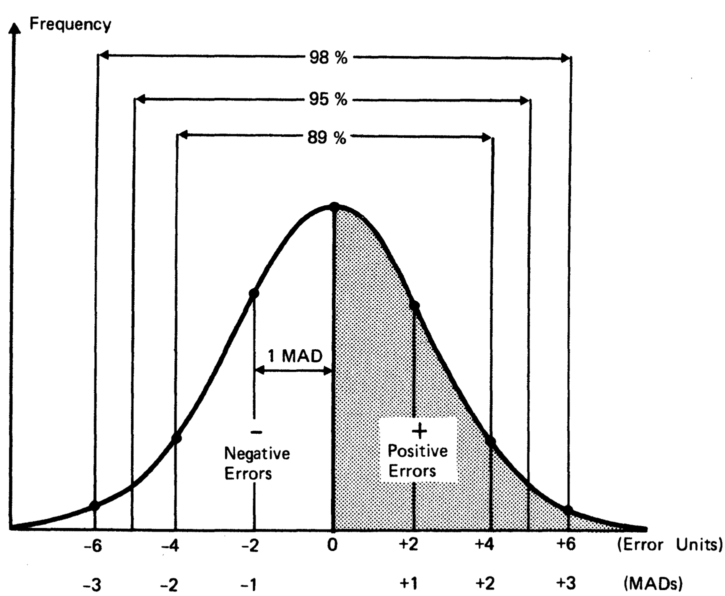


Figure 3. The distribution of forecast error

Using a statistical measurement called "mean absolute deviation" (MAD), it can be said that in about 89% of the cases, the error will not be greater than ±2 MAD, and that in 98% of the cases the error will not exceed ±3 MAD.

The forecasting system described in this chapter automatically calculates a frequency distribution of error for all forecast items; that is, each item has its own particular distribution. How the error distribution is used can be illustrated by an inventory example.

Using the sample error distribution in Figure 3, if the forecast were for 100 units, it could be said that in 98% of all periods, the demand would not be more than 106 units or less than 94 units (that is, 98% of the time, the error would not exceed ±6 units). Therefore, if the inventory were to cover most of the demand for the period, there would have to be a buffer of six units over and above the 100 forecast.

If there were a wider distribution of forecast error, as shown in Figure 4, a larger inventory buffer would have to be maintained. In this distribution, it would take a buffer of 30 items to assure that inventory could cover demand 99% of the time (98% covering ±3 MAD, plus 1% for the negative error in excess of 3 MAD). Therefore, the distribution of forecast error has a large impact on the required inventory level.

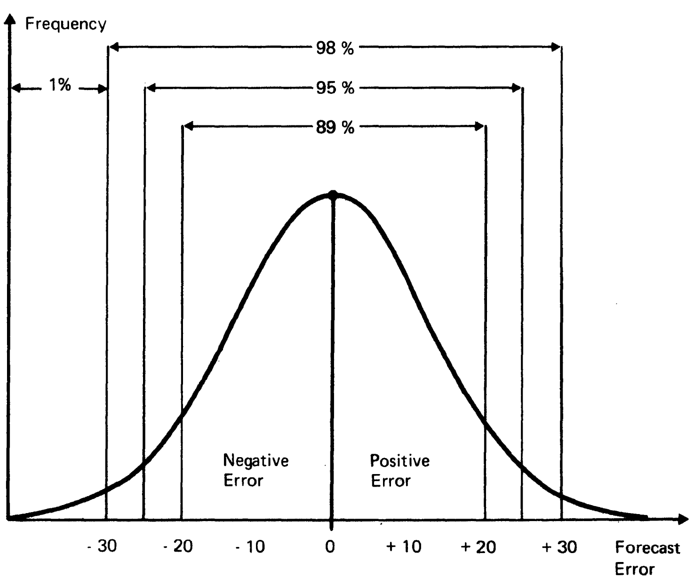


Figure 4. The larger the forecast error, the larger the buffer needed

The system uses this measure of forecast error to help to establish buffers in many production areas. As already indicated, the more error in the forecast for end products, the higher the planned level of inventory required to meet possible high demand (see *Chapter 5, Inventory Management* for more detail).

The same error measurement technique is also used to determine:

- The amount of extra (buffer) lead time needed to assure on-time delivery
- The amount of work to release to the shop floor to make sure machines do not run out of work – that is, how much "queue" buffer is needed in front of each machine
- The number of extra (buffer) pieces to start on the initial machining operation to assure a particular yield after the final operation – that is, a scrap allowance
- The amount of machine downtime (buffer) to allow for in planning utilization of available capacity
- The amount of tool usage (buffer) to allow before tool replacement, regrinding, and so on

The major uses of statistical forecasting and forecasting error measurement are detailed in the particular sections in which they apply.

Improved forecasting techniques reduce the amount of forecast error. When error is reduced, the business buffers maintained to absorb the forecast error can also be reduced. This means less inventory, fewer stockouts, etc.

applies simple techniques in most cases

The more elaborate mathematical models proposed by forecasters are safe to use only if they are thoroughly understood and known to apply to actual conditions. Simple forecasting techniques frequently provide results nearly as good as the more complex techniques, which may cost more to operate than can be justified by a marginal improvement in accuracy. As long as forecast error (MAD) is measured and used correctly by the planning system, the impact of forecast inaccuracy on company operations is minimized. The advantage of simple approaches is that they can be understood by nontechnical personnel, are less expensive to implement, and therefore can be applied in the wide number of cases required in production.

Few items in inventory, few finished products, and very few management standards are important enough to justify the expense of elaborate forecasting techniques.

Figure 5 illustrates a typical distribution by value of demand for one class of inventory. It says that 80% of the value of demand is caused by only 20% of the items in inventory. Most manufacturers do not believe this until they perform an analysis of their own stock movements. However, history has proved the principle to be amazingly accurate. From company to company the percentages may vary, but the fact remains that most of the demand comes from a small number of items. The more advanced forecasting techniques, if used at all, should be reserved for those 20% of the items representing 80% of the demand.

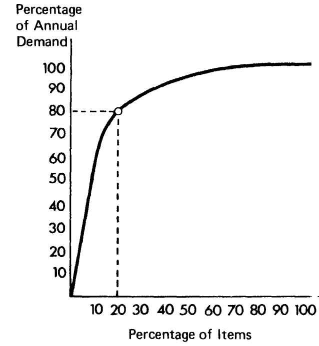


Figure 5. Elaborate techniques should be reserved for high demand items

Forecasting functions addressed

The basic forecasting functions outlined in this chapter are summarized in Figure 6. They include:

- Data conditioning, which points out historical data problems such as missing data, extremely high or low points of demand, etc.
- Forecast model selection techniques that find the best way to represent consistent patterns of demand, thereby improving forecast accuracy.
- Procedures used to forecast items with unusual demand patterns. This includes low sporadic demand (items with periods of zero demand).
- Projection of future demand by time period for as many periods as required by the planning system using the forecast.
- Adjusting of individual item forecasts to coincide with forecasts of the item's group – for example, forecasting of options to agree with the forecast of the product on which the option is used.
- Application of life curves that modify the longer-range projections on the basis of the history of similar items, increasing the accuracy of long-range forecasts and new products.
- Easy application of judgment factors, which allow management to correct for the effect of one-time occurrences known in advance (such as sales contests, new product announcements, market expansion, pricing changes, etc.).
- Forecast model maintenance techniques that cut down forecasting costs by reducing the need to store volumes of historical demand data.
- Monitoring procedures which assure that the current forecast models continue to apply and which minimize manual intervention.
- Development of forecast models based on economic and other business factors external to the business (extrinsic forecasting).

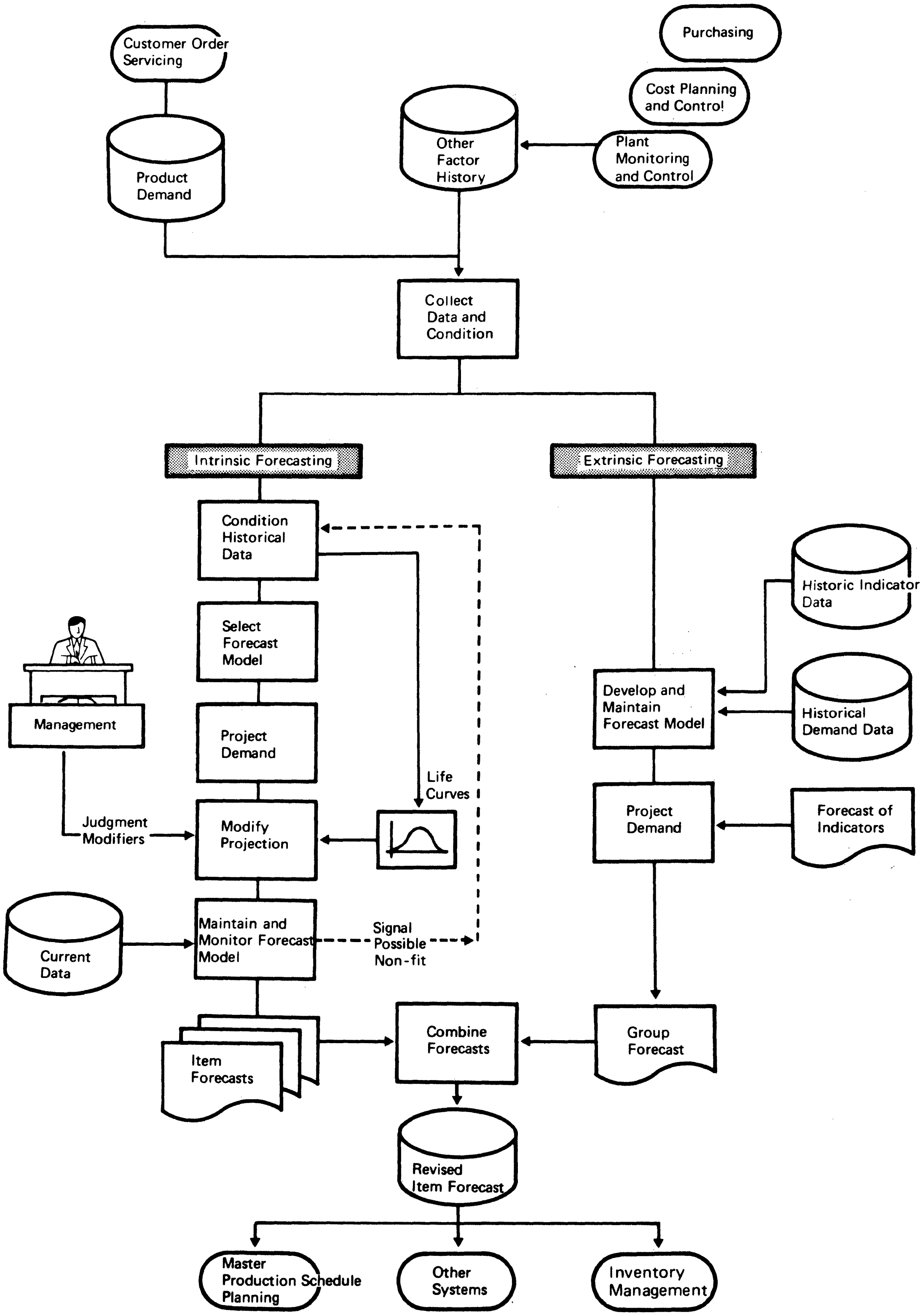


Figure 6. The basic functions addressed in this chapter

Relationship with other areas of manufacturing

Formalized forecasting is used in many areas in manufacturing, one of the most important being the development of the master production schedule (Figure 7). This is a schedule specifying planned production for future time periods.

MASTER PRODUCTION SCHEDULE

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PRODUCT A	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
PRODUCT B	800	800	800	800	810	870	830	840	820	810	800	800	800	800	800	
PRODUCT C	130	132	134	136	135	141	144	147	150	153	156	160	164	168	172	
PRODUCT D	100	0	0	0	0	100	0	0	0	0	0	100	0	0	0	
PRODUCT E	0	0	0	0	0	0	500	0	0	0	0	0	0	0	500	

Figure 7. The development of a master production schedule is one of the most important areas in which forecasting is used in manufacturing

All manufacturing companies develop and maintain some form of master production schedule. The creation of such a schedule is addressed in *Chapter 4, Master Production Schedule Planning*.

On the basis of this schedule, detailed plans are made concerning the acquisition of materials, manpower, and other production facilities. How these details are developed is discussed in *Chapter 5, Inventory Management* and *Chapter 6, Manufacturing Activity Planning.*

The interrelationship of other sections of the overall system is summarized in Figure 8. The detailed plans developed provide sufficient lead time to obtain the necessary components, raw materials, and production capacity needed to implement the production plan. If the forecast is unrealistic, costly replanning, expediting, and late customer orders result.

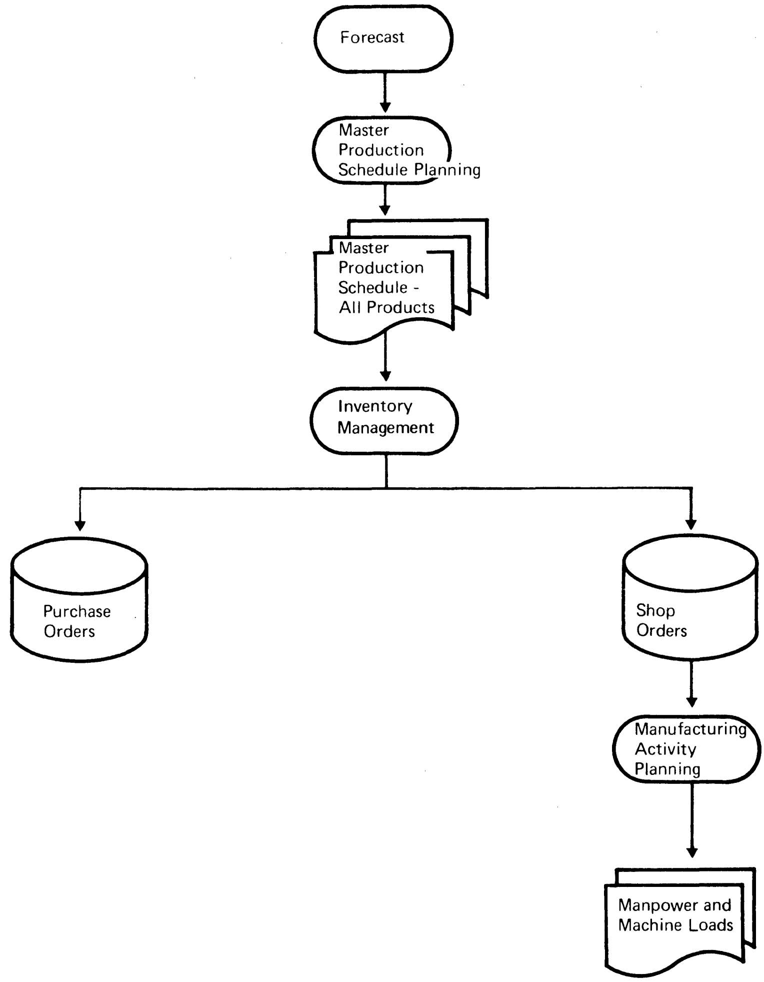


Figure 8. Forecasting serves as the basis for the development of detailed material and manpower planning

Many of today's specialized products are modifications of some standard product – modifications designed for a particular customer. Normally, manufacturers cannot wait until the receipt of the order to start production, so they stock lower-level components, subassemblies, and raw materials in anticipation of future orders.

In Figure 9 the total manufacturing lead time for this product is 30 periods. However, the delivery quoted to customers is nine periods. This means that the component and subassembly buildup, nine to thirty periods before delivery date, must be based on orders expected to be received later. The anticipation of future orders is the job of forecasting.

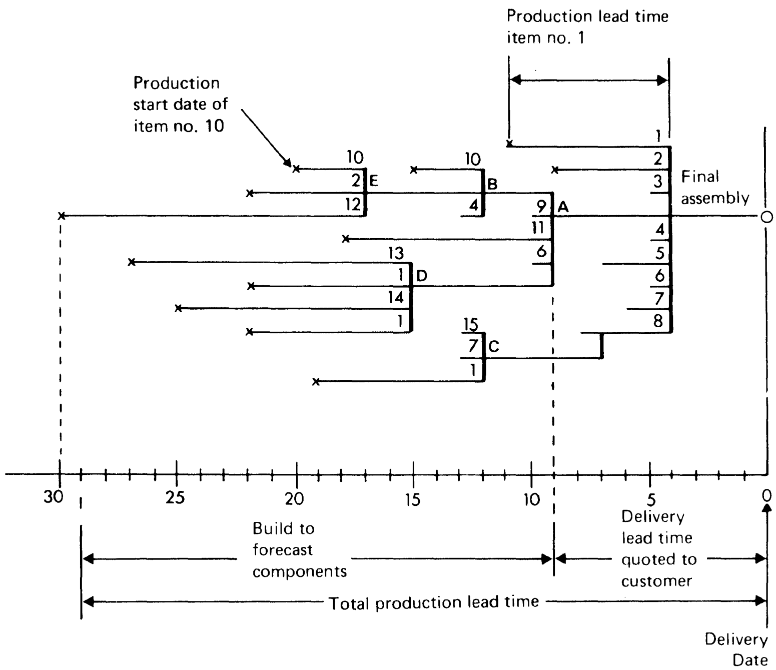


Figure 9. Short lead times require that the requirements for lower-level components and subassemblies be forecast

use of forecasting in manufacturing control

The use of forecasting techniques in production systems is not limited to end products. The following list outlines some of the areas in which forecasting can also be used. These are summarized in Figure 10.

- *End products.* Major emphasis is placed on forecasting end product demand. This is because of its impact on the detailed materials and capacity planning systems. End products include major finished assemblies, service parts, supplies, or other items furnished directly to the customer.
- *End product variations and options.* The end product and its variations are forecast independently. A variation includes such things as 110 V or 220 V power supply, right- or left-hand doors, with or without air conditioning, etc. The variant forecast is then combined with the end product forecast to assure that a sufficient level of variations is stocked to produce the required number of end products.
- *Maintenance parts and supplies.* Here demand is generated from within the production system. The forecast covers lubricating oils, filters, spare parts, etc.

- *Indirect supplies.* This includes demand for cutting tools, gauges, grinding wheels, etc. The "demand" is generated on the basis of a wear rate dictated by end use. Office supplies could also be included.
- *Miscellaneous demand.* This includes demand for production items required by other departments – for example, Product Engineering, Product Testing, Development.
- *Management performance standards.* These include a large number of items found in all manufacturing companies – for instance, component scrap factors, work center labor efficiency, cost trends, and machine downtime. These items are forecasted because they impact the size of purchase and manufacturing orders, or affect manpower planning, production scheduling, etc.

  In fact, forecasting techniques can be more widely used in developing management performance standards than in any other area. These performance standards are essential if true "management by exception" techniques are to become a reality; (for more detail see "Establishing Management Standards" later in this chapter).

Demand on Inventories	
Forecast	Not Forecast
End products Service parts End product variants Maintenance parts Indirect supplies Disposable tools	Component parts Jigs and fixtures Gauges Production equipment use
Management Performance Standards	
Forecast	Not Forecast
Labor efficiency Scrap factors Tool wear Rework load Machine downtime	Standard product cost Work center load Cash requirements

Figure 10. Forecasting can be used in a large number of areas in manufacturing

Forecasting should not be applied in all situations. If demand is "dependent" upon previously forecasted data or can be developed from existing data, forecasting should not be used.

when to forecast

The best example of this point in manufacturing is the relationship between a component part or subassembly and the finished product on which it is used. The demand for the finished product may be relatively regular (see A in Figure 11). However, the finished product is rarely produced at a rate equal to its demand, but instead is produced in some economical lot size (see B in Figure 11). Therefore, it is the assembly of the product, and not product demand, that creates the component demand. The demand for the component is not very smooth; it is lumpy. That is, there are periods of zero demand and periods of high demand. The demand is dependent upon the production schedule of the finished assembly (see C in Figure 11). For this reason, forecasting techniques do not work very well with most component parts and subassemblies. How to determine component part demand is addressed in *Chapter 5, Inventory Management.*

Other information dependent upon previously developed information includes the machine load on work centers, which can be accurately developed from the planned shop orders generated by INVENTORY MANAGEMENT. Jig and fixture demand is also dependent on when planned shop orders are scheduled. Cash requirements can be developed using projected accounts receivable from CUSTOMER ORDER SERVICING, projected accounts payable from PURCHASING, and projected labor costs from MANUFACTURING ACTIVITY PLANNING.

It must be emphasized that forecasting is not, in itself, planning. For example, the forecast may be 10,000 units and current production capacity may be only 9,000 units. A plan must be established to increase capacity to accommodate 1,000 more units, or potential business will be lost. How such planning can be assisted by the computer is addressed in *Chapter 4, Master Production Schedule Planning.*

relationship of forecasting and planning

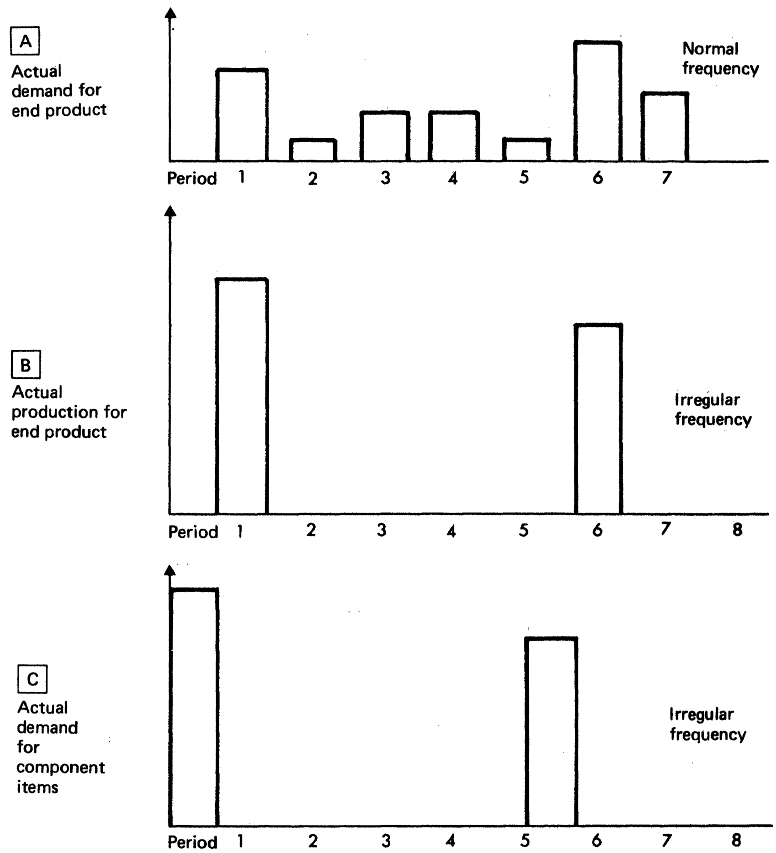


Figure 11. The demand for component parts may be irregular despite regular demand for the end product

Intrinsic forecasting systems are widely accepted. The vast majority of forecasting applications used in manufacturing control are based on intrinsic forecasting models. They assume that what has happened in the past will continue to happen in the future.

All forecasting techniques are somehow associated with historical events. Even informal estimates are based on the forecaster's past experience in similar situations. When forecasting new items, the projection is based, at least in part, on the past performance of similar items.

There are four basic elements of intrinsic forecasting:

- Obtaining the historical data required for analysis
- Determining the forecast model that best fits past demand data
- Using the developed model to make a projection of future demand
- Maintaining the forecasting model as new demand data becomes available

Historical Data Requirements

The basic requirement for intrinsic forecasting is the existence of historical demand data. As this data is collected, the following points should be considered:

- The data should represent sales demand, not just shipments.
- The more data collected, the better the results of the forecasting model.
- Attention should be given to the length of the time period (for example, week or month) for which data is collected.
- The data must be reviewed and conditioned to eliminate unusual patterns such as those caused by sales contests.

Sales versus demand data

"Demand" refers to a customer's request for a quantity at a specific delivery date. For several reasons the shipment and sale may not be recorded until some time later.

For example, if an out-of-stock condition occurs, sales may be transferred from one time period to the next. This artificially creates high and low periods of demand and distorts the true demand pattern.

Unrealistic demand patterns can also be introduced when management artificially extends or shortens the sales order booking period for a few days in order to increase or decrease sales for a period. For example, if orders in May are running higher than expected, management may decide to place sales for the last days of May into June. This will help ensure a good month in June, but will distort the demand pattern.

Care must also be taken that orders with deferred shipping dates are handled correctly. In this case, the demand must be placed in the period when the shipment was requested and not in the period when the order was received.

Demand may not be accurate in situations when orders are sometimes placed orally. In out-of-stock situations, a lost sales reporting system has to be created so that this demand can be reflected.

The effect of these distortions in demand is to increase the forecast error and consequently the business buffers and associated expenses needed to absorb the fluctuations.

Therefore, demand data must usually be carried separately from sales data.

In reality, most companies have only sales or shipment data available when initializing the forecasting system; that is, they do not normally have data on the actual *demand*. The system can use such data in analyzing and establishing an initial estimate of the trend and seasonal demand pattern. However, if the historical data is suspect because of a high incidence of possible demand distortion, the data should be dropped as soon as a sufficient volume of correct demand data can be gathered.

Amount of demand data required

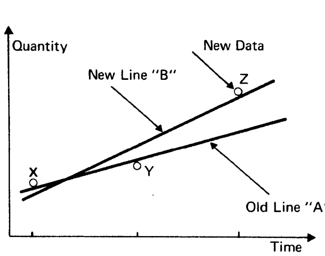


Figure 12. The effect of new data on a forecast

Line A in Figure 12 represents a forecast line developed from only two data points, X and Y. When data point Z is added, the direction of the line is changed dramatically. With few data points there is very little confidence in the direction the line actually takes. As data points are added, the direction of the line becomes more stable and there is more confidence that the line represents the true situation.

The conclusion is that the larger the quantity of data, the more confidence can be placed in the forecast, provided there have been no significant changes in the marketplace.

How much data is actually required varies from item to item. The general rule is: the more, the better. For less important items, seven data points would be sufficient if the forecast results were manually reviewed carefully. For more important items, 12 observations is a practical minimum. If the product is subject to seasonal demand, that is, if it always sells better in the spring than in the summer, then at least two years' data is required. However, seasonal demand patterns can sometimes be developed with less data (see "Forecast Model Development").

Effect of period length on the forecast model

The period length selected has an effect on the forecast model. One year's demand can be divided into either 52 weeks, 13 four-week periods, twelve months, or four quarters.

Care must be taken not to make the time period either too short or too long. Figure 13 shows the effect of the period length. In situation A, demand was accumulated for a four-week period. The resultant demand pattern is very level. In situation B, demand was accumulated by weekly periods. The real fluctuations in demand are more apparent. Since much of the planning of business buffers is based on the size of the fluctuation, care must be taken not to level out the fluctuations by forecasting with periods that are too long.

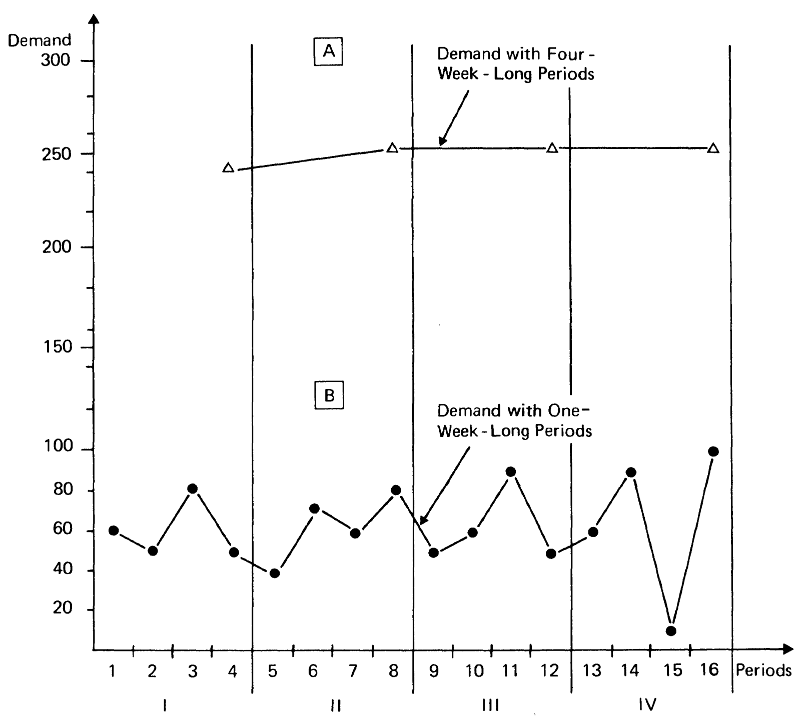


Figure 13. The effect of period length on fluctuations in demand

If periods are too large – say, yearly – significant seasonal patterns can be missed; if they are too short – say, weekly – deviations in demand will vary significantly.

Data conditioning

One of the important roles of the system is to edit the large volume of historical data when first setting up the forecasting system. Before attempting to determine a forecast model, all demand data is subject to the following checks:

- Is there sufficient demand data? If not, the initial forecast values have to be set manually.
- Is data present for all periods? If some periods are missing, the system can substitute an average of the periods on either side of the missing periods.
- Are there periods of very unusual demand, caused, for example, by a large nonrecurring order? If some are detected, they can be replaced automatically by an average demand figure.

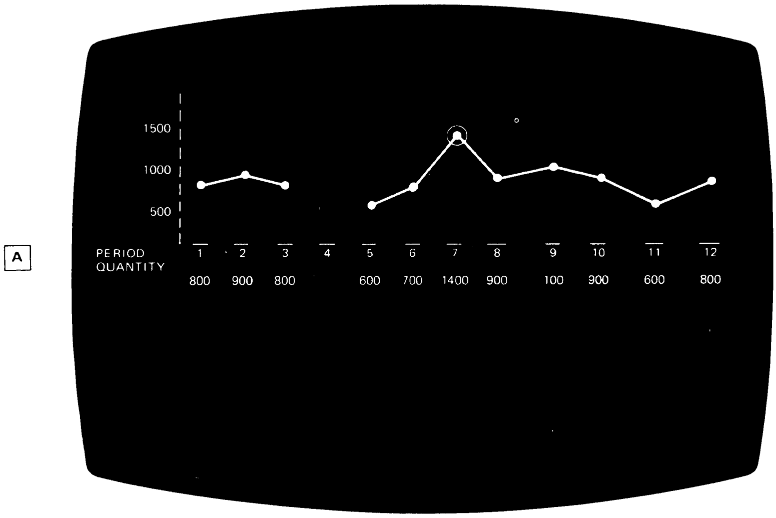
For important items, terminal displays of historical data can assist in conditioning data. In the case of missing data or exceptionally high or low data (Figure 14A), the forecast analyzer can substitute demand values that may be more realistic than the averages automatically substituted by the system. Terminal displays may reveal demand patterns in which it is obvious that certain periods of data should be rejected.

In Figure 14B, for instance, periods 1 and 2 may be rejected because they represent the introductory period of the product. In Figure 14C, periods 5 to 7 may represent the results of a special promotional program and therefore should not be included in later forecasts. The forecast analyzer can substitute whatever values he feels are appropriate, direct from the terminal.

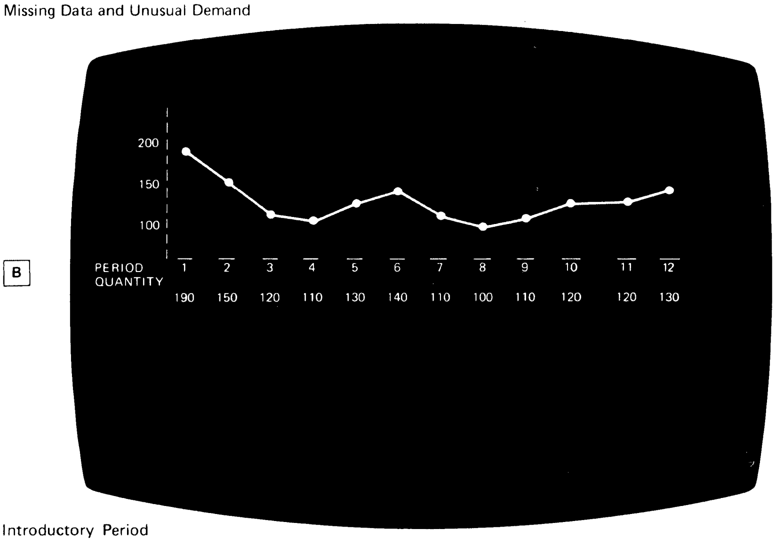
Forecast Model Development

Once a sufficient quantity of historical demand data has been gathered and conditioned, the second step of intrinsic forecasting, developing the forecast model, can be taken.

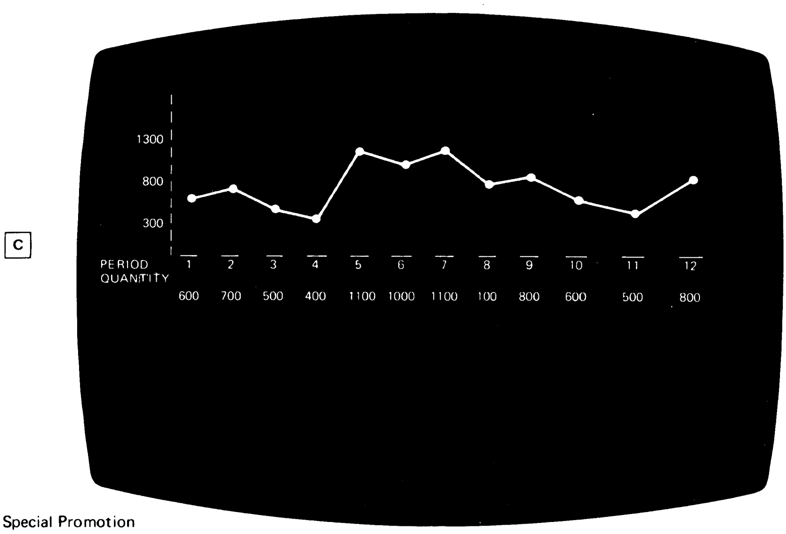
The trend of past data that can be safely projected into the future is first determined. The next step is to see whether the trend is influenced by seasonal factors.



Missing Data and Unusual Demand



Introductory Period



Special Promotion

Figure 14. **A terminal display of data points can assist in making a judgment concerning the conditioning of data**

After the trend and the seasonal factors are determined, some unexplained variations remain. These variations can be averaged to provide a measure of how well the model, consisting of trend and seasonal factors, actually fits the data.

Where items are subject to low demand or periods of zero demand, normal model fitting procedures may not give good results. As discussed later, the forecasting system can detect such conditions and apply special techniques in these situations.

Determining the model of past data

There are many possible model types that can be applied to historical data to determine trend. Although there are several variations of model types mentioned later, the following detailed discussion is limited to the most common type, the linear or straight line model.

fitting a straight line model

The line fitting procedure can be described as one of minimizing the squared distances between the line and the data points. This procedure, called "regression analysis", is performed automatically by the computer. The result of such an analysis is represented graphically in Figure 15. The line can be thought of as a weighted average of demand through time.

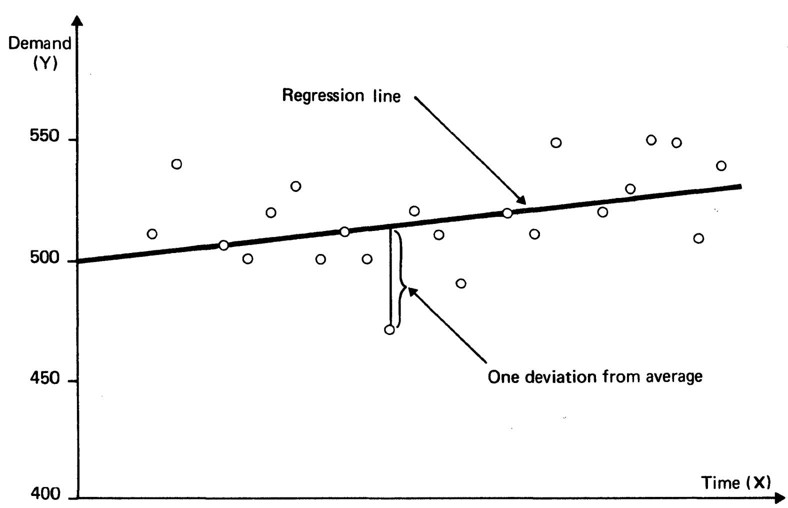


Figure 15. Regression analysis fits a straight line which minimizes the distance of the data points from the line

Any straight line can be represented by the mathematical statement:

$Y = a + bX$

where:

Y is the most likely demand for any time period X.

a is a constant representing the value at the beginning of the line (500 in Figure 15).

b is a constant value describing how fast the line is rising or falling (the trend or slope of the line).

measuring how well the model fits

The distance between any one point and the line is called a "deviation". The forecasting system sums the absolute value (without regard to plus or minus) of all these deviations and calculates an average deviation from the line. Mean absolute deviation or MAD is a measure of this average deviation.

It is this measure of deviation that tells the system how well the line fits the data. The object of the forecasting system is to fit a line or model that reduces deviations, and therefore MAD, to a minimum. Figure 16 represents two sets of historical data. In both cases a level regression line at a value of 100 was calculated. (There was no trend.) However, situation B fits the data much better; that is, the amount of forecast error, measured by MAD, is much smaller in B than in A.

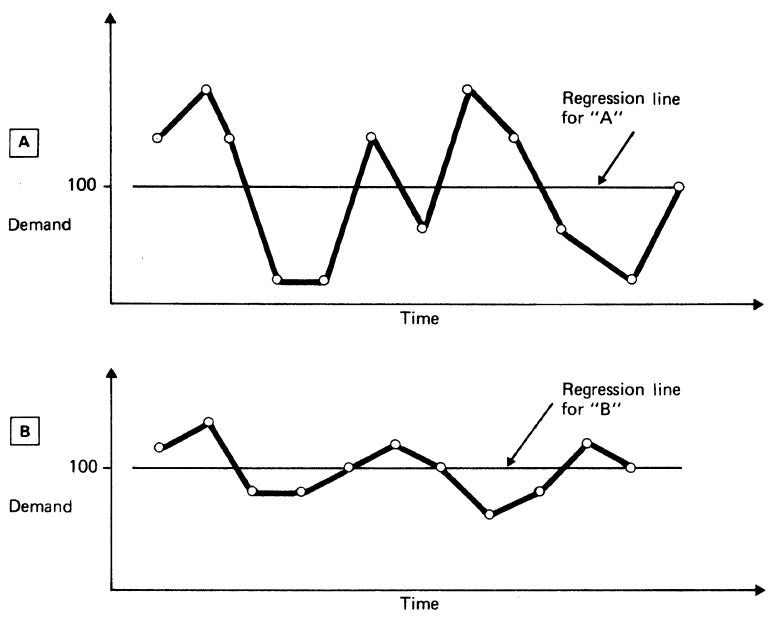


Figure 16. Item B has a smaller average deviation than A and therefore provides a more reliable regression line

If the regression line were extended one period into the future, there would be more confidence in B's projection than A's. Therefore, the smaller the MAD, the more confidence in the forecast.

Regression analysis will fit a line even when the data is so randomly distributed that no trend really exists. The calculation of an average deviation (MAD) is the only measure of how well the line fits.

Reasonableness Check. For important products (for example, the 20% representing 80% of sales) the trend result should be manually reviewed. If no reasonable explanation for the trend can be found, the calculated trend should be rejected in favor of a nontrending model line.

Terminal Analysis of Poorly Fitting Models. The system will notify the forecast analyzer when MAD exceeds a specified maximum. The data can then be displayed on a screen (Figure 17). Using judgment, the analyzer can use the terminal to delete old data or specific data points. In the example (Figure 17) he may choose to eliminate periods 7 to 10. He can then ask for another fit with new data values inserted. Data modification and regression analysis can continue on an interactive basis until the error is reduced to a satisfactory level.

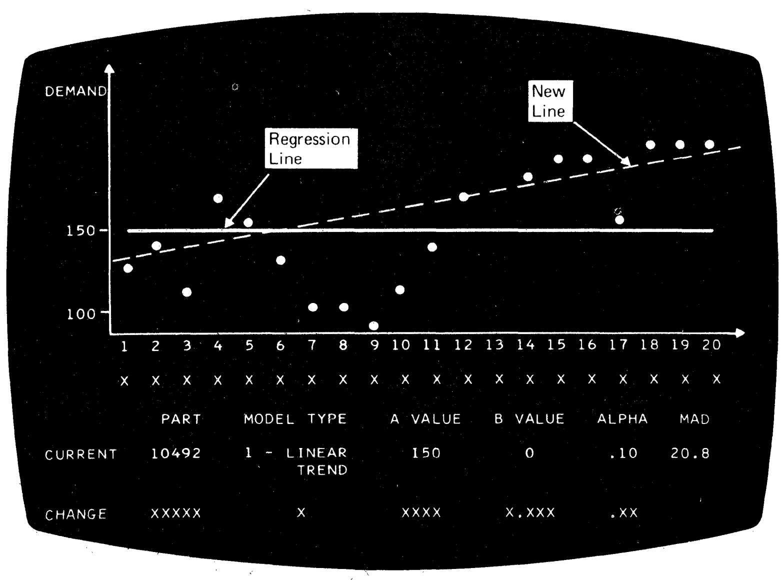


Figure 17. A terminal display of the regression line and data points allows human judgment to assist in finding a regression line

other forecast model types

Regression lines are of two types, linear and nonlinear. If the forecast error (MAD) is large and in the judgment of the analyzer another model looks better, the system will fit more complex lines (Figure 18).

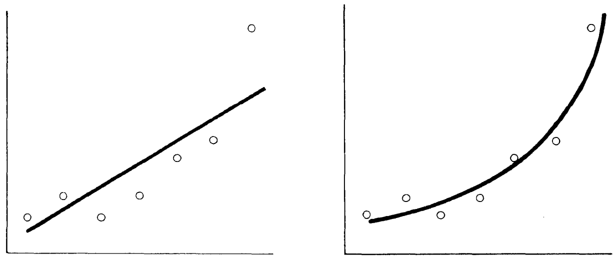


Figure 18. Simple curves may fit better than straight lines

Figure 19 graphically illustrates some common model types the system can fit.

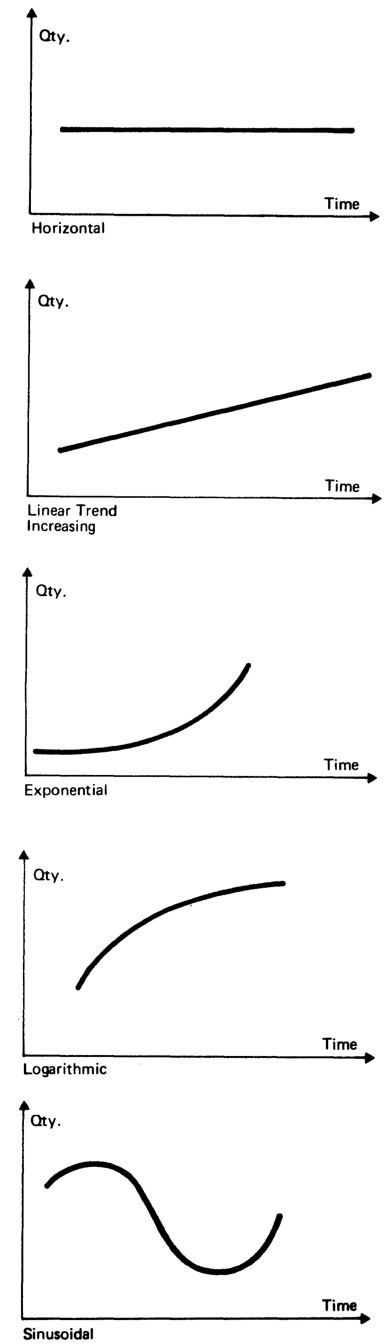


Figure 19. A graphic illustration of some of the common forecast model types

Seasonal demand

Seasonal or cyclical patterns of demand are characterized by peaks and valleys that occur at regular intervals. In Figure 20 high demand occurs in the summer months and low demand in the winter. Sales of air conditioners is a good example. This high-low cycle repeats every year. Cycles may be yearly (seasonal) as illustrated, or they may exist within a month, week, or day.

To qualify as seasonal, a demand pattern must pass two tests performed by the system:

- The peak period must occur during the same period of each cycle – for example, every summer.
- The demand of the peak period must exceed average demand by approximately 1/2 MAD.

There is one additional test that must be applied by the forecast analyzer – namely, will the cycle recur, in other words, is there a reason for the seasonality?

A larger amount of data is required to detect seasonal fluctuations. At least two cycles of data are needed to make an estimate – that is, two years of data if the cycle is yearly. Statistically, a minimum of seven cycles (just as for fitting a linear regression line) would be more realistic. If the cycle again is yearly, however, seven cycles would mean seven years of data. However, data going back that far would be subject to question because of the changing business environment. In addition, few businesses would maintain data that long.

It is therefore more realistic to construct a group of similar items (for example, all piston rings used primarily on farm equipment) and calculate the seasonal pattern for the group. The group's seasonal pattern can then be applied to each item within the group.

The output of the analysis is a *seasonal factor* to be applied to each period within the cycle (bottom line, Figure 20). The seasonal pattern is a supplement to the long-term trend; that is, it appears as a periodic fluctuation around the trend. For example, in Figure 20 the long-term trend would indicate that the forecast for December of the first year is 1,000. The seasonal factor for December is 0.8. Therefore, the actual forecast is 0.8 x 1000 or 800 units.

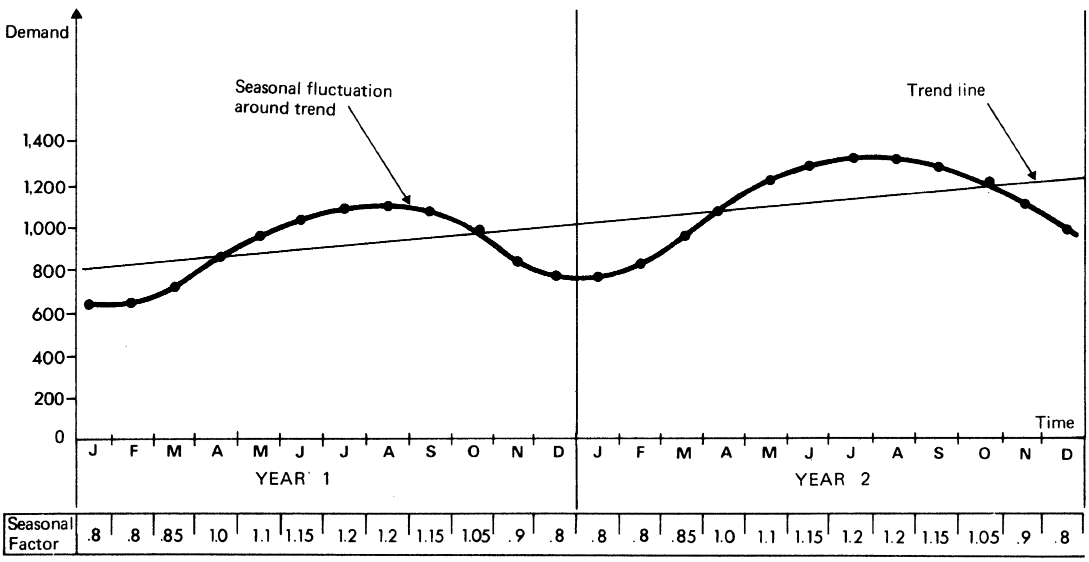


Figure 20. Seasonal fluctuation around the trend occurs at the same time every year

Results of regression analysis

What regression analysis succeeds in doing is to separate three elements of demand:

- The long-term trend, represented by the regression line's mathematical expression ($Y = a + bX$, or other types)
- The seasonal element, expressed as a series of modifiers to the regression line
- The average magnitude of deviation, which can be expressed as the mean absolute deviation from the combined regression line (these deviations can be attributed to the normal, random fluctuation in business)

Frequency of forecast model development

Although the largest amount of forecast model development occurs when starting the forecasting system, model development is a continuing process. Figure 21 shows why. It shows that at different periods during the life of a specific product, four different regression lines applied. The forecasting system constantly reviews historical data and automatically indicates when the current model no longer seems to apply. The method of detection and the correction procedure will be discussed under "Maintenance of the Forecast Model".

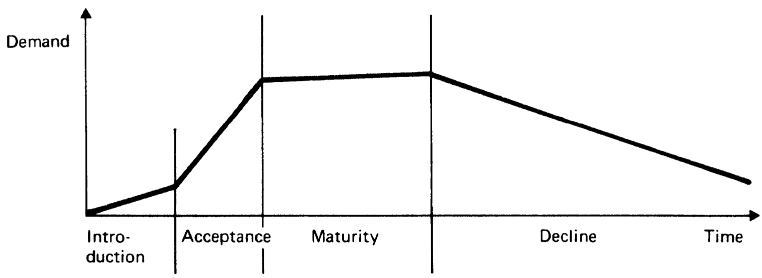


Figure 21. During the life of a product several different forecast models may be required

Forecast models for low-volume, lumpy demand

Before forecast model fitting is attempted, the system examines the demand data for conditions that make the use of normal regression analysis impractical. A condition found very frequently is *low, lumpy demand.* As Figure 22A shows, the pattern of this type of demand is often zero but sometimes reaches comparatively high values.

forecasting date of order receipt and order size

Fitting a normal regression line to a low, lumpy demand pattern results in a forecast of an average demand in every period. There would be no points of zero demand forecast (see Figure 22B).

One way to avoid this is to calculate the average order size and the average number of orders received each period. If the order size is fairly constant, the system can use techniques that forecast the amount of time between orders. Once the forecast of "when" the order will occur has been made, it can be converted to unit demand by extending by the average order size. The advantage of this approach is that the forecast demand pattern has a lumpy pattern similar to that of historical data (Figure 22C) and is therefore more accurate.

group forecasting for low, lumpy demand

In intrinsic forecasting, each item is normally dealt with individually. However, when items move at a slow rate, group forecasting techniques can be applied. This is because the low demand rate makes forecast demand and seasonal cycles difficult to calculate.

When similar items are grouped together, enough volume is generated for demand patterns to be determined normally.

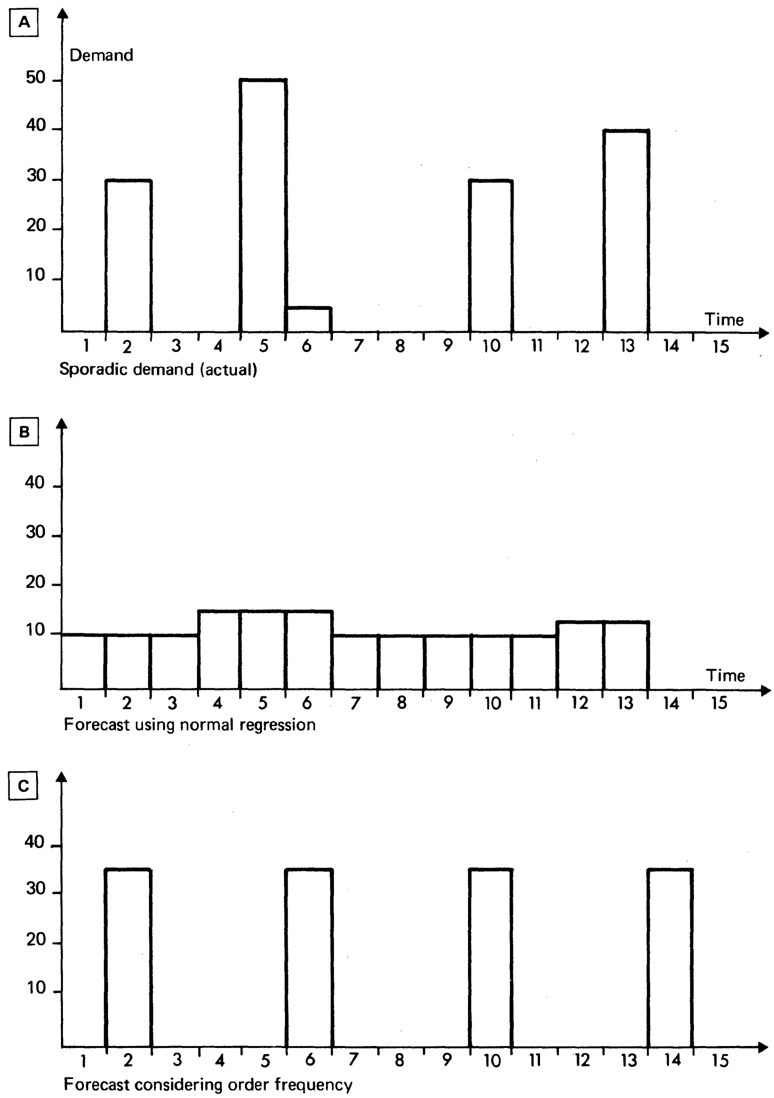


Figure 22. For lumpy demand items the system can forecast a pattern that more closely approximates actual demand

The forecast model for the individual item is then determined by applying the percentage the item contributes to the group model. Each item's average deviation is then calculated separately, on the basis of actual demand versus the value of the percentage of the group total. Figure 23 summarizes this procedure. The key to this approach is to make sure that all items in the group are truly similar.

Period	1	2	3	4	5	6	7	8	9	10	11
A Group Forecast	160	180	180	200	220	260	260	220	200	180	180
B % Item of Group (5 %)	8	9	9	10	11	13	13	11	10	9	9
C Item Actual Demand	12	10	7	9	13	11	15	10	6	7	9
Item Deviation C - B	4	1	-2	-1	2	-2	2	-1	-4	-2	0

Figure 23. With low demand, the seasonal pattern can be derived for a group of similar items and then used by each of the items in the group

Forecast Projection

Once the forecast model has been developed, it is used to make forecast projections for as far into the future as desired. However, care must be taken when using intrinsic forecast models for long-term projections. The longer the projection, the more care must be taken.

Method of projecting forecast

The forecast is made by extending or extrapolating the regression line into the future (Figure 24). The forecast for any future period is determined by the intercept points on the line; for example, the forecast for period 3 is 350, for period 5 is 400. The computer can project a forecast for as many periods as required. The number of periods forecast, called the "forecasting horizon", can vary for individual items. In addition, the projection system can vary the length of the forecast period as it projects further in the future; for example, the forecast may be by weeks for the first 26 weeks, by months for the next six months, and by quarters for the next year. The forecast for end products is retained in the system's data base, by time period, for use by later systems such as MASTER PRODUCTION SCHEDULE PLANNING.

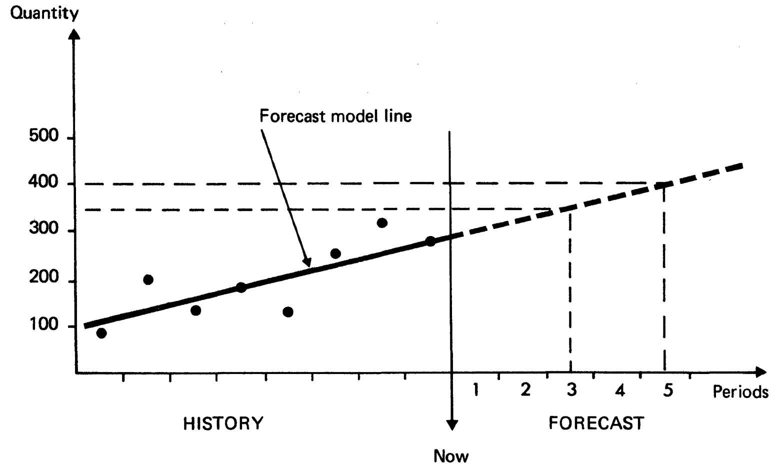


Figure 24. The forecast is made by extending the forecast model line into the future

number of periods forecast

The number of periods projected, that is, the length of the forecasting horizon, varies with the end use of the forecast. Whereas a reject rate or management standards forecast may cover just one period, a product forecast must cover the total manufacturing lead time for the product, that is, from the lowest level of component (see Figure 9), and may therefore extend over many months. If it is to be used for long-range planning of manufacturing facilities, it may be extended for years into the future.

However, as Figure 25 indicates, the further into the future the forecast extends, the wider the range of possible error. The original forecast line in this illustration was plotted with a small amount of data. As additional data became available, a new forecast was made and the direction of the line changed. As previously discussed in "Historical Data Requirements", the more data available, the more likely is the second line to be realistic. The important point is the amount of error in the first forecast. At the start, the difference between the two lines is small, but as the lines are projected further out, the error becomes larger. Hence the conclusion that the further out into the future the original forecast, the greater the chance for error.

Long-term forecasts for important items should be carefully reviewed to make sure that current trends have not been projected erroneously. A method of automatically modifying long-term forecasts is discussed in "Forecast Projection Modification".

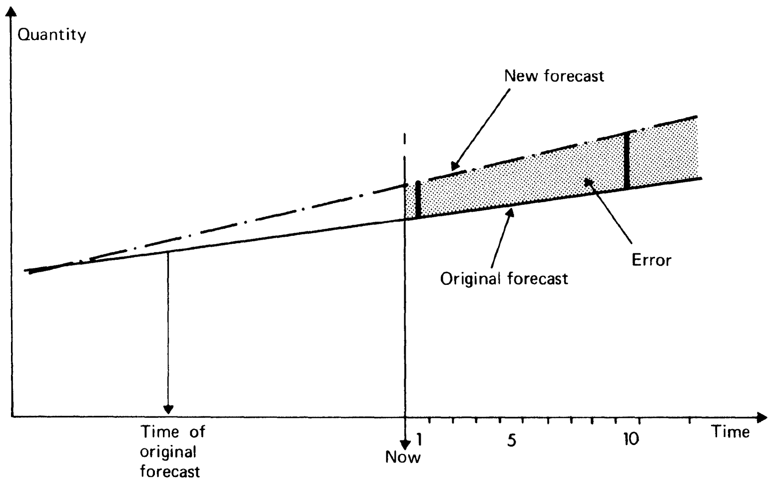


Figure 25. The further into the future the forecast is projected, the greater the chance of forecast error

frequency of forecasting

Normally, a revised projection is made as soon as new data becomes available. For important items this may be weekly; for less important items, monthly or quarterly. Changes to the previous forecast are used by MASTER PRODUCTION SCHEDULE PLANNING in altering the production schedule.

Measuring forecast reliability

Production people using forecasts should have some basis on which to measure the reliability of the forecast for a particular item and period. Unfortunately, most of the measurements are stated in statistical terms that are difficult for a non-statistician to interpret.

For important items, the forecasting system can develop a set of ratings that will help management gauge the reliability of forecasts – for example:

Very reliable

Reliable

Of limited reliability

Very questionable

These serve to indicate when forecasts should be reviewed for possible modification based on judgment. They can significantly reduce the time needed to review the forecast.

The reliability rating should take into account such things as:

- The size of the mean absolute deviation from the present model (the larger the deviation, the lower the reliability rating)
- The amount of historical data used in model development (the more data, the higher the rating)
- How far into the future the forecast extends (the further out, the less reliable)

Forecast Projection Modification

One pitfall to be avoided is overreliance on the mechanics of the forecasting system. Forecasting methods are based on the assumption that what has happened in the past will continue to happen in the future. This assumption does not necessarily hold. Therefore, the forecasting system constantly monitors actual demand in an effort to detect an unusual change in trend (see "Maintenance of the Forecast Model").

Unfortunately, a change is normally detected several periods after it has occurred. In the meantime, forecast errors have caused upsets in the production control system. If human knowledge of new factors affecting demand were given to the forecasting system, much of this error would be eliminated.

Judgment must also be exercised when making long-term forecasts. The use of life curves can assist in applying modifications to long-term forecasts.

Applying judgment modifications to statistical forecasts

In many cases, management knows in advance of events that will affect product demand, for example, a sales contest, a new competitive product, market expansion, etc. The forecast must be adjusted to reflect the effect of these factors.

This effect is reflected via "judgment modifiers", which are percentage adjustments to an individual period. For example, if, because of a sales contest, an item's demand were expected to increase by 10% for the next two periods and then drop to 5% above forecast for the third period, and 5% below for the fourth period, this would be expressed as indicated in Figure 26. The factor is expressed as the expected percentage deviation from forecast demand. The system then automatically modifies its own forecast by the indicated factor.

To simplify the use of judgment modifiers, the system allows their application by product group or by any other classification carried in the item's record. For example, the modifier could be applied to all sports equipment, all boating equipment, all outboard motors, etc., in addition to any particular outboard motor.

The responsibility for making judgment modifications must be carefully controlled to avoid having different individuals make competing adjustments to the same item.

The system compares the results of its normal forecast and the modified forecast with actual demand. This encourages the persons responsible for modification to evaluate their performance.

If the effect of the change is permanent, as in the case of an expansion, the system eventually adjusts its forecasts – provided the difference is not too great. For this reason, modifiers must be reviewed after a new forecast is made. Large changes cause the system to discontinue forecasting until a new model can be developed (see "Maintenance of the Forecast Model").

If the effect of the judgment modifier is not permanent, as in the case of a sales contest, the system can be instructed to disregard the data or to modify it by a factor supplied at the completion of the period. For example, if the effect of the sales contest were to increase forecast sales by 30%, the actual demand would be reduced by 30% before being used to revise the forecast model.

Period	1	2	3	4	5	6
Judgment Modifiers	1.10	1.10	1.05	1.00	0.95	1.00
Statistical Forecast	500	550	600	600	550	550
Adjusted Forecast	550	605	630	600	522	550

Figure 26. Period modifiers are used to reflect new or unusual factors that will affect demand

Use of life curves in long-range forecasting

As previously indicated, one difficulty with long-term forecasts is the increase in error as the projection moves further out in time. This is one reason why it is dangerous to project trends far into the future.

Figure 27 portrays the long-term demand for a particular product. During its life, several different forecast models applied. If a long-term forecast had been made at the four points indicated, the projection for period 100 would have been 3,000 at point 1, 12,000 at point 2, zero at point 3, and 1,500 at point 4. Long-term forecasts must be modified to reflect the various phases of demand a product may go through: introduction, acceptance, full production, and phasing out.

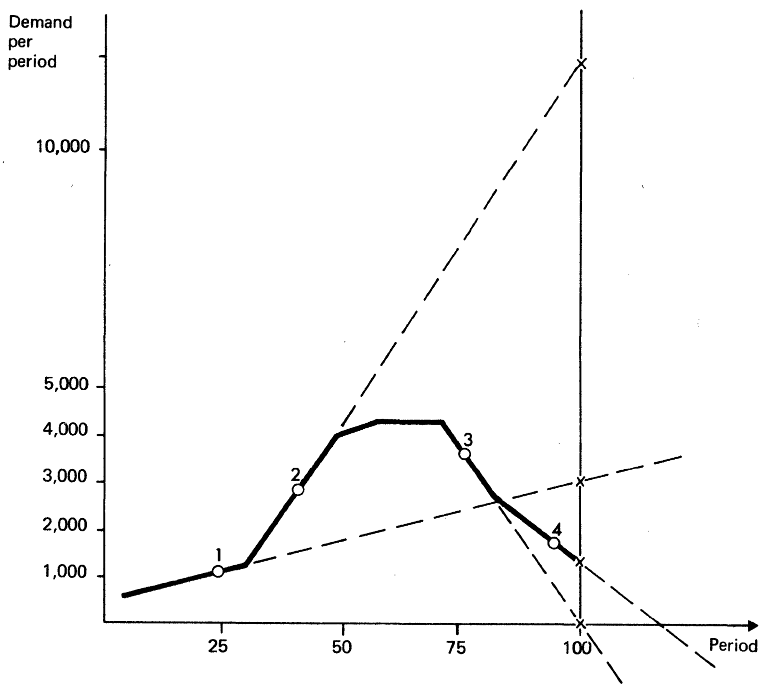
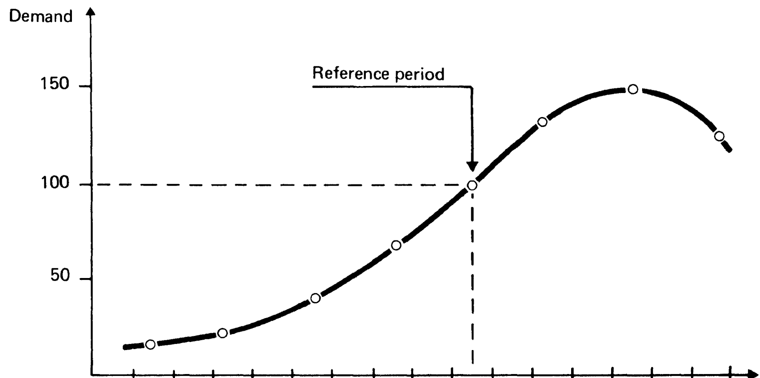


Figure 27. The forecast for a time period far out in the future can vary drastically depending on the phase of the product's life at which the forecast is made

The method of modification is accomplished via a series of modifiers representing a life curve. The modifier in Figure 28 is expressed as a percentage of some mean or reference period. For example, if the reference period is the tenth period after introduction of the product, period 10 will have a modifier value of 1.0. If demand for period 14 is expected to be 50% higher than period 10, period 14 will have a modifier of 1.5.



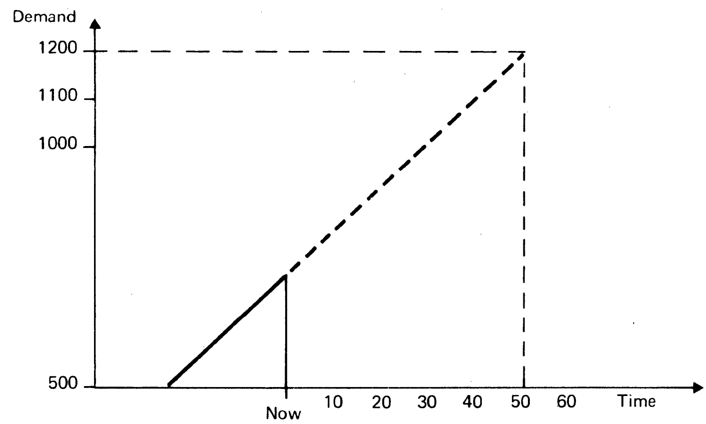
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Life Curve Modifier		.2		.3		.5		.7		1.0		1.3		1.5		1.4

Figure 28. A life curve is stated as a series of modifiers based on a reference period which has a value of one

When these life curve modifiers are applied to a forecast, they will not allow the forecast for 15 periods from product introduction to exceed the forecast for period 10 by more than a specific percentage, in this case 50%. If the projection exceeds the limit, the forecast analyzer is notified.

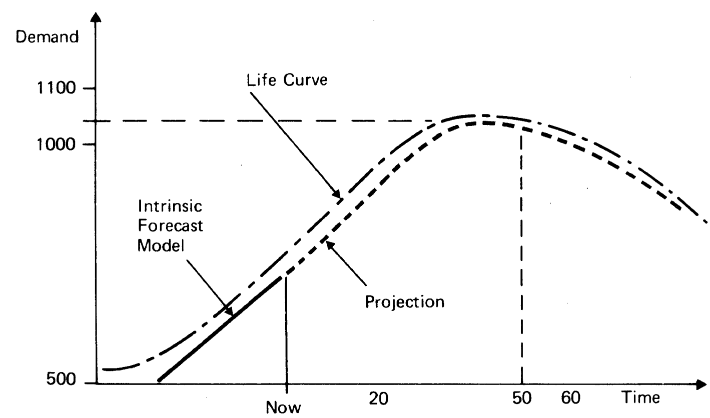
The analyzer can instruct the system either to stop the forecast at the point where the limit is reached or to follow the limitation of the life curve for the remaining periods of the projection. Figure 29 illustrates this effect. In situation A, a projection for period 50 would yield a forecast of 1,200. If a life curve had been assigned, as in situation B, the forecast would be limited to 1,050.

A



Forecast with no modification

B



Forecast with projection and life curve modifiers

Figure 29. Life curves can be used to limit the value of long-term projection

Depending on such factors as market acceptance, product life, effect of fashion, etc., life curves can assume many different shapes (Figure 30). Normally they are developed for groups of products. A code carried in the item record associates each end product with a life curve modifier series. Life curves need be assigned only to items that are subject to long-range forecasts.

The key to the effective use of life curves is the accuracy of the shape assigned. The assignment of a curve shape is a matter of judgment.

Life curve shapes can be developed using manual techniques. When data is available, a better alternative is to analyze statistically the demand data for a product group, using normal regression analysis techniques (Figure 31).

Life curves are also called S-type growth curves. Many models have been developed which allow life curves to be represented by a mathematical equation rather than a series of period modifiers. The advantage is that a large number of different life curve shapes can be represented by a small amount of data. Equations are also necessary when developing a life curve model statistically.

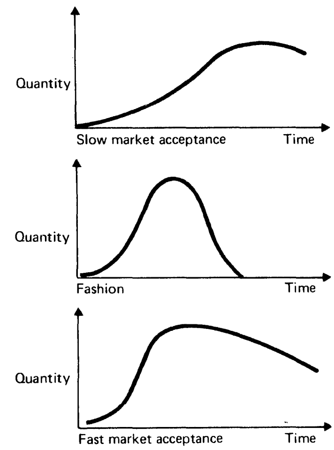


Figure 30. Modifier series can represent many different life curve shapes

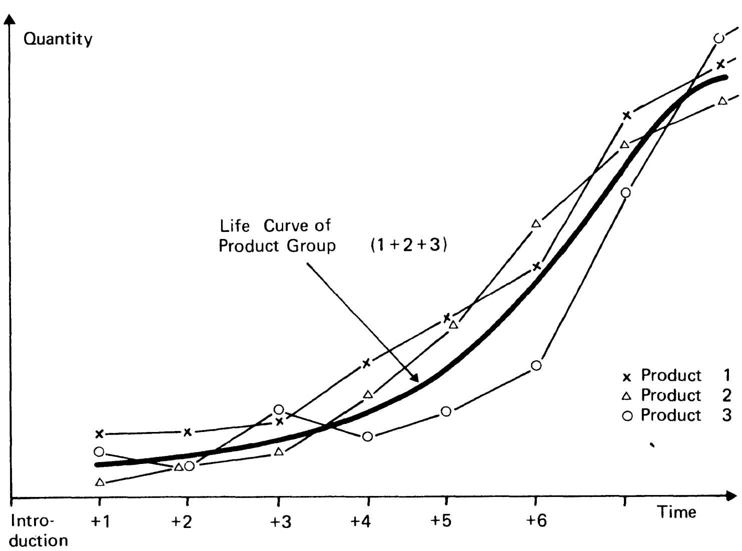


Figure 31. Life curves can be developed statistically on the basis of an analysis of similar items

Maintenance of the Forecast Model

A computer forecasting system is self-maintaining; that is, it not only establishes the initial forecast model, but, as new demand data becomes available, it automatically adjusts the model to reflect the latest demand pattern. The forecast analyzer becomes involved when the system, via monitoring techniques, detects that recent demand is not holding to the old demand pattern.

At the end of each period, the supporting system supplies the actual demand for the period just completed. For end product demand, the supporting system is CUSTOMER ORDER SERVICING. This data is used to maintain and monitor the system.

There are two basic functions in maintaining the forecast:

- Adjusting the forecast model to reflect current trends either by refitting a regression line or by exponential smoothing
- Monitoring to make sure the demand fits the established forecast model

If the forecast monitoring system detects that the forecast model no longer applies, a new model will have to be initiated. Historical data may have to be reanalyzed and a new model developed, or the forecast analyzer may initiate an entirely new model because historical performance data no longer applies.

Forecast maintenance via refitting a new regression line

The procedure for refitting a new regression line is similar to that used to establish the initial line. The only difference is that additional and more current data points have become available, and therefore the new regression line will be more current and reliable. The procedure for fitting regression lines is time-consuming compared with other methods. Therefore, constantly refitting new lines should be limited to a few items.

Forecast maintenance via exponential smoothing

Exponential smoothing is a technique that can be used to update the forecast models of most items in manufacturing. The major advantages are:

- It reduces the need to retain historical demand data, thus reducing data storage costs.
- Being a simple procedure, it reduces the systems time needed for updating the forecast model.
- It can adapt to change without manual intervention.

As indicated in "Forecast Model Development", a straight line model is represented by a mathematical expression in the form of

$$Y = a + bX$$

where Y is the forecast for any time period X. Figure 32 represents a regression line in this form. The y axis intercept, a, is 150; the trend, b, is 6.66 units per time period. Therefore, the line is expressed as Y = 150 + 6.66 X. The forecast three periods from the present is:

$$\text{Forecast (Y)} = 150 + 6.66\,(3) = 170$$

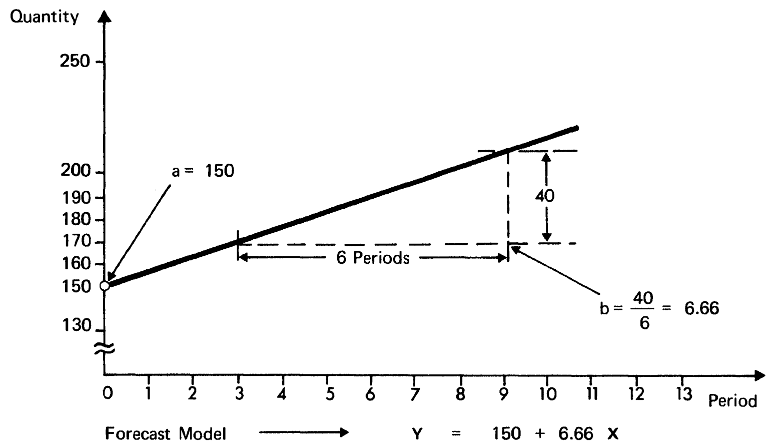


Figure 32. The linear forecast model can be represented by a relationship between two values: a, the forecast level, and b, the trend of the forecast

The addition of new data changes the direction of the line (Figure 33), thus changing the value of a and b in the forecast model. Therefore, to update or alter the forecast, only the value of a and b need be changed. This alteration is the function of exponential smoothing. It maintains the value of a and b using a weighted averaging technique.

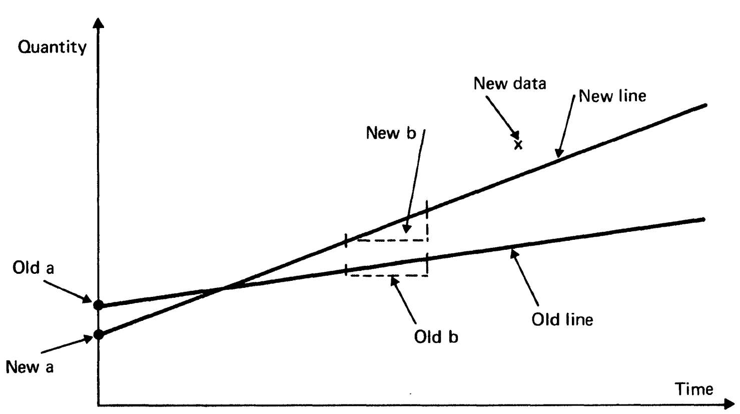


Figure 33. When a new period of demand is added, the regression line may change direction

maintenance technique for a model with no trend

A forecast model with no trend is in the form:

$$Y = a$$

which means simply that the forecast equals the old average. If this forecast were extended, every period would have the same forecast value.

To update the average using exponential smoothing, the following formula is used:

New forecast = old forecast + α (new demand - old forecast)

If the old average (forecast) was 50, the most recent period's demand was 60, and the constant α is 0.1, then:

New forecast = 50 + 0.1 (60 - 50) = 51

The data requirements for a new forecast are minimal. They consist of the current forecast, a, and a value of alpha (α) for each item forecast. A new forecast is made when a new period's demand is available.

the importance of alpha

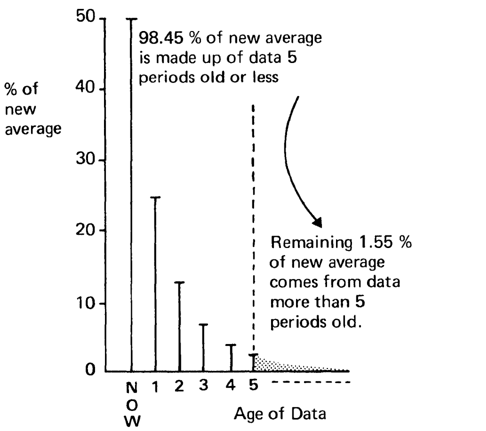
Alpha (α) is called the smoothing factor. Its value varies between 0 and 1.0. The closer the value is to 1.0, the more the recent demand affects the new forecast. In the example above, if α had been 0.5, then

New forecast = 50 + 0.5 (60 - 50) = 55

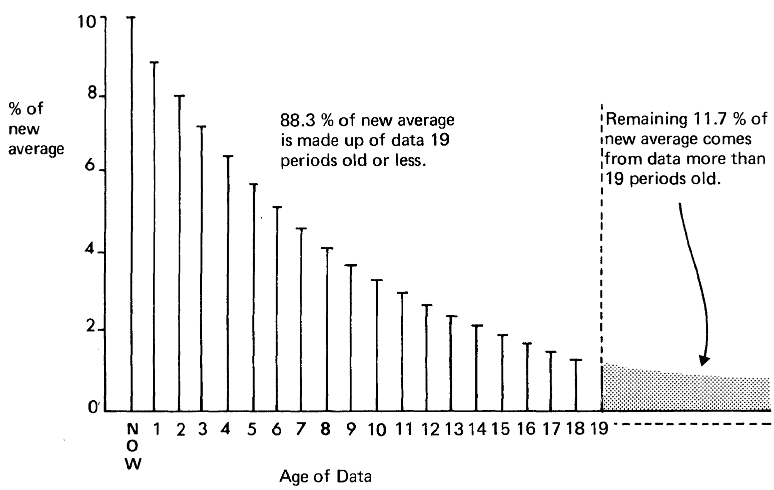
Therefore, the larger the constant α, the faster the forecast responds to a change in demand.

For most items α will be between 0.05 and 0.2. Each item that has been forecast can have a different value of α, although it is normal to assign one value to an entire product group.

The value of α determines how past periods of demand are to be weighted. Figure 34 shows how past periods are weighted with two different values of α, 0.5 and 0.1. With a value of 0.5 only 1.55% of the new average comes from data more than five periods old. With an α of 0.1, older data is given more weight.



Weighting of data with alpha (α) = 0.5



Weighting of data with alpha (α) = 0.1

Figure 34. Alpha (α), the smoothing constant, determines how past history is to be weighted

The actual effect of alpha is illustrated in Figure 35. Actual demand is represented in the upper graph. The lower graph shows the forecasts made with two different values of α. The forecast with an α of 0.5 reacts very quickly to changes in demand. The forecast with an α of 0.1 is more stable.

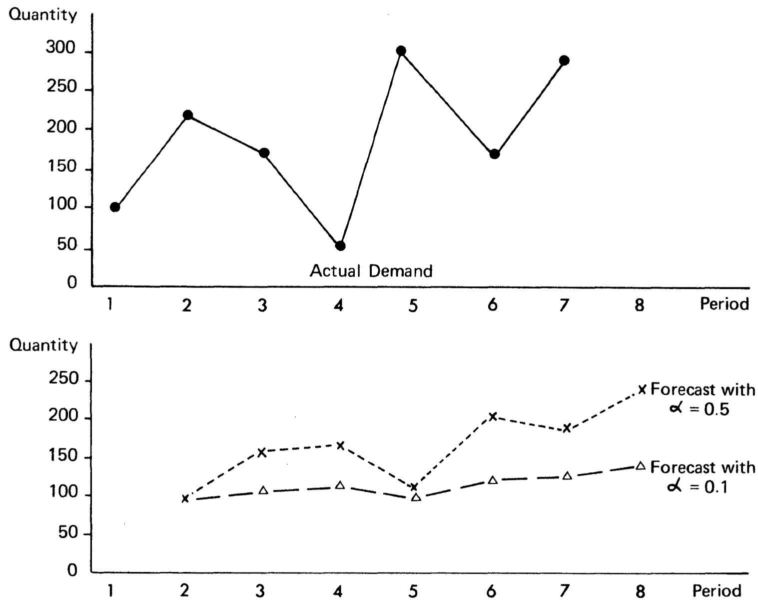


Figure 35. High alpha (α) factors respond more quickly to demand changes

Any master production schedule based on a forecast with a high value of α is subject to a lot of change. This in turn causes a lot of expediting and replanning. A schedule based on a forecast with low α introduces minimal changes but may not react fast enough to trends in customer demand. This could result in running out of stock, or, if the trend is down, carrying excess inventory. Experience has shown that an α in the range 0.05 to 0.1 yields the best results for most end product forecasts.

maintenance of a trend model

The value b in the forecast model $Y = a + bX$ represents the amount of trend. Updating of the values b and a is done in basically the same manner:

New trend = $(1 - \alpha)$ old trend + α (new average forecast - old average forecast)

The use of a trend factor permits the use of a lower α and consequently a more stable forecast, and still provides better response to demand changes. A higher α on a model with no trend can provide the same degree of response but will yield more volatile forecasts.

revising forecast error

As pointed out in the Introduction, under "Objectives of Forecasting", the business planner is able to calculate the size of business buffers on the basis of the amount of forecast error. The point is that the larger the deviation error, the larger the required buffer—for example:

- The more deviation in product demand, the larger the inventory level must be to avoid out-of-stock conditions.
- The more deviation in the size of the work backlog, the larger the backlog must be to avoid machine idle time.
- The more deviation in delivery time, the sooner the order will have to be released to assure on-schedule delivery.

The forecast error is measured each time the forecast model is updated. When the supporting system supplies last period's demand, the forecasting system compares it with the forecast for the same period (Figure 36).

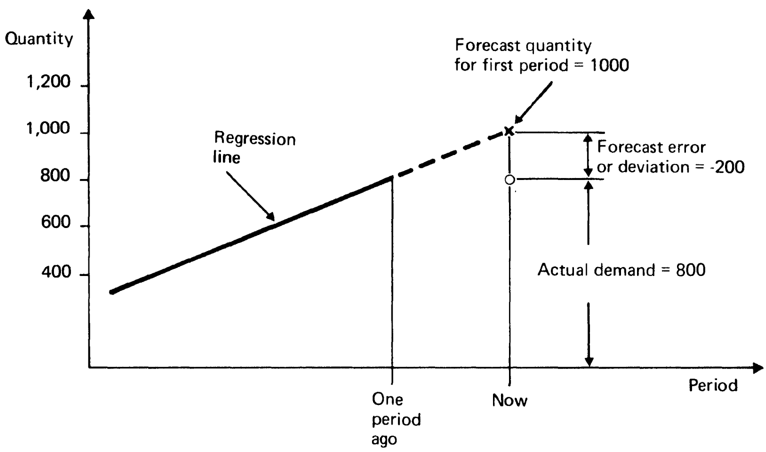


Figure 36. Forecast error is the difference between the forecast made one period ago and the actual demand for the period

In the example, the deviation was minus 200. For purposes of calculating the average deviation, the sign is dropped to get the absolute (or unsigned) value. The average or mean deviation is also calculated using the assigned smoothing constant.

$$\text{New MAD} = \text{old MAD} + \alpha \mid \text{current deviation} - \text{old MAD} \mid$$

The distribution of forecast errors approximates a normal distribution (Figure 37). The MAD can be used to make such statements as "98% of all deviations (errors) will be within ±3 MAD". That is, if MAD is calculated to be 5 units and the forecast is for 100 units, then 98% of the time the actual demand will be in the range 100 ± (3 x 5), or between 85 and 115 units. For planning purposes this means that if 115 units were on hand at the beginning of each period, an out-of-stock condition would occur in only 1% of the planning periods.

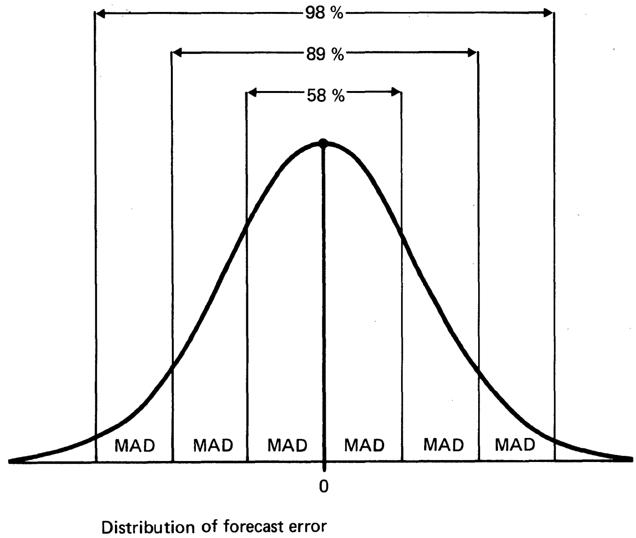


Figure 37. Forecast errors are usually distributed in a normal way around an average of zero

If ± 2 MAD is picked, actual demand will be in the range 100 ± (2 x 5), or between 90 and 110 units. In this case, 5% of the planning periods would have a potential out-of-stock condition. Is the five-item decrease worth the 4% drop in service (from 99% to 95%)? This question can be answered only when management carefully evaluates the consequences of lower customer service. The point is that management can set the level of customer service at any point it chooses and can know in advance the consequences of its decision. The planning systems set up and monitor the buffers that make sure the desired service level is achieved.

Management can alter its decision by simply adjusting one number, the desired service level. The system converts this into inventory units by using the measure of forecast error (MAD).

Therefore, MAD and an expression of the desired service level provides a management control knob that can be set according to needs. For example:

- Finished goods inventory can be reduced by lowering the service level for customer demand.
- Inventory in process on the plant floor can be reduced by altering a service factor that plans the work backlog at each machine center.

Forecast monitoring

Monitoring takes two forms:

- How well does the new demand fit the forecast model? This is done via a "tracking signal".
- Is the new demand consistent with periods of previous demand? This is done via a "demand filter".

monitoring performance

If the forecasting model is realistic, the sum of the deviations (errors) from the past forecasts should be approximately zero. Thus, if the error in the last five periods was, respectively,

+400, +100, -300, +200, -500

then the "sum of the error" at the end of the five periods equals -100. However, if the forecast is consistently high or low, the accumulated error will become very large. For example, a consistently low forecast might cause a series of errors such as

-400, -100, -300, -200, -500

where the sum is minus 1500.

When the sum of the errors becomes too large (for example, 4 x MAD), the system can highlight this item, indicating that something may be wrong. The system can record the number of consecutive periods during which this condition has occurred. If this tracking signal persists during the following period, the item should be investigated. Rules can be established that ensure that high-value items are checked each time, the next group of items on the second signal, and so on. Figure 38 shows an example of a sudden change in demand. The change could be caused by:

- Entry into a new phase of a product's life curve
- Competitive actions such as a new product or an expansion of the sales force
- Internal changes such as a higher or lower price, addition of complementary items to the product line, or expansion or contraction of marketing areas.

All data preceding the point of discontinuity must be rejected from further consideration. How much data to discard is very often difficult to determine, because the change might not be as sudden as indicated in the example. A visual display of the data points can assist in making the decision. The forecast analyzer can then more effectively use his judgment in establishing the discontinuity point (see "Data Conditioning").

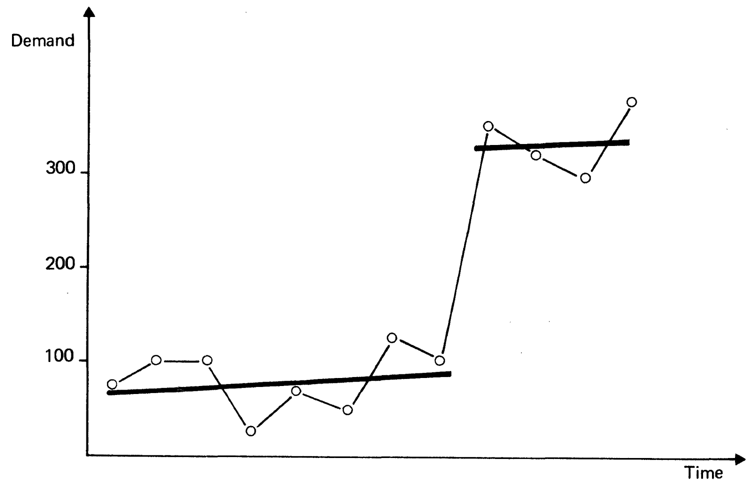


Figure 38. An example of a sudden change in demand

The analyst can also, via a terminal, initiate actions such as assigning new values to a and b, or assigning a life curve.

There are several tracking signal formulas that measure how well a forecast model is performing. For example, one exponentially smooths the deviations rather than maintaining a sum of the errors. This allows the tracking signal to be reduced as the forecast model improves (Figure 39).

Period	1	2	3	4	5
Actual Error	+ 200	+50	+50	+10	+ 5
Sum of Errors	+200	+250	+300	+310	+315
Smoothed Error α = 0.1	200	+ 185	+ 171	+ 155	+ 140

Figure 39. Smoothing the tracking signal lowers its value as the forecast accuracy improves

monitoring new demand data

The system detects whether the current period demand is unusually high or low by comparing it with the forecast, measuring the deviation, and comparing the deviation with a multiple of MAD – for example, ± 4 MAD. The problem is to determine whether the first occurrence of unusual demand means the beginning of a new trend, or is only random forecast error.

The forecasting system detects all cases of unusually low or high demand. The demand pattern can be displayed on a terminal for analysis, as indicated earlier. In addition, the analyzer can display detailed demand history from the order history file. If a nonrecurring order (such as a large export order) is found, the analyzer can reduce the demand accordingly. If the analyzer is unable to determine the reason for the sudden change, he can allow the demand to be averaged into the model. The system detects continuation of unusual demand via the tracking signal check.

Models with automatic adjustment to changing demand patterns

Some advanced forecasting models can adapt more rapidly to a change in demand pattern. This means that manual intervention by a forecast analyzer is required less frequently and that forecast accuracy is reinstated more quickly.

One approach, adaptive smoothing, utilizing exponential smoothing techniques, is to modify the smoothing constant alpha (α) in proportion to the size of the tracking signal. As the size of the tracking signal becomes larger, the value of α is increased. This places more weight on recent data, and the forecast adapts to the new trend more quickly. Because of its magnifying effect, this method should not be used where large forecast errors may be encountered.

Adaptive forecasting

An advanced forecasting method available is an approach known as "adaptive forecasting". Its major feature is its ability to compute accurate forecasts for many items that are normally difficult to forecast, such as items with significant seasonality and items with changing demand patterns. Therefore, it should be used for important items that have either of these characteristics.

Adaptive forecasting assumes that the demand pattern for any item can contain trend with a seasonal pattern. If the demand pattern for an item does not contain trend or seasonality, the values of the trend or seasonality factors are merely set to zero. This greatly reduces the amount of analysis that must be performed, since by using a single technique, adaptive forecasting can handle horizontal, trend, or trend-seasonal demand patterns with equal facility.

Three of the basic features of adaptive forecasting are:

- The use of sine and cosine functions to model seasonality
- The model fitting technique
- Adaptive smoothing, the method used to update the forecasting model

The use of sine and cosine functions to model seasonality avoids many of the problems ordinarily encountered in forecasting seasonal items. For example, the interaction of the sine and cosine functions with the adaptive smoothing technique just described gives adaptive forecasting the ability to automatically adjust to most changes in seasonality without the need for any manual intervention.

The model fitting method used in adaptive forecasting consists of two steps: a least squares fit to obtain an initial least-squares model, and aging of the model so that the more current sales data is given greater weight than older sales data. This method provides a more accurate starting forecasting model than is available with most other forecasting techniques and therefore provides more accurate initial forecasts.

Figure 40 illustrates the result of an adaptive smoothing process. The pattern of demand changed dramatically in the middle of the second year. By the third year, the forecasting system had completely changed the model.

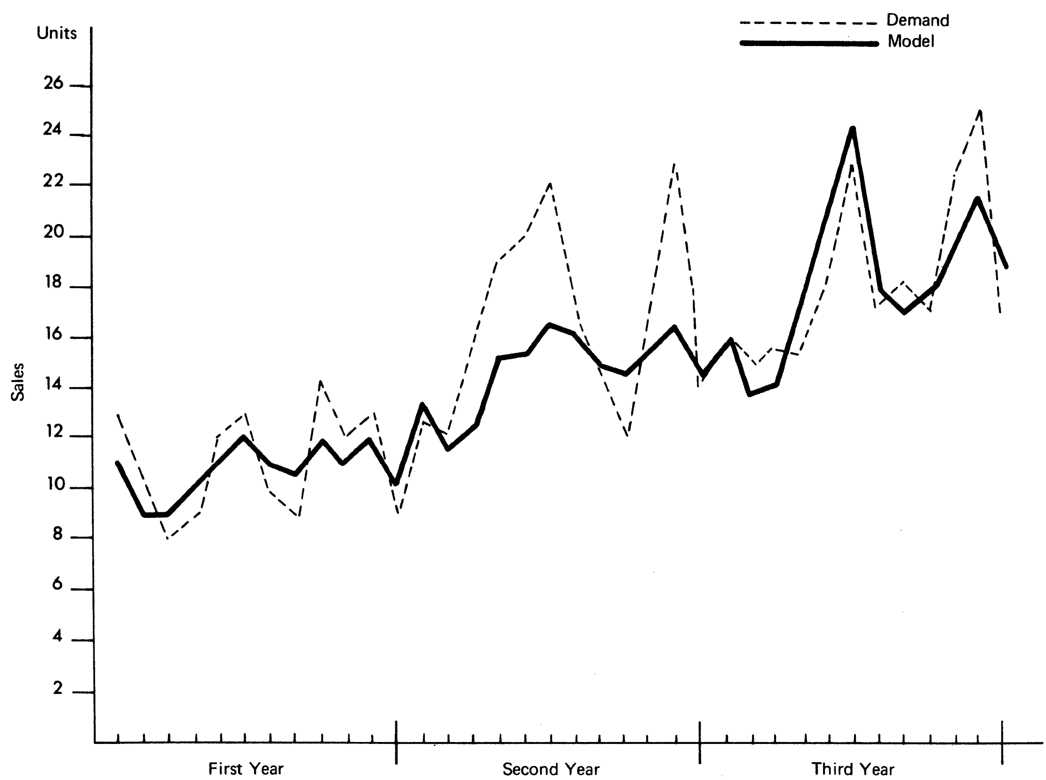


Figure 40. Example of a forecast model automatically adapting to a change in demand pattern

Demand data retention requirements

For each item exponential smoothing has to maintain only smoothed averages of:

- a – the average
- b – the trend
- MAD – the measure of forecast error
- Tracking signal – the measure of how well the model is holding
- Seasonal factors – the measure of cyclical demand

When new demand data becomes available, the above values are calculated and averaged (exponentially smoothed) into the old values and the original demand data is disposable.

As pointed out in the discussion of life curves, however, the established demand pattern does not last forever. Therefore, when exponential smoothing is used for important items, the historical data should be retained. If an item is subject to seasonal demand, two to five years' data should be retained. If the tracking signal is tripped by the system, this historical data can be displayed for manual analysis or used for model selection.

For less important items, such as hardware, slow movers, etc., the errors caused by temporary lags in the forecast are not extensive enough to cause problems in manufacturing planning. Historical demand, therefore, can normally be discarded.

Forecasting New Items

Life curves can be used when forecasting new items or items that lack historical data. If the new item is similar to previously introduced items, the initial section of the life curve can be used in place of historical data.

The forecaster makes an estimate of the demand during the reference period of the life curve (see "Use of Life Curves in Long-Range Forecasting"). The system then projects backward from the reference period, using the period modifiers.

If, after a few periods, the item does not appear to be following the shape of its assigned curve, the analyzer can assign a more appropriate curve by simply changing the curve shape code associated with the item (Figure 41).

The value of the forecast can be changed by altering the value of the reference period. Raising the quantity of the forecast for the reference period will raise the forecast for all other periods by a proportionate amount.

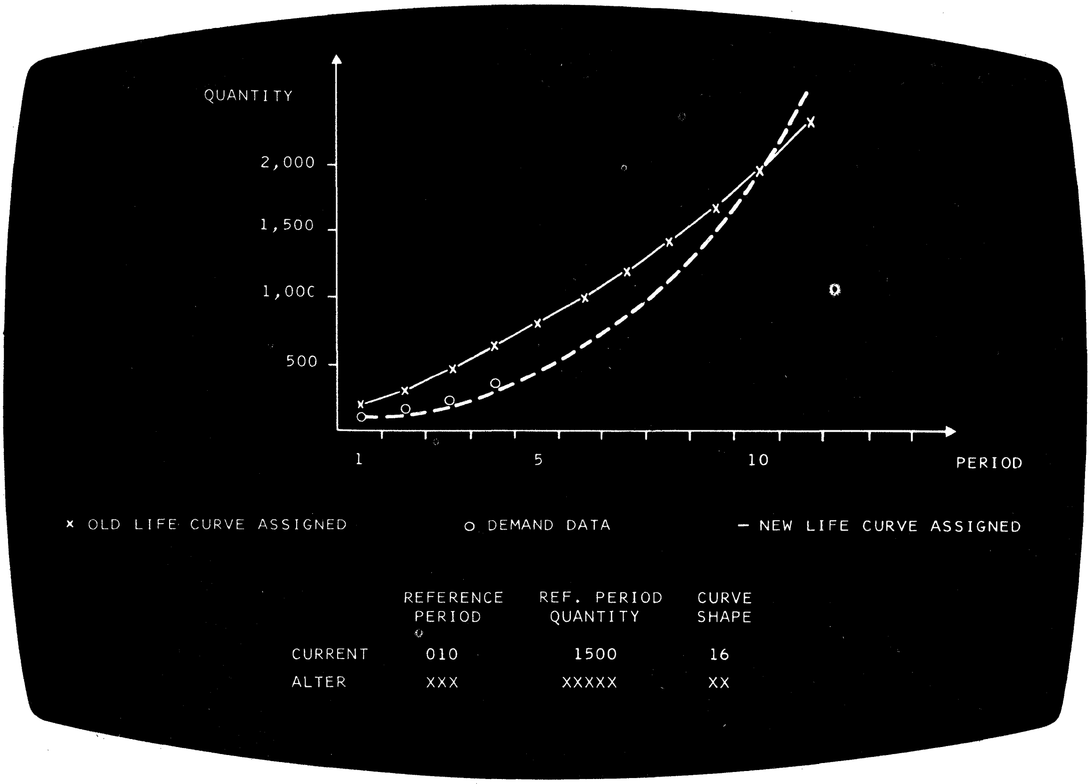


Figure 41. Life curves can be used to help forecast new products. A terminal can assist in determining a revised curve as demand data becomes available

Once a sufficient quantity of historical data has been gathered, normal forecasting techniques should be applied.

The same technique can be used when an item experiences a sudden change in its demand pattern (a discontinuous demand). When this occurs, historical data no longer applies. In effect, forecasting from the point of discontinuity is similar to forecasting for a new item.

If the item represents a new product technology, and therefore life curve experience is not available, the forecast will have to revert to executive opinion, market research survey, etc.

Establishing Management Standards

Forecasting techniques can be applied to the development of management standards. The large number of standards required for effective "management by exception" precludes their establishment and maintenance by normal methods (see "Measurement Standards" in *System Requirements*).

Forecasting is not needed in situations where standards have already been developed accurately, as in the case of labor standards or product standard costs. Where standards do not normally exist, however, forecasting methods can be used.

For management standards, the term "forecasting" does not imply a long-term projection. It is merely a method of developing an average for the level of some past activity on which the measurement of future performance will be based.

For example, what should be the standard allowance for cleanup in a particular work center? A percentage of total man-hours utilized in the work center may be the standard. However, is it fair to assign the same standard to all work centers? Some centers may require more cleanup work than others. Even if it is possible to establish manually a fair standard for each center, will the standard be changed as machines, men, types of parts, etc., change? The question is, How much should these standards be changed as conditions change?

This problem is multiplied by the number of indirect labor categories that require control standards, and by the number of work centers to be controlled. When other types of standards are considered, the problems increase dramatically. They include such factors as material move times between work centers, scrap allowances, machine downtime targets, reject rates, absenteeism rates, nonincentive labor allowances, and many more.

Simple exponential smoothing techniques can be employed to calculate averages of past activity. The average becomes the standard for the next time period. With selection of the proper smoothing constant (α), the averages can readily adapt to changes on the shop floor.

Management can adjust the number of items called to their attention by altering a number designating how much deviation is to be allowed before it is considered an exception. This is equivalent to setting a service level for customer product demand.

Improvements in performance against standard can be developed by applying an improvement factor to the historical average. For example, the system can plan to reduce the current average of queue at a work center by 5% and set this as a separate standard. Measurement then continues against the revised standard rather than the maintained smoothed average. Once the target is reached, the system reverts to the exponentially smoothed average.

Extrinsic Forecasting

The intent of extrinsic forecasting is the same as intrinsic, that is, to project future demand. Normally, however, extrinsic forecasting is concerned with product groups rather than individual items – for example, all air filters rather than a particular size filter. It can be used to forecast the entire sales of the company.

Instead of projecting a product's past history, extrinsic forecasting finds a causal relationship between some external factor, such as housing starts, and past demand. Then, given a forecast for the external factor, the forecast for demand can be developed.

The procedure to develop and use extrinsic forecasting is similar to that for intrinsic:

- Collect and condition historical data on demand and external factors.
- Develop and maintain the extrinsic model.
- Project from extrinsic model.

Data Requirements

Two types of data must be gathered: historical demand for the product group, and past values of external indicators.

Indicator data

An external indicator such as economic indicator data is supplied by such bodies as government agencies and trade associations. It must be assigned a period number in order to associate it with group demand data for the same period. Some examples of indicators are gross national product, industry sales, inventories, housing starts, retail sales, price index, and unemployment rate.

External indicators can also come from internal sources. The size of the sales backlog of one product group may indicate later sales of some associated product line – for example, sales of automobiles will occur some months in advance of sales of spare parts. The shipments of the automobiles would then be called a "leading indicator" for the sales of the spares items.

Historical demand

The demand data requirements are basically the same as those for intrinsic forecasting:

- The data should reflect demand and not sales.

- The quantity of data must be sufficient to justify confidence in the forecast. About 30 or more observations are needed for each forecast indicator.
- The data must be conditioned by eliminating unusual demand and correcting for missing periods (see "Data Conditioning").

If individual item demand is to be grouped together, care must be taken to assure that the group is homogeneous.

Development and Maintenance of the Extrinsic Forecast Model

The data for extrinsic models is associated as shown in Figure 42. In period 23 there were 12,000 housing starts (new residential construction permits) when demand for carpeting was 5,300; in period 17 there were 18,000 starts, when demand was 5,800; etc.

Using the statistical technique of regression analysis, a line is drawn through the data. The distance from each data point to the line is called a deviation. The regression line is drawn to minimize the sum of the squared value of the deviations.

The mathematical expression of the line (if linear, then $Y = a + bX$) describes the *causal relationship* of the two factors. In the example an increase of 3,000 housing starts causes an average increase in carpet demand of 200 units.

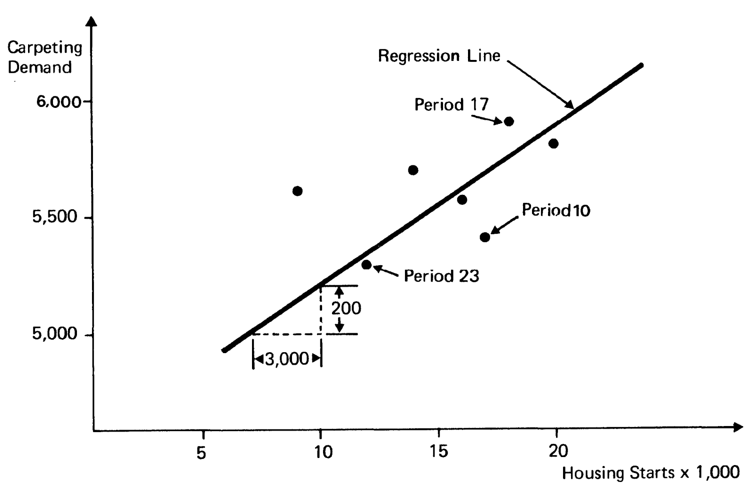


Figure 42. Extrinsic forecasting tries to find a causal relationship between demand and some external indicator(s)

A regression line can be drawn through any set of data, thereby establishing a possible relationship. However, it may not be valid. The validity of the relationship is a function of:

- The amount of deviation of the data from the line. If the deviation is too large, the forecasting system rejects the line.
- The degree to which the relationship can be explained logically. For example, the relationship between housing starts and demand for carpet is logical, whereas the relationship between housing starts and the demand for aircraft repair parts is unexplainable and therefore not valid.

Demand as a Function of Multiple Factors. Demand is seldom a function of only one economic indicator. For example, other economic indicators affecting the demand for quality carpet could include the average selling price of completed houses, income, sales of other floor covering products, etc.

The statistical technique of multiple regression analysis helps determine how much each factor contributes to total demand. The resultant forecast model is represented mathematically as:

$$Y = a + b_1X_1 + b_2X_2 + \ldots\ldots\ldots b_nX_n$$

where:

Y = forecast for demand
$X_1 - X_n$ represents the number of indicators causing demand
$b_1 - b_n$ represents the weighting factor for each indicator

The notation X_n indicates that the number of factors is not limited – that is, it could range from one to 100 or more. However, in most models only four or five indicators have any real significance.

The indicators themselves may be related. For example, income and the average price of completed houses are related. The effect of this relationship must be eliminated so that the model reflects only the direct contribution of the indicator to demand.

Because a large number of factors and data are normally involved, computers offer the only practical solution to the time-consuming calculations required by multiple regression techniques.

The output of the analysis is a mathematical expression describing the interrelationship of the indicators and the contribution each one makes to the demand. These results should be interpreted by qualified statisticians.

Model Maintenance. Extrinsic forecasting assumes that past causal relationships will continue into the future. Because of dynamic business and economic conditions, these relationships may, however, change through time.

Therefore, model maintenance is a continuing job. As new data becomes available, multiple regression and correlation techniques should be reinitiated. Changes in the relationship of indicators must be reflected, and the addition of new, and deletion of old indicators must also be evaluated to improve the performance of the model.

Extrinsic Forecast Projection

Projection is accomplished in two ways:

- From actual data on leading economic indicators
- From forecasts of the level of indicators

Projecting with leading indicators

The dream of every forecaster is to discover a leading indicator, that is, an item whose present value is related to a demand that occurs several periods later. For example, the birth rate leads the demand for baby food by several months. Figure 43 shows how, for another example, carpet demand trails housing starts by approximately three periods.

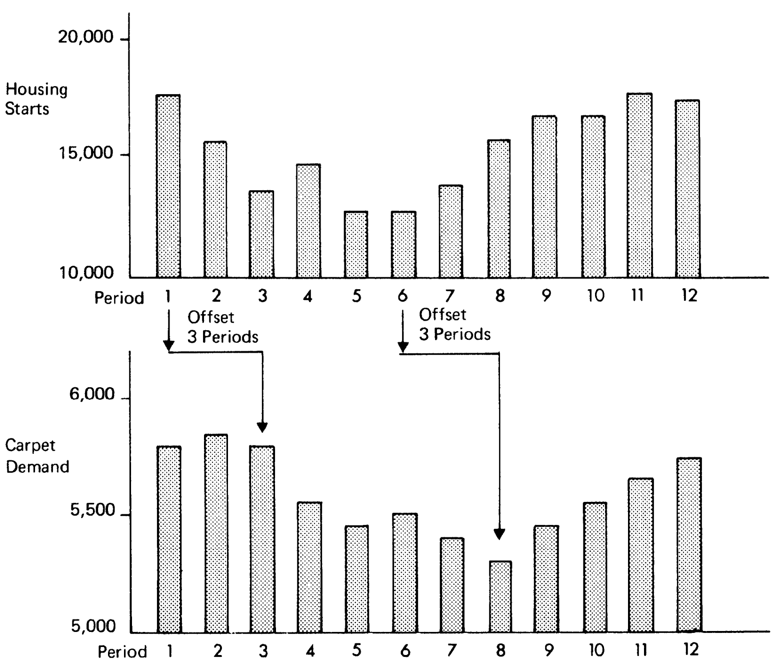


Figure 43. An indicator is "leading" when a change in its level precedes a proportionate change in the level of demand by a fixed number of time periods

If a leading indicator, which is closely associated with demand, can be found, forecast accuracy can be significantly improved. This is because the projection is based on actual fact and not on some estimate.

Projecting with indicator forecasts

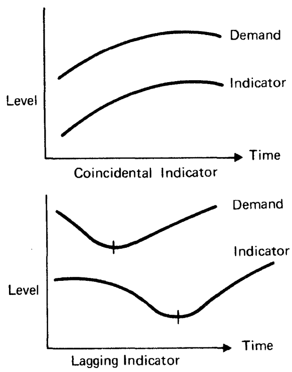


Figure 44. Examples of coincidental and lagging indicators

In many cases the indicators are not leading but are coincidental or lagging (Figure 44). The level of demand changes in the same period with a coincidental indicator. With a lagging indicator, changes in demand precede a change in the indicator. Therefore, before a forecast of demand can be made, a forecast must be made of the indicator(s). For example, the relationship established in Figure 42 is an increase of 200 units of carpeting for every increase of 3,000 housing starts. If this relationship were coincidental, a forecast of 6,000, 9,000, 9,000 and 12,000 housing starts in periods 1 through 4 would yield a forecast for carpeting of 400, 600, 600 and 800 units in periods 1 through 4.

The advantage of extrinsic forecasting with coincidental or lagging indicators is that it can use the "expert" forecasts made by government agencies and trade associations that have access to more data about the economy or the industry. In effect, once the causal relationship is found and the forecast model established, these organizations are actually making the projection.

The accuracy of the demand forecast is, of course, at the mercy of the accuracy of the indicator forecast. However, the forecasting system can measure the reliability of indicator forecasts (if not already supplied by the agency) and can reflect it in its reliability estimate of demand. Forecasts of indicators can also be made by the company itself.

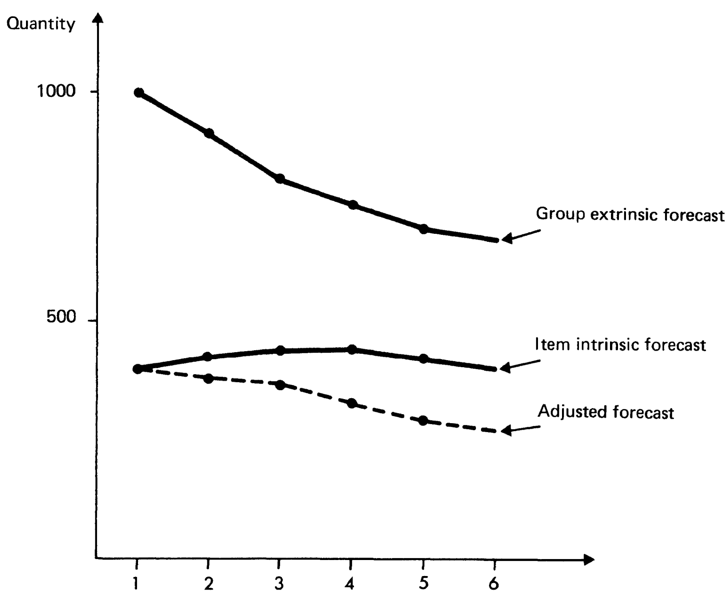
Econometric Models

Econometric models go several steps further than those previously discussed. In addition to establishing a relationship with economic indicators, econometric models establish a relationship with factors which, for example, may be under the direct control of the company forecasting demand.

A model may attempt to measure statistically the effect of factors such as price changes, type and amount of advertising, salesman's compensation adjustments, sales contests, etc., on a product's demand. With such a model, management can test the impact of alternate corporate strategies before implementing them.

A company may employ both intrinsic forecasting methods for individual items and extrinsic forecasting for the group to which the item belongs. If detailed analysis of the forecast's impact on company resources is to be evaluated, the effect of the extrinsic forecast must be reflected at the item level and not the group level. For example, extrinsic forecasting provides demand for all plastic pipe used for commercial plumbing (the group). Intrinsic forecasts project the trend by size of pipe (the item). Even though the intrinsic demand for large-size pipe may be increasing, the effect of a forecast reduction in housing starts may be a reduction in its level of demand.

A technique for allocating an extrinsic demand forecast to the items within the group is to adjust the item forecast by the relative change in the group forecast. Figure 45 shows an extrinsic forecast of a downward trend. This trend can be expressed as a relative change from period 1 by a series of adjustment factors, for example, period 3 is 80% of period 1, etc. The adjustment factors are applied to the intrinsic forecast to develop a combined forecast.



Extrinsic adjustment factor	1	0.9	0.8	0 .75	0.7	0.675
Intrinsic forecast	400	420	440	440	420	400
Combined forecast	400	378	352	330	294	270

Figure 45. The relative change in the extrinsic group forecast can be used to adjust the individual intrinsic item forecasts

Forecasting Product Options

In manufacturing, there is a definite plan to assemble a specific quantity of an end product, such as tractor or an electronic instrument. It is called the master production schedule and it is *exploded* to obtain detailed requirements of components, subassemblies, and raw materials (see *Chapter 5, Inventory Management*).

There may, however, be a number of options and accessories that are not specified until the firm customer order is received. For example, the tractor may have one of several kinds of transmission, and the electronic instrument may have various voltage ranges or special protective covers. *Variations* usually refer to something like a transmission, where one is needed on every product, but there are alternatives. *Options,* such as special covers, include the alternative of not supplying any at all. Both variations and options are treated in the same manner by saying that the absence of an option is a variation.

For example, suppose that there were only two variations, A and B. Historically, A has been used on the average 40% of the time and B 60%. If the production schedule calls for a total of 100 units, we can estimate that 40 of option A and 60 of option B need to be available to make 100. In any one period, however, the mix can be quite different. It would be possible for one series of orders to require 60 of option A, but since the planning schedule is for only 100 there could then be only 40 of option B.

One common approach in material requirements planning is to provide some sort of cushion, or protection, in addition to the average requirements of the options. For example, one could add "10% for protection" and cover 44 of option A and 66 of option B. There will be, on the average, a total of 10 option units not used, but there is no way of knowing which ones.

Alternatively, each option could be forecast independently, with a buffer inventory built for each option. This may lead to excess inventory and a situation where option inventories get out of balance with finished product forecasts and demands.

Another approach can be taken when the total for the end product is already known (forecast). Instead of forecasting each option, all that is needed is the probability of each option being present on an order. The exponentially smoothed average percentage of each option's appearance is a good estimate of that probability; that is, option A appears 40% of the time, B 30%, C 20%, and D 10%.

A mathematical relationship known as the binomial theorem makes it possible to compute quite accurately the average deviation of the number of each option required. Knowing the average deviation allows the amount of buffer stock of each option to be calculated. The difference is that starting with a known end product schedule, the use of the binomial theorem makes sure that the feature forecast will be kept in balance with the end product schedule.

The further application of this concept is presented in *Chapter 5, Inventory Management.*

Summary

Forecasting techniques are used in many areas in manufacturing. A forecast is essential for the development of the master production schedule, which initiates all detailed production planning.

All companies now forecast in one way or another. Computers can be used to improve forecast accuracy by using advanced forecasting techniques and impartially analyzing all available data. A computer forecasting system also calculates the forecast error. The measure of this error (MAD) is used by the planning systems to determine the size of business buffers such as finished goods inventory and work-in-process inventory.

The system also makes it easy to apply modifications to the forecast based on judgment. The accuracy of long-term forecasts is improved through the use of life curves.

The choice of the forecasting technique depends on the importance of the item. For slow-moving, inexpensive items and for most management standards, simple exponential smoothing procedures are sufficient. For items where seasonality is the principal concern, adaptive forecasting models can improve accuracy.

For major product groups, extrinsic forecasting techniques may discover economic indicators closely related to demand. The extrinsic group forecast can be used to modify realistically the intrinsic item forecast.

Improvement in forecast accuracy eliminates many of the unrealistic and costly schedule changes that production planning is requested to meet. Knowledge of forecast error allows realistic business buffers to be planned. This, in turn, allows production planning to absorb normal fluctuations without expensive expediting and overtime. The forecasting techniques allow management to balance the requirement for a level production schedule with the requirement for a forecast responsive to customer requirements.

Chapter 4. Master Production Schedule Planning

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Introduction

Every manufacturing company faces the same fundamental questions: What products should be produced? In what quantity? By what date? Without the answers to these questions, no detailed planning is possible. MASTER PRODUCTION SCHEDULE PLANNING *outlines the information needed to answer these questions and maintains the results in the form of production schedules for all end items.*

The production schedule for a product normally reflects predicted or actual customer demand. A change in the forecast implies an adjustment to the schedule. When implemented, MASTER PRODUCTION SCHEDULE PLANNING *can be used to help adjust production schedules in accordance with changing demand.*

Customer demand is not the only factor involved. For instance, production rates are often leveled over a period of time; demand fluctuations cannot always be followed, and items are made for "stock" in periods of low demand. Under the concept of MASTER PRODUCTION SCHEDULE PLANNING, *production schedules can be based on average predicted demand, and so stabilize production rates.*

Because production resources are limited, it is often not possible (and sometimes not worthwhile) to meet every demand. Certain choices must be made which the system alone cannot determine; human judgment is necessary. Production schedules normally cover a wide range of products and represent a variety of conflicting considerations, such as the demand, cost, and selling price for each product; the availability of men, machines, material and money; the company's marketing strategy and investment policy.

To determine the best end item schedules, which together constitute the master production schedule, requires an assessment of a large volume of information that must be summarized conveniently for decision-making. When implemented, MASTER PRODUCTION SCHEDULE PLANNING *can provide the information necessary for management decisions.*

When all these factors are considered, the number of feasible *combinations* of schedules for all products may be limitless. How can the best combination, and thus the best master production schedule, be chosen? It is impractical to try out each possibility on the shop floor; a prediction of the results from the most likely production schedules is required. If the effect of each plan is tested in advance, or *simulated,* management can make the necessary comparisons before making decisions. The MASTER PRODUCTION SCHEDULE PLANNING *concept includes fast simulation of alternative master production schedules.*

For illustration, assume that a management meeting has been called to consider changes to the current schedules. The company manufactures power tools, and Marketing is confident that sales of a certain hand drill could rise considerably next year as a result of an advertising campaign. The current forecast does not reflect this potential increase in sales.

An inquiry is made into the system and the current sales forecast for the hand drill is displayed on a terminal in graphic form (Figure 1). If this forecast is now thought to be too low, a new forecast can be "drawn" on the terminal screen.

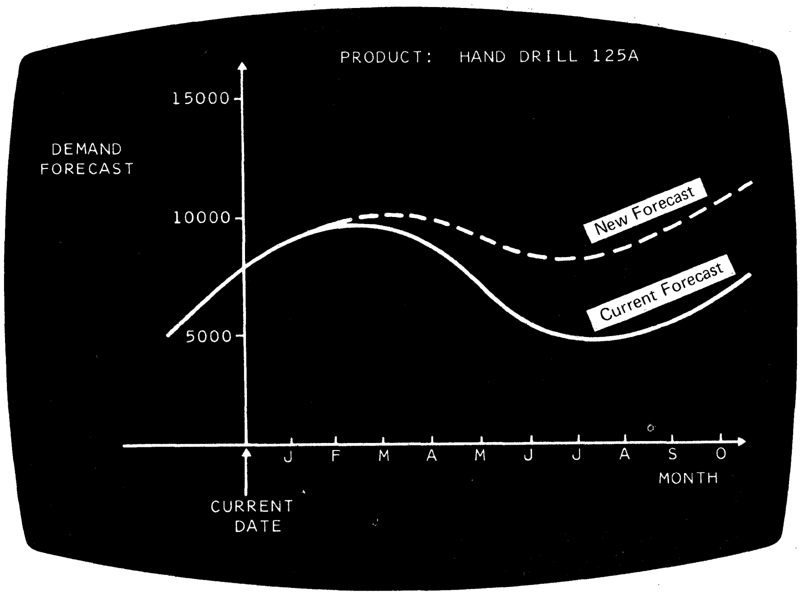


Figure 1. End item demand forecast can be displayed and altered graphically

Though the demand for hand drills is seasonal, it is management policy to maintain a level production rate throughout the year. The next step is to determine the average rate of production required to meet the increased demand. The system displays this rate on the screen, together with the current schedule (Figure 2). The difference represents a 50% increase. But is this possible with the present labor force? In particular, the final assembly department for this product is known to be working at full capacity.

In response to a further inquiry, the system displays three lines (Figure 3) showing:

- The work capacity of the department concerned
- The current workload
- The effect of the proposed increase

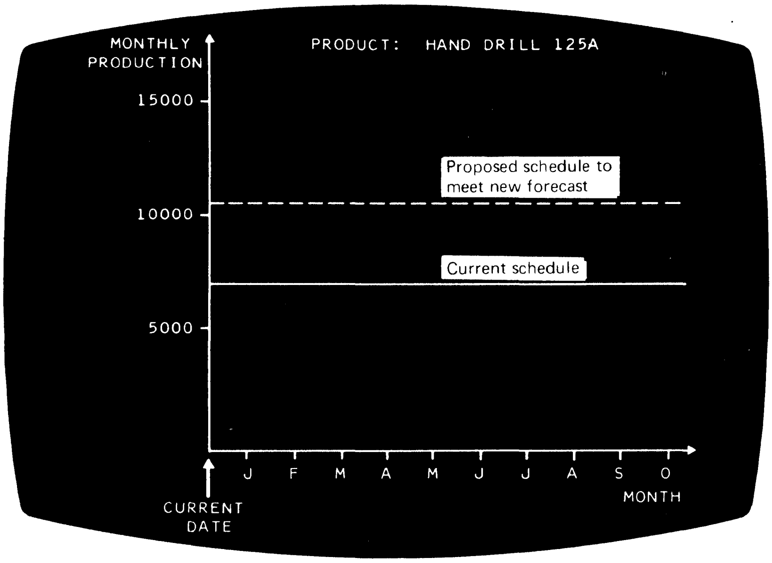


Figure 2. Revised and current production schedules are displayed for comparison

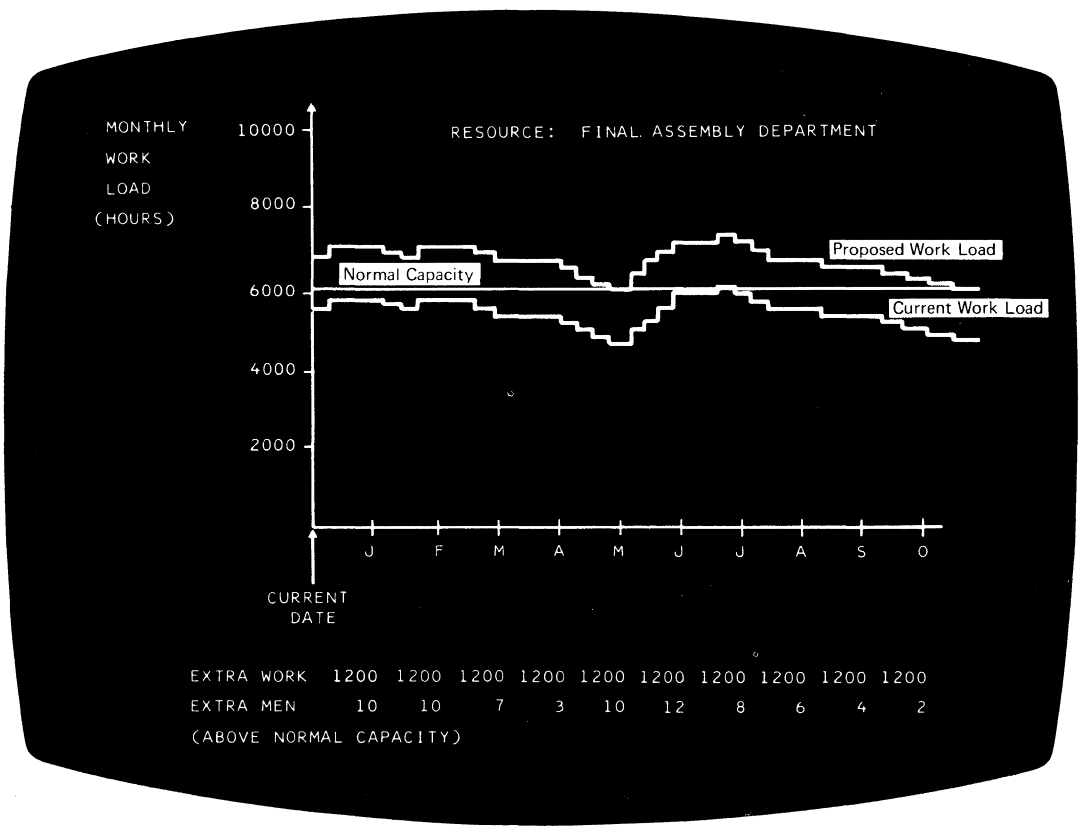


Figure 3. The effect of changed demand on selected resources is displayed

The increase would demand about eight extra workers. The management group thinks that these could probably be transferred from another underloaded department, and verifies this possibility by further "conversation" with the computer system, along the lines just mentioned.

Once the changes are agreed upon, both the forecast and the production schedule for the hand drill must be updated. The system is accordingly "informed" that the changes to the schedule should be made firm. MASTER PRODUCTION SCHEDULE PLANNING *is designed to allow adjustment of the master production schedule in accordance with management decisions.*

The individual end item production schedules constantly maintained by the system make up the master production schedule and thus represent a master plan that forms the basis for all future manufacturing operations. It must be a reasonable estimate of what will actually happen if detailed planning is to be effective.

Any such plan imposes certain demands on the company's resources: on design, machining, and assembly departments; on finances; on storage space. For efficient planning, these demands must be known well in advance. The design of MASTER PRODUCTION SCHEDULE PLANNING *includes long-range estimates of the demands on company resources.*

These long-range estimates may be for a number of years ahead. How far ahead planning is done depends on the industry, the environment, and the type of product.

Functions of the master production schedule

A production schedule is defined as a statement of requirements for a particular end item, specified by date and quantity (Figure 4). Such schedules reflect management policies as well as customer demands. Together, for all end items, they constitute the master production schedule, which represents the overall manufacturing program for a plant. The master production schedule represents a plan of *production,* and should not be confused with a *forecast.* The functions of developing a forecast, and laying out a schedule of production, should be kept distinct.

MASTER PRODUCTION SCHEDULE PAGE 25

PRODUCT: ELECTRIC MOTOR 927

MONTH	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	
QUANTITY	700	750	800	850	900	900	900	900	

Figure 4. Production schedule for an individual end item

MASTER PRODUCTION SCHEDULE PLANNING maintains the production schedules for each end item (including selected service parts, or spares) manufactured by the company. Production schedules for all other items are maintained in INVENTORY MANAGEMENT and cover:

products represented on the master production schedule

- Items whose demand is wholly *dependent* on the requirements for end items and higher-level assemblies (that is, component parts).
- Items that are made to meet both *independent* demand (forecast demand) and *dependent* demand (component parts). Examples are service parts that are also used for current production.

In industries that manufacture complex, highly engineered products (such as machinery, electrical equipment, etc.) it is not practical to maintain production schedules in terms of the products themselves. Instead, major (highest-level) assemblies are treated as end items for production schedule purposes. For instance, a heavy vehicle would be made up of a chassis, engine, transmission, etc. Each of these would have its own production schedule.

The master production schedule has two principal uses:

principal uses of the master production schedule

- Over the "short horizon" – to serve as the basis for planning short-term material requirements (assemblies, manufactured and purchased components, raw materials) and production capacities, as well as to govern shop priorities.
- Over the "long horizon" – to estimate the long-term demands on the company's resources: required capacity (plant, machines, manpower), engineering workload, cash requirements, etc.

Short Horizon. To determine requirements at *all* levels of manufacture, end item production schedules are "exploded" through their respective bills of material, as described in *Chapter 5, Inventory Management.* The result is a series of detailed production schedules. MATERIAL

REQUIREMENTS PLANNING determines when work should be started on each item. If these start dates are to be feasible, the time span covered by the master production schedule must equal or exceed the total manufacturing lead time for the product (Figure 5), so that production or purchase of the lowest-level items can be initiated. This time span is known as the "materials planning horizon". Note that its length can vary with the end item concerned.

In this respect the purpose of MASTER PRODUCTION SCHEDULE PLANNING is to make a "trial fit" of the master production schedule before finalizing it for the detailed planning of both material requirements and capacity requirements.

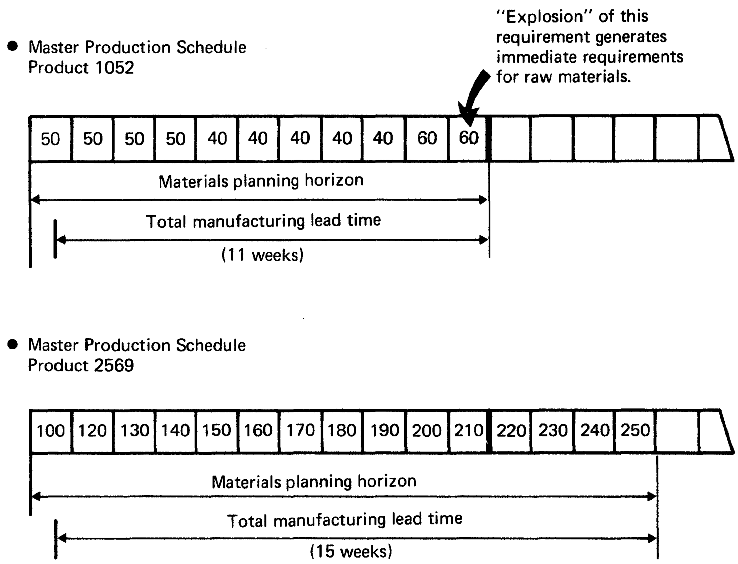


Figure 5. The materials planning horizon must be equal to or longer than the total manufacturing lead time

The master production schedule also plays a very important role in governing shop priorities. Shop order (and purchase order) due dates established by MATERIAL REQUIREMENTS PLANNING are the direct result of the timing of end item requirements as stated in the master production schedule. The master production schedule thus governs the relative priorities of all open shop orders. Job (operation) priorities are determined principally through shop order due dates. MATERIAL REQUIREMENTS PLANNING has the ability both to establish and to *maintain* valid order due dates, provided that the master production schedule is kept valid at all times. If the master production schedule is unrealistic in terms of capacity (for example, if behind-schedule work is piled on top of current-period work, thus exceeding available capacity), formal shop priorities generated by the system will break down and the "informal system" of expediting according to the assembly shortage list will take over.

The same situation will occur if the master production schedule specifies requirements that are impossible to meet because of critical machine breakdown, delayed vendor deliveries, excessive scrap, etc. To maintain valid shop priorities, the master production schedule must not exceed gross productive capacity in any one period, and must also be adjusted, as required, to reflect the realities of production.

Long Horizon. RESOURCE REQUIREMENTS PLANNING provides long-term estimates of resources required to meet the master production schedule. Because some of these resources, such as new machinery and plant, may take a year or more to acquire, the master production schedule normally spans a longer period of time than that dictated by the manufacturing lead time – perhaps several years (see "Resource Requirements Planning").

the changing schedule

One certainty regarding a manufacturing schedule is that it will change. Every master production schedule is in a state of flux. There may be little relationship between today's requirements and the values predicted a year or even a few months ago.

The master production schedule can be represented by a moving scroll (Figure 6). The longer the time span, the more uncertain is any prediction of requirements. As time passes, requirements are more accurately known, and when they enter the materials planning horizon they should represent a reasonably firm commitment. This commitment may change, however. Urgent customer orders may be added to the original schedule at short notice. If these orders are scheduled with less than the normal manufacturing lead time, requested delivery dates and quantities may be changed, etc. Thus the master production schedule can be considered static only when it becomes history.

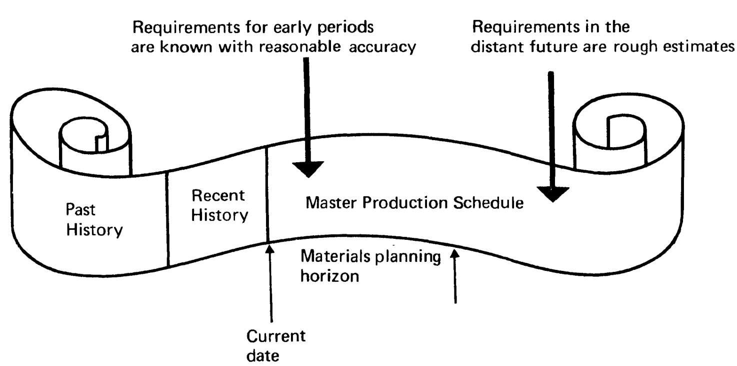


Figure 6. The master production schedule is constantly changing

Problems with Manual Systems. Because of the amount of information involved, constant updating of schedules to reflect changing requirements is a problem in manual systems. By the time one change has been made, new ones are necessary. The limited time available for decisions makes it even more difficult to experiment with alternative schedules, and impossible to determine the full effect of each. As a result, long-range planning by manual methods is normally performed infrequently, with little consideration of alternative plans, and with results that often do not reflect the current market environment.

System functions

As Figure 7 indicates, the major functions designed into the MASTER PRODUCTION SCHEDULE PLANNING concept are to:

- Estimate the total long-term demands on the company's resources – manpower, equipment, and money
- Plan the gross capacity requirements on the engineering and production departments and other critical facilities such as indirect labor, warehouse space, and transport facilities, thereby ensuring that the plan is not beyond the ability of the company to implement it
- Provide information that will enable management to determine the best production schedule for each end item, within the planned resources
- Maintain the master production schedule as changes occur (forecast changes, changes in customer requirements, etc.) and notify management of any out-of-line situations, such as excessive overloads or expenses
- Provide a simulation or "look-ahead" capability by which management can test the effect of alternative master production schedules and changes in capacity

Relationship with other application areas

MASTER PRODUCTION SCHEDULE PLANNING is a "gross" planning function. Its purpose is to ensure that production schedules are feasible and that the detailed plans developed from them can be executed. Its relationship to the other application areas of the overall system is shown in Figure 7.

The detailed planning systems that depend on MASTER PRODUCTION SCHEDULE PLANNING are:

- MATERIAL REQUIREMENTS PLANNING (see *Chapter 5, Inventory Management*). This system determines the requirements for all lower levels of production – assemblies, manufactured and purchased components, and raw materials. The master production schedule, which is the prime input to MATERIAL REQUIREMENTS PLANNING, ensures that adequate lead time will be available in

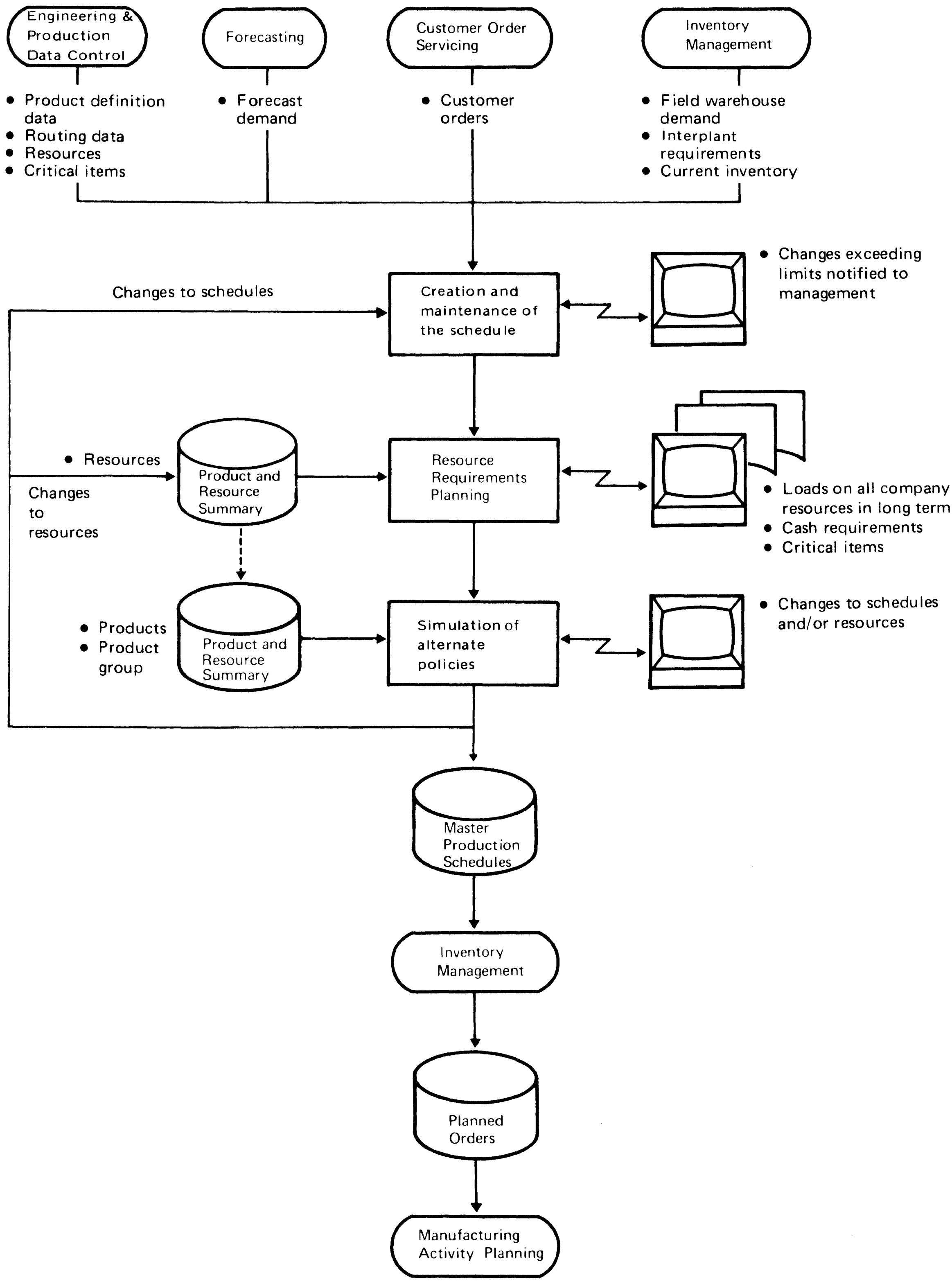


Figure 7. The functions of MASTER PRODUCTION SCHEDULE PLANNING and its relationship with other application areas

which to order materials, and that capacity will also be available to manufacture the planned orders.

- MANUFACTURING ACTIVITY PLANNING (see *Chapter 6*). This system determines detailed capacity requirements imposed on the production facilities (work centers, machine groups, and individual machines). It also determines shop order release dates and, on the basis of priorities, the sequence in which orders will be processed. MASTER PRODUCTION SCHEDULE PLANNING provides a gross estimate of the loads on the overall resources of the company to ensure that adequate capacity can be made available in sufficient time and that there are few overloads or underloads that cannot be resolved later by MANUFACTURING ACTIVITY PLANNING.
- PURCHASING (see *Chapter 10, Purchasing and Receiving*). This system is notified of critical items planned for in MASTER PRODUCTION SCHEDULE PLANNING, critical items being those with lead times longer than the materials planning horizon – for example, certain castings and raw materials.
- COST PLANNING AND CONTROL (see *Chapter 12*). By calculating the planned load (in hours) on production resources and converting it into monetary terms, the system can determine the cash requirements needed to meet the production schedules. The projected cash income can also be established on the basis of expected delivery dates (shipping budget).

Input to MASTER PRODUCTION SCHEDULE PLANNING comes primarily from FORECASTING, CUSTOMER ORDER SERVICING, INVENTORY MANAGEMENT, and feedback from other systems:

- FORECASTING (see *Chapter 3*). The input from this source is in the form of a forecast demand on the plant; that is, it is the best estimate of what products Sales requires from Manufacturing. It includes human judgment factors, application of life curves, etc. The forecast demand from Sales is not, in itself, a production plan, but is converted into a master production schedule on the basis of:

  Inventory policy

  Availability of resources

  Maintenance of stable production
- INVENTORY MANAGEMENT (see *Chapter 5*). Forecast demand for field or branch warehouses is lot-sized according to handling loads and delivery schedules before becoming input to MASTER PRODUCTION SCHEDULE PLANNING (see "Field Warehouse Inventory Control" in *Chapter 5, Inventory Management*).
- CUSTOMER ORDER SERVICING (see *Chapter 2*). This system allocates specific customer orders against the master production schedule and checks orders that do not fit within this schedule.

On an interactive basis, management can decide whether to accept the schedule change or reject the order. Accepted orders revise the planned product availability established by the master production schedule. In industries manufacturing "to-order" or "custom-built" types of products, the complete master production schedule may be built up in this way.

- *Feedback from other systems.* Much of the basic data used in planning is generated and maintained by the other systems, that is, work center capacities, bills of material, routings, forecast data, cost data, and inventory and order status. It is extracted and used as required by MASTER PRODUCTION SCHEDULE PLANNING.

Net change

All information processed by MASTER PRODUCTION SCHEDULE PLANNING can be in the form of a "net change". This means that only the plus or minus changes to the original schedule are input to the detailed planning systems. In Figure 8, for example, the original production schedule calls for 50 items per period. If the revised schedule now calls for 60 items from periods 5 to 7, and only 40 items in periods 9 to 11, the information passed to MATERIAL REQUIREMENTS PLANNING will be +10 in periods 5 to 7 and -10 in periods 9 to 11.

Normally, changes to forecasts occur only at the end of a period (monthly, quarterly, etc.). Other changes, such as new or changed customer orders, may occur at any time. These changes can be accepted by MATERIAL REQUIREMENTS PLANNING as they occur.

Original Master Production Schedule - Product A

Period	1	2	3	4	5	6	7	8	9	10	11	12
Requirement	50	50	50	50	50	50	50	50	50	50	50	50

Revised Master Production Schedule - Product A

Period	1	2	3	4	5	6	7	8	9	10	11	12
Requirement	50	50	50	50	60	60	60	50	40	40	40	50

Net Change to Product A

Period	5	6	7		9	10	11	
Changes to Requirement	+10	+10	+10		-10	-10	-10	

Passed to Material Requirements Planning

Figure 8. Net change. A change to a production schedule involves passing only the plus or minus changes to MATERIAL REQUIREMENTS PLANNING

Creation of the Schedule

A master production schedule is a statement of future requirements on production resources. The method of determining these requirements varies with the type of industry. In "repetitive" manufacturing, future requirements are generally based on past demand. Forecasting techniques are used to project past values into the future. In nonrepetitive manufacturing, forecasting plays a less important part. In a company making large turbines, known customer orders may represent the total production requirements over several years. But even in this environment some forecasting is necessary.

In many companies the environment usually lies between these two extremes, causing the master production schedule to be derived from a number of sources.

Requirements Based on Past Demand

A forecast is usually based on historical demand for standard products and service parts. It may, however, be modified according to management's prediction of future conditions. The following types of requirements are reflected in the forecast:

- *Field warehouse requirements.* The demand that the field (or branch) warehouse places on the plant is based on the forecast demand on the warehouse. It is lot-sized by the warehouse into the required delivery shipments.
- *Orders for stock.* In order to maintain a stable work force, products are often manufactured during periods of low demand in anticipation of future orders (see "Stabilization Stock"). Stock replenishment orders, where sales are made from factory stock, also belong in this category.
- *Customer orders.* Where no forecast demand exists (as for large custom-manufactured products), the schedule consists primarily of firm customer orders. In repetitive manufacturing, anticipated customer orders are normally represented by the forecast quantities in the schedule. Orders accepted above this level, however, would be added to the master production schedule.
- *Interplant orders.* These are orders placed by other plants of the company for items manufactured by a given plant. These orders are normally the net requirements developed from "exploding" the master production schedule at the ordering plant.

The individual requirements from each of the above sources are defined and consolidated for input to the master production schedule. Current inventory and capacity availability are then considered before the master production schedule is finalized.

The demand model

Developing a forecast model is discussed in *Chapter 3, Forecasting.* A demand curve, or "model", is fitted to the values for past demand and projected into the future. Demands can be expected to lie within certain limits of the projected values (Figure 9). When the demand consistently falls outside these limits, a new model is derived.

The model reflects any trends in the past demand and also detects seasonal fluctuations. The fitting of the model, its projection, and the calculation of the limits, can be performed automatically by the system, using statistical techniques.

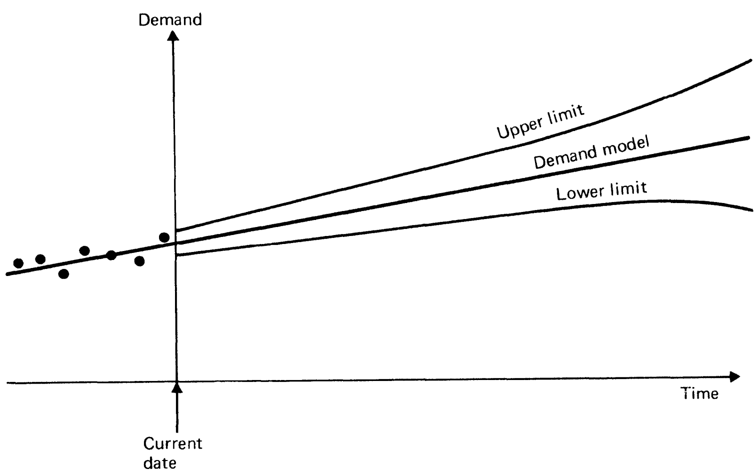


Figure 9. Confidence limits are placed on a demand model projected from past demand

The demand forecast

The demand model is often adjusted by manual intervention. The result is the "demand forecast". The model alone can seldom provide accurate, long-term forecasts, because it cannot represent all factors governing demand. Demand can be stimulated by sales campaigns, or it can be decreased by a reduction of advertising or of salesmen's commissions. It can rise and fall with the efforts of competitors.

Similarly, when a *new* product is introduced, a demand model may not be available, and the forecast may be almost entirely a management estimate.

When a revised model is derived by the system (Figure 10), it is reviewed and adjusted, as necessary, to produce a new forecast. The adjustment may be by means of "life curves" or "judgment" modifiers, as described in *Chapter 3, Forecasting.* Each forecast is management's best estimate of customer demand for the product.

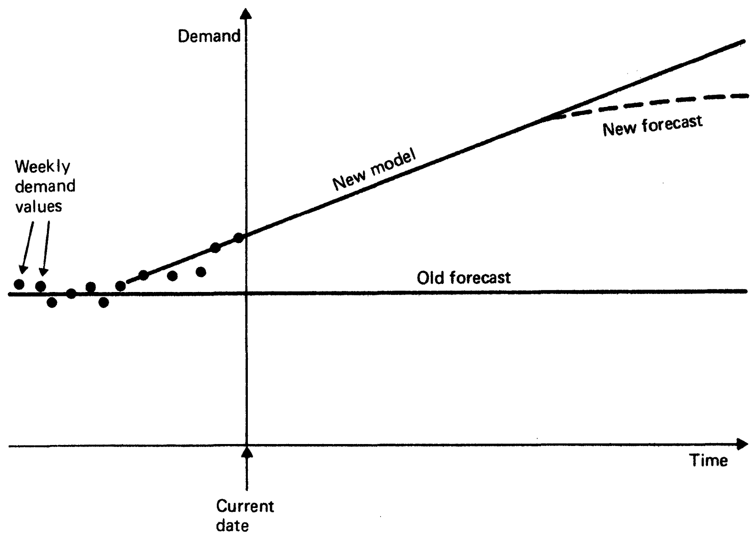


Figure 10. The system recognizes that the old forecast is invalid and fits a new "model" curve

Safety stock

Since actual demand will invariably fluctuate from the forecast demand, a buffer of "safety stock" is often planned. Its size is determined by the level of service required (see "Calculating Safety Stock" in *Chapter 5, Inventory Management*).

As a general rule, safety stock should be applied at the end item level, not the component level. The function of safety stock is to provide protection against the effect of fluctuation in demand, that is, to compensate for the forecast error. As demand should be forecast for end items (products, major assemblies, service parts) rather than for the individual components of these end items, the forecast error pertains to the former. Logically, therefore, the protection against this forecast error belongs at the end item level.

Where the master production schedule embodies safety stock, the detailed requirements and corresponding order quantities for all items below the end item level will automatically be generated by MATERIAL REQUIREMENTS PLANNING. If safety stock were applied individually for each component and raw material item, the result would be not only an excessive inventory, but ill-matched quantities of the related items as well.

Field Warehouse Requirements

Forecast customer demand on field warehouses is not used as a direct input to the master production schedule, because the requirements on the plant are based on shipments to be made *to the warehouse*, not to the customer. The master production schedule is based, therefore, on a shipping schedule for the warehouse (Figure 11). This shipping schedule is derived from forecast customer demand on the warehouse, but allows for economical handling quantities based on shipping costs, handling costs, delivery cycle, etc. The derivation of the shipping schedule is discussed under "Field Warehouse Inventory Control" in *Chapter 5, Inventory Management.*

Period	1	2	3	4	5	6	7	8	9	10	11	12
Forecast demand on warehouse	100	100	110	110	110	110	120	120	120	120	150	150
Shipping schedule required from plant	240		240		240		240		240		240	

Figure 11. The shipping schedule placed by a field warehouse on the plant is based on economical handling and carrying costs at the warehouse

Stabilization Stock

As shown in Figure 12, forecast demand can fluctuate widely – particularly in industries affected by seasonal demands, such as toys, agricultural equipment, etc. In order to maintain a stable work force, products can be made during periods of low demand and carried in inventory until a period of peak demand. This planned inventory, or "stabilization stock", ensures that production is maintained at a constant rate. The system helps determine the level of capacity necessary to meet the demand (Figure 12).

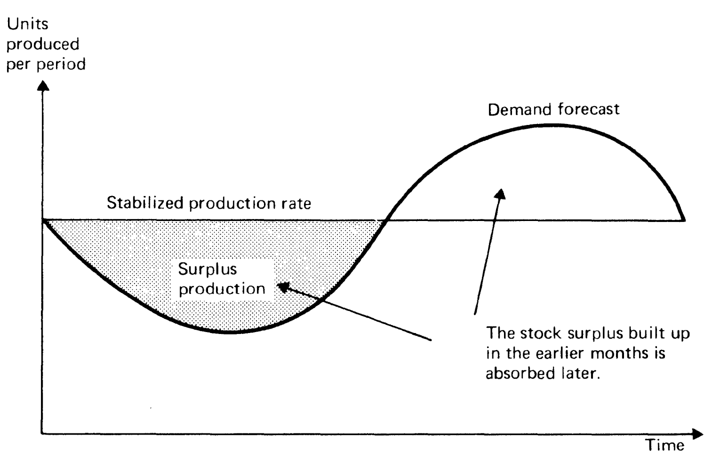


Figure 12. Stabilization stock enables production to be maintained at a constant rate during periods of fluctuating demand

Stock Replenishment

Where products are shipped to customers "off the shelf", that is, from factory stock, stock replenishment orders represent a source of end item requirements. In these cases, the individual products (typically small and of standard design) are the end items from which the master production schedule is made up.

With MASTER PRODUCTION SCHEDULE PLANNING, demand for each of the products is forecast over a planning horizon which extends beyond the next replenishment order. Several future replenishment orders, and their timing, are projected (see "Time-Phased Order Point" in *Chapter 5, Inventory Management*) so that the master production schedule can serve its function of long-range resource requirements planning and as prime input to MATERIAL REQUIREMENTS PLANNING. It is through the *planned orders* generated by the latter that capacity requirements are determined (see *Chapter 6, Manufacturing Activity Planning*).

Customer Orders

Where requirements are based on a forecast, actual customer orders are not carried in the master production schedule. Instead, the allocation of specific orders against the schedule is performed in CUSTOMER ORDER SERVICING (Figure 13). Where an order is accepted that does not fit the schedule, it has to be added as discussed later in "Trial Fitting of Orders".

Product 107420

Period	1	2	3	4	5	6	7	8	9	10	11	12
Forecast demand	(20)	(20)	(20)	20	20	20	20	20	20	20	20	20

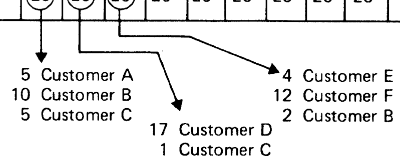


Figure 13. Allocation of actual customer orders against the schedule is done in CUSTOMER ORDER SERVICING

In custom manufacturing, where few orders are "repeats" and demand quantities are in ones and twos, previous demand is of little value. As an example, suppose a company, whose product line included locomotives, received orders for quantities of 3, 0, 7, and 2 in four successive years. Any prediction of future demand would be less accurate than the informed guess of a sales manager in close contact with customers.

In these cases statistical forecast models are not applicable, and the master production schedule consists of known and predicted customer orders. Prediction is based on past experience, the current order backlog, knowledge of the market and the economy, company policy, and judgment.

Interplant Orders

Interplant orders are orders placed by one company plant on another. They usually represent a "net requirement" of the plant placing the order.

An end item at one plant may be a "dependent demand" item (component part) at another plant. At an engine plant, for instance, the master production schedule would not include a fuel pump, because its production schedule depends on the engine manufacture. At the plant manufacturing fuel pumps, however, the master production schedule would include it because it is an end item.

The date on which the interplant item is required should allow for delivery, handling, and inspection at the ordering plant.

The Master Production Schedule

Input to the production schedule for an end item can be derived from any or all of the above sources of demand. An end item is defined as the highest-level item described by a part number. An end item is not a component to a higher-level assembly recognized by the bill of material, and thus by the material requirements planning system. Certain items, such as service parts, may have demands from many sources; others may have only one source of demand – for example, customer orders for large, specially engineered products. The accumulation of these inputs is shown in Figure 14.

Product 107420

Period	1	2	3	4	5	6	7	8	9	10	11	12
Forecast demand direct on plant	50	50	50	50	50	50	50	50	50	50	50	50
Shipping schedule field warehouse A	240		240		240		240		240		240	
Shipping schedule field warehouse B	120		120		160		160		160		120	
Interplant orders	70	100		120	50	50		130	140	100	100	
Total requirement	480	150	410	170	500	100	450	180	590	150	510	50

Figure 14. Input to the production schedule for an end item may be derived from many sources of demand

The schedule of factory requirements

Demands from any and all sources for all of the end items, when consolidated, represent a schedule of factory requirements. The master production schedule is derived from it but is not identical to it, because:

- Some of the demands stated by the schedule of factory requirements may be met from inventory.
- The load represented by the schedule of factory requirements may grossly exceed productive capacity.
- The load may show excessive fluctuation.
- The schedule of factory requirements may be stated in product models (product families) without specifying alternate optional features.
- Requirements described by sales item numbers (generically coded) require translation into major assembly part numbers before becoming input to MATERIAL REQUIREMENTS PLANNING.
- Product lot sizing considerations, important from the production point of view, are not reflected in the schedule of factory requirements.

Developing the master production schedule

The schedule of factory requirements represents the basis on which the master production schedule is developed. The considerations just mentioned apply to the process of transforming factory requirements into a master production schedule. Thus a specific manufacturing program is created that forms the basis for all subsequent planning and production activity.

In addition to safety stock and stabilization stock, the available end item inventory and any unfulfilled requirements must be considered (see Figure 15). Orders already released to the shop are taken into account in INVENTORY MANAGEMENT.

current inventory

Product 107420

Period	1	2	3	4	5	6
Factory requirement	480	150	410	170	500	100
+Safety Stock	10					
Period 1 requirement	490					
−Available inventory	60					
Master production schedule	430	150	410	170	500	100

Figure 15. Safety stock and available inventory must be considered in determining the master production schedule

The plant cannot always make a product at the rate required to meet the demand. For instance:

availability of capacity

- There may not be sufficient capacity to meet the total requirements. A plant with a maximum capacity of 500,000 hours cannot produce 600,000 hours' output (Figure 16).
- A stable work force is desirable even though demand fluctuates widely. One solution is stabilization stock. Another is to level the load when developing the master production schedule, and later by adjusting due dates of actual orders. This is discussed under "Resource Requirements Planning" later in this chapter and under "Order Release Planning" in *Chapter 6, Manufacturing Activity Planning.*

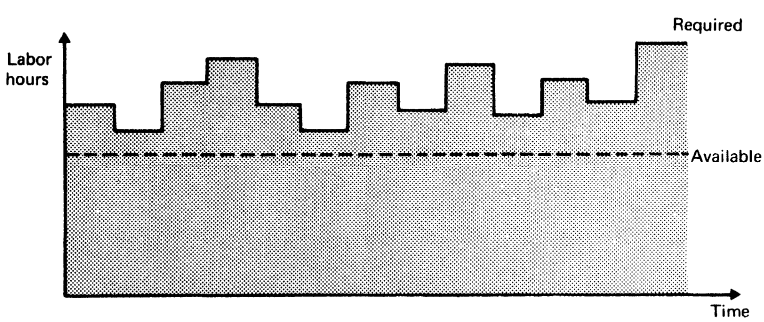


Figure 16. The master production schedule has to reflect limited capacity availability

Where production is limited by the available or planned resources, changes may have to be made to requested delivery dates or quantities. It is important that a delivery date quoted to a customer be reliable.

optional product features

In a previous example, the major assemblies or units of a heavy vehicle were discussed. Each of these units is considered an end item. In the case of product options, however, individual forecasts of demand should not be made for each unit, only for the type of vehicle itself. Hence, demand for each of the units has to be derived from the forecast for the vehicle.

The system can determine the production schedules for such options by prorating their forecast across the forecast for finished products. In so doing, the system uses a technique based on binomial theorem. This method determines how many of each type of unit must be built to meet the forecast for the required number of vehicles. For example, assume 100 vehicles are to be built and the forecast (see Figure 17) is that:

60% will require diesel engines

40% will require gasoline engines

If 60 diesel engines and 40 gasoline engines were scheduled and later the actual vehicle demand were for 63 diesel and 37 gasoline, only 97 vehicles could be completed. The probability of meeting the variation in demand is determined and it may, for example, be necessary to plan for 64 diesel engines and 43 gasoline engines in order to deliver 100 vehicles in that period. The excess stock of these units would be applied to a requirement in a later period.

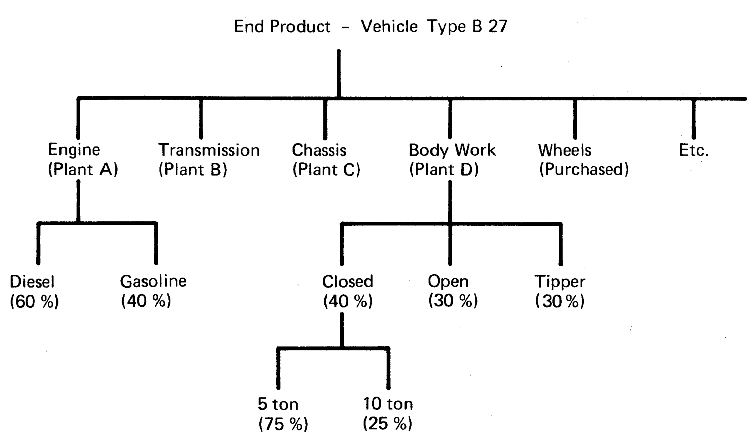


Figure 17. Optional major units or assemblies have their own production schedules based on the forecast demand for the end product

Relatively simple products (appliances, hand tools, machine attachments, clocks, etc.) are end items. So are "one of a kind" special machines engineered to order. Each complex standard product with many variable or optional features (automobiles, machine tools, industrial equipment, computers, etc.), however, is normally not treated as an end item for production planning purposes because of the often astronomical number of *feature combinations* possible. The number of unique end products would be excessive for purposes of bill of material maintenance and storage. In these cases, major assemblies and groups representing variations are treated as end items. The final product is eventually assembled from the end items planned by the system. In the process of developing the master production schedule that must be stated in terms of end items, the forecast or schedule of factory requirements, normally expressed in *generic* terms (models, product families, etc.), must be translated into *specific* codes, that is, item numbers. Only these item numbers (assembly numbers) have bills of material, and only item numbers can be input to the material requirements planning system.

product variants treated as end items

The schedule of factory requirements shows demand for the various products by quantity and date, without regard for production economics. In the process of developing the master production schedule, product lot sizing considerations will cause the individual production schedules to deviate, in both quantity and timing, from the requirements of the various sources of demand.

product lot sizes

For example, standard machine tools are not planned by ones, twos, or threes, even though those might be the factory requirements for a month, or for a quarter. The master production schedule will meet these requirements by scheduling a lot of, say, ten at a time. Additional lot sizing may take place subsequently at the component part level.

The final assembly schedule

In some industries, the master production schedule and the final assembly schedule may be identical. This would be the case with relatively simple products that have few or no optional features, and can be expressed as end items on the schedule. This would also be the case with more complex products produced "to order".

In industries that produce complex products to anticipated future demand (that is, where the manufacturing lead time exceeds customer delivery time), the final assembly schedule is created – usually on receipt of actual orders – later in time than the master production schedule.

This means that the availability of components, including assemblies, that results from planning and activities set earlier in motion by the master production schedule, acts as a constraint within which the final assembly schedule must be accommodated. It is impossible, on short notice, to build more, or different, products than the quantities of available components allow.

A master production schedule must be considered in relation to the load it places on the resources of the company. If the resources are not adequate to meet the schedule, they must be increased or the schedule modified. Resources here include not only production capacity but engineering manpower, cash, etc.

Unless the accurate planning of resource requirements takes place before the planning of production, on-time deliveries cannot be guaranteed, and much of the effort spent on detailed planning is wasted (Figure 18).

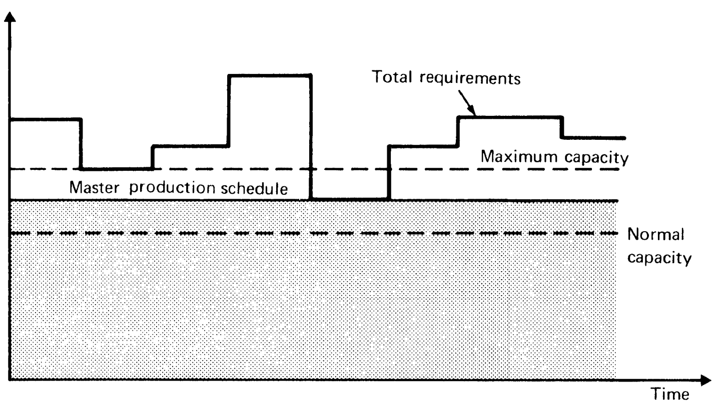


Figure 18. The master production schedule may be restricted by limitations in manufacturing capacity or other resources

The RESOURCE REQUIREMENTS PLANNING concept involves primarily a long-range planning function aimed at ensuring an effective balance between meeting customer demand at a reasonable cost and maintaining a level load on the resources of the company. It covers:

- Defining the resources that must be considered
- Determining the "product load profile" for each product, that is, how much load is imposed on the resources by a single unit of an end product
- Extending these product load profiles by the quantity called for in the master production schedule, and thus determining the total load, or "resource requirement", on each of the production facilities and other resources
- Simulating the effect of the different master production schedules in order to make the best possible use of resources

Changes to a master production schedule cause changes to resource requirements. Large increases in demand may imply expenditure for additional machinery, additional labor, and investment of cash in increased inventories. The function of RESOURCE REQUIREMENTS PLANNING is to determine the effect of such changes on the resources. A distinction must be made between changes required in the short term and those in the long term.

Short-term schedule changes

Short-term here means "within the materials planning horizon". Schedule changes within this horizon should be of a minor nature, except when demand falls off sharply. If there is suddenly increased demand, it may already be too late to react, because neither materials nor manpower can be made available in time. A buffer against such short-term fluctuations can be provided by end product safety stock, and production, therefore, need not be geared to follow every change.

The effect of short-term changes to the schedule can be simulated by techniques described in *Chapter 5, Inventory Management* and *Chapter 6, Manufacturing Activity Planning.* These techniques are used to check the availability of materials and estimate the necessary increase in work capacity. The schedule is revised only if no serious problems are revealed.

If the change is made, MATERIAL REQUIREMENTS PLANNING replans the materials and MANUFACTURING ACTIVITY PLANNING adjusts the schedule dates for individual operations or shop orders to level the load and also indicates specific needs for:

Subcontracting

Hiring new manpower

Working extra shifts

Overtime

Long-term schedule changes

Long-term changes may have more pronounced effects than short-term changes. Significantly increasing production over the next few years may make it necessary to build a new factory, buy additional machines, and hire and train a new labor force. All these resources must be made available at the appropriate time. RESOURCE REQUIREMENTS PLANNING is also essential in planning budgets, subcontracted work, etc.

Types of Resources

The resources considered in RESOURCE REQUIREMENT PLANNING are those that must be planned well in advance; they vary from company to company. They include not only manufacturing capacity (machines and manpower), but also indirect departments, such as Engineering and Drafting, and certain purchased items, factory floor space, and cash.

In general, resources should be broadly defined. For instance, an entire assembly department may be considered a single resource, even though it comprises many work centers (see *Chapter 6, Manufacturing Activity Planning*). This broad grouping has two advantages:

- The total number of resources defined is reasonably small. The resource requirements calculated by the system can be presented in an easily digestible form, facilitating management decision-making.
- Calculation of resource requirements is fast. This is an important consideration if many alternative production schedules are to be simulated.

Typical resources considered are shown in Figure 19. In certain cases, small units (an exception to the general rule) may be defined as resources. For example, if a particular class of skilled labor is in short supply, the demands on that group need special consideration and should be independently calculated. Similarly, a single bottleneck machine tool may be defined as a resource.

While a company would have to define those resources that it wishes to have covered by RESOURCE REQUIREMENTS PLANNING, the most typical resources are addressed in the discussion that follows.

Machine tools and direct labor

A machining resource normally comprises all machines with a similar function – for example, all lathes, all milling machines, etc. Critical or bottleneck machines may be treated individually or in subgroups. The level of detail at which resources are specified is dictated by individual company needs.

Direct labor can be specified as several resources, by work center and/or skill classification.

Engineering departments

Manpower in engineering departments is often critical during the development of new or improved products. This is especially true of custom-designed products where each order requires special engineering. The load on these departments is expressed in terms of man-hours, by period. It is derived from estimates based on similar types of products. Other departments that have limited resources, such as Testing, can be treated similarly.

Selected purchased items

Some materials considered as resources are those that are in short supply, or those whose purchase must be negotiated even before exact specifications are available, or whose lead time is greater than the materials planning horizon. For instance, all precision castings might be defined as a resource. The system calculates the estimated total weight required, and capacity negotiations can begin well in advance of production. When the exact requirements become known, the supplier is notified accordingly.

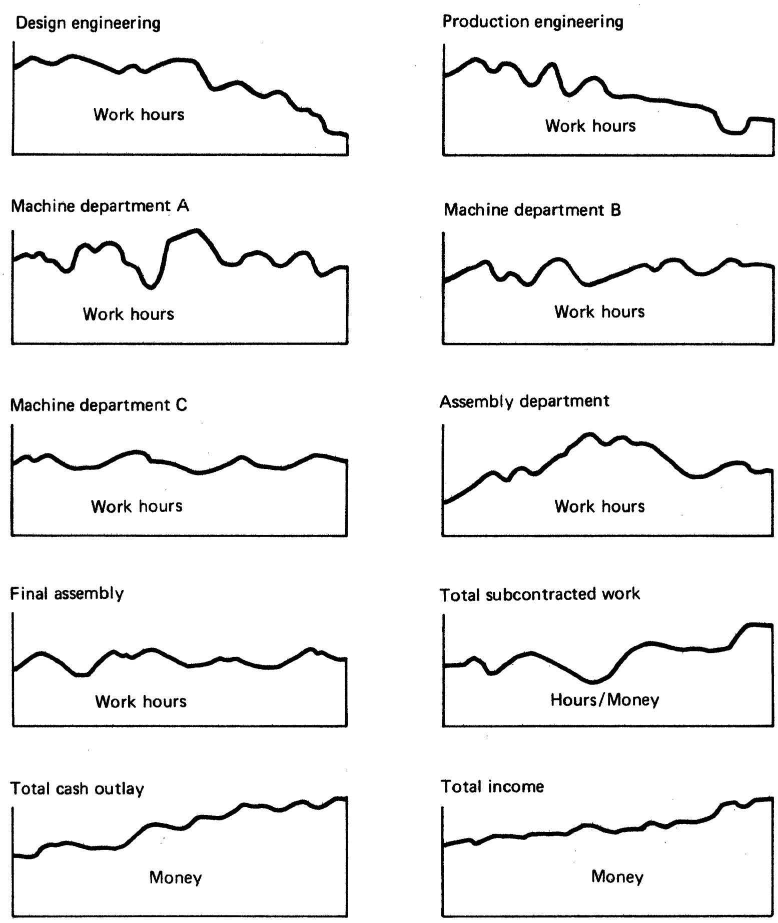


Figure 19. Some of the resources considered in MASTER PRODUCTION SCHEDULE PLANNING

Interplant and subcontractor suppliers

Where major items are normally supplied by an interplant source or a subcontractor, the supplying plant can be defined as a resource. By generating long-term estimates of the requirements for each such item, the system provides each supplier with advance information about the work he can expect.

Cash

Cash is an important resource and it is possible to determine what production costs will be incurred by implementing the master production schedule. These are estimated from the "standard costs" developed for each product by the accounting function (see *Chapter 12, Cost Planning and Control*). More detailed methods are used to calculate cash requirements for individual resources.

For example, the cash required for the payment of subcontractors is calculated from the requirements for individual subcontracted items. It is often the practice to pay suppliers of major products in instalments ("progress payments") during the manufacture of the goods. The stages at which payments are to be made, and the amount, are obtained from the purchase order record and included in Purchasing's forecast of cash commitments.

Resource group codes

When resources have been defined by management, a unique code is assigned to each. At particular times, however, it is often desirable to summarize requirements for a whole *group* of resources. If, for instance, six manpower resources are defined, as in Figure 20, they can be summarized as either "fabrication" or "assembly" resources. The system can then determine total requirements (man-hours) for each of the two resource groups. Each group is assigned a special code.

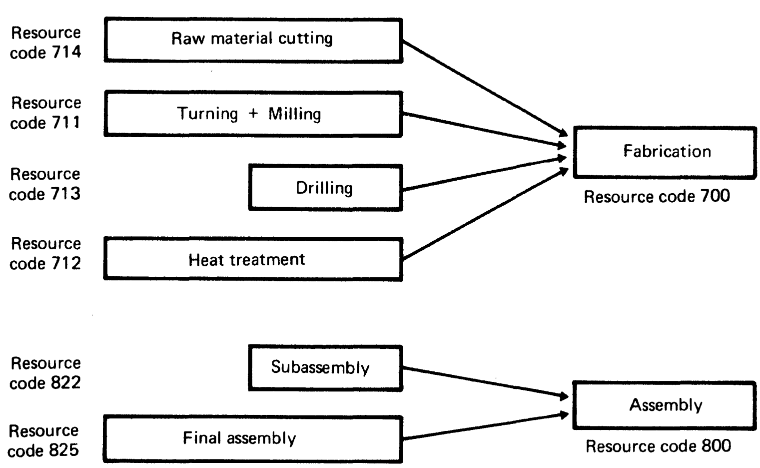


Figure 20. Individual resources can be summarized into resource groups as required

If necessary, a whole hierarchy of resource codes can be devised, and requirements determined at any level (Figure 21).

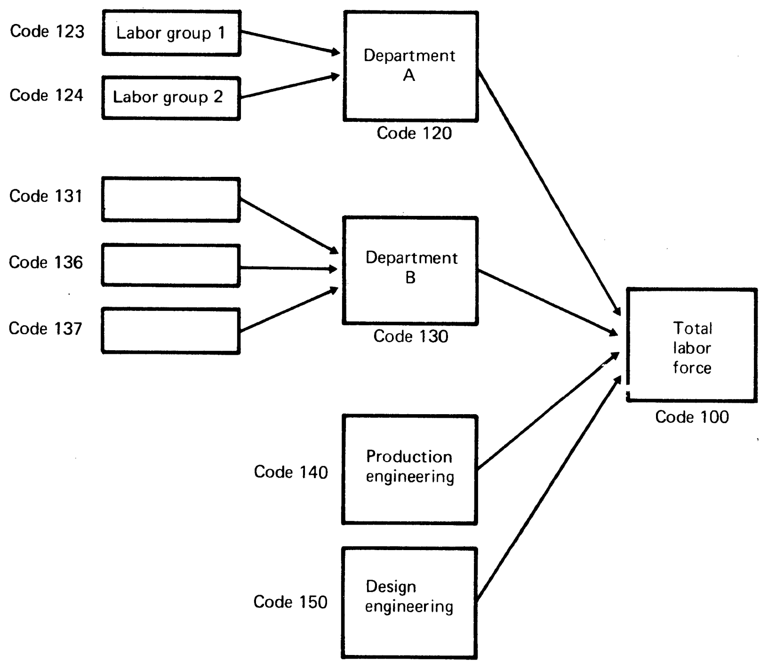


Figure 21. A hierarchy of resource codes can be developed

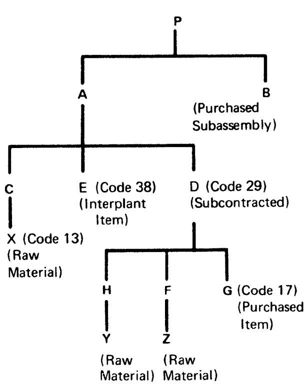


Figure 22. Resource codes for critical items can be noted at any level of the product structure

Product Load Profiles

The end item quantity in each production schedule imposes corresponding loads on the resources. The system determines these loads by time period and, by summing them across all the products represented by the master production schedule, estimates the *total* requirements for each resource.

The first step is to determine the resource requirements for a single unit of each end item. These are "product load profiles". Each end item has its own product structure indicating the components involved and their quantities. In Figure 22 many of the items (B, G, X, Y, Z) must be purchased from suppliers. One item (E) is provided by another plant within the company. Item D is normally subcontracted, that is, the components F, G, and H are sent to a subcontractor for assembly.

Each of these components, therefore, creates a "resource requirement". The system now determines *when* the resource is required in relation to the completion date of the end item. This is achieved by exploding the end item and offsetting each requirement according to its manufacturing lead time (Figure 23).

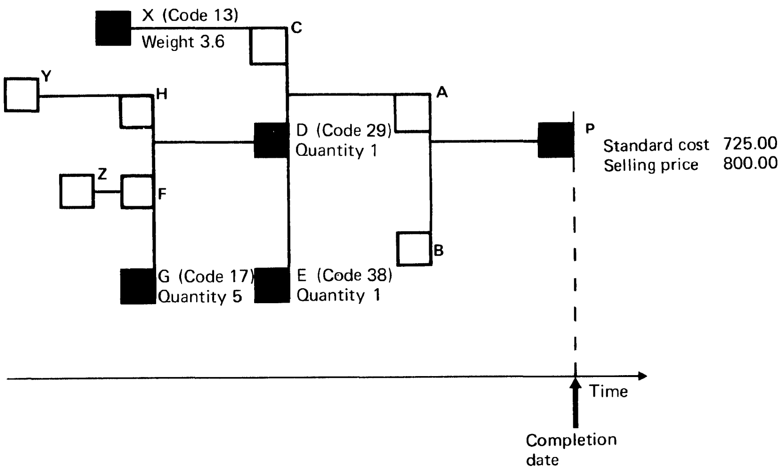


Figure 23. Resource requirements for a unit of end item P. The items shaded are critical components and are treated as loads on resources

The production of the end item also requires certain *work* resources (machines and manpower). Items P, A, C, F, and H are manufactured within the plant. The operations involved are listed in the appropriate routings. The work (number of hours) required to perform the operation on one unit of the item is the "standard run time". The treatment of setup will vary, depending on whether setup standards exist, that is, whether setup is considered direct labor or overhead expense.

Where the routings contain setup standards, setup hours are part of the product load profiles discussed in the next section. The setup load profile is stored separately from the run time load profile because of the different treatment each will receive when total loads are calculated.

If setup standards are not maintained, the resource requirement they represent must be estimated. Setup work often represents a rather small fraction of the total work required. For a given resource (for example, a group of lathes), the relationship can be established by an historical analysis of work center activity. Suppose the average total hours recorded for setup work represent 10% of the total hours of productive work. This relationship can be expected to continue, so the future requirements for setup can be derived from the resource requirements based on run times, developed for the lathe department (Figure 24).

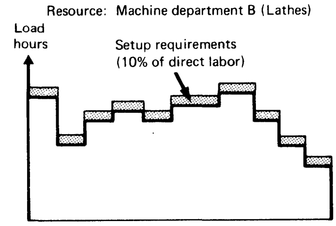


Figure 24. Setup requirements can be specified as a percentage of the run time

The system performs the necessary calculations and modifies the requirements to include the setup load. It thus determines the total hours of work required to produce one unit of end item (Figure 25).

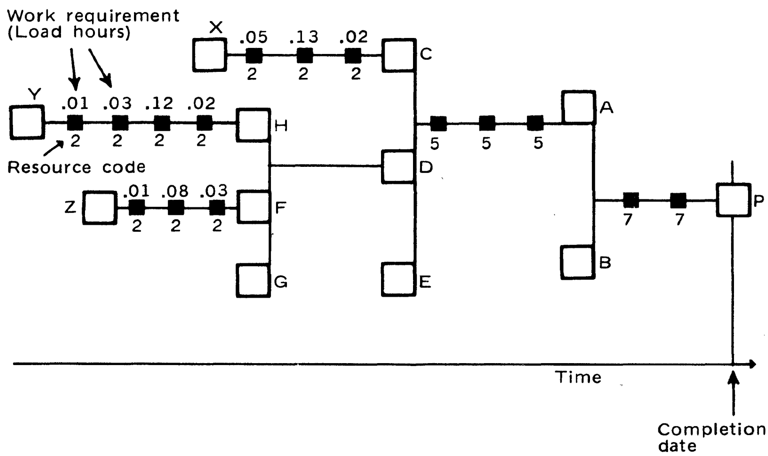


Figure 25. Resource requirement for a unit of end item P, showing the workload requirement for each manufacturing operation

The resource codes indicated are those assigned by management to the various work centers. In this example, each item is made on a single resource, and therefore has only one resource code. If a particular labor skill is critical, both machine and labor group may be defined as resources. The operation then has two resource codes and requirements for each of these can be developed.

When each end item is exploded, only gross requirements for components are developed and offset, without regard to current inventories or to lot sizing. The effect is that the dates of specific orders cannot be pinpointed. This level of detail, however, is not intended in MASTER PRODUCTION SCHEDULE PLANNING.

The system now summarizes the unit requirements for the end item. The elements are accumulated by resource and time period (Figure 26). The diagrams show the resources required in the production of one unit of the end item together with the time interval between the requirement and the completion date. This is called a *product load profile.*

The profiles are stored by the system. A set of profiles (one per resource) can be maintained for every end item. An exception to this rule is made when two or more products are variants produced by similar processing methods and therefore have a similar effect on resources (for instance, domestic and export models). Product load profiles are then derived for only one variant, which can also represent the others in determining the loads on resources.

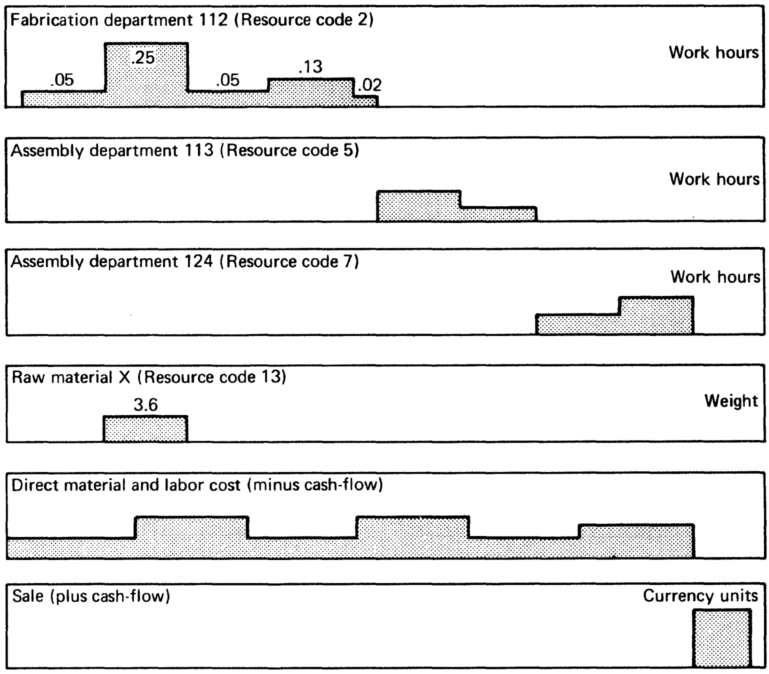


Figure 26. Product load profiles for end item P

Requirements for products with no specifications

Since MASTER PRODUCTION SCHEDULE PLANNING can cover a period of several years, it is likely that new products will be introduced during the planning horizon; the requirements they will generate have to be considered even if detailed specifications have not yet been established. In the case of products made to order, most orders (known or predicted for the future) may be for products without detailed specifications. In this type of manufacturing it is common for bills of material and routings to be prepared only weeks ahead of manufacture.

These products, however, are often similar to ones previously manufactured. Therefore, when product structures and routings are not available, product load profiles cannot be derived by the techniques described; alternative methods must be applied. Requirements for resources are developed from production estimates (Figure 27), which provide essentially the same information as the product load profiles derived by the system. In custom manufacturing such an estimate is often developed in response to a customer request for a quotation. The workload on each department is estimated and costed by the appropriate department, and material costs are finally added to complete the quotation.

PRODUCTION ESTIMATE

Customer :
Product :
Delivery Date :
Start Date :

WORK RESOURCES	Work Load (Hours)
Design Engineering Production Planning Foundry Toolroom NC Machines Other Machines Welding Final Assembly Testing	

MATERIAL RESOURCES	Weight or Value
Steel Copper Other Metals Electrical Components Miscellaneous	

Figure 27. An example of a production estimate for products with no bills of material or routings available

For the purpose of MASTER PRODUCTION SCHEDULE PLANNING, additional information is required – namely, the approximate distribution of the resource requirements across the total lead time.

The time span over which a resource is required can be many weeks or months, and usually the requirement is not evenly distributed across that span. For example, suppose a product requires 800 hours of welding work, spread over 50 days. On the average, this means two men working eight hours a day, but in fact the number of men employed varies between one or two in the early stages and perhaps the entire department during the peak period.

Because the load on each facility will vary (Figure 28), it is specified as a percentage load by period, and the system calculates the load hours in each period on the basis of the total estimate.

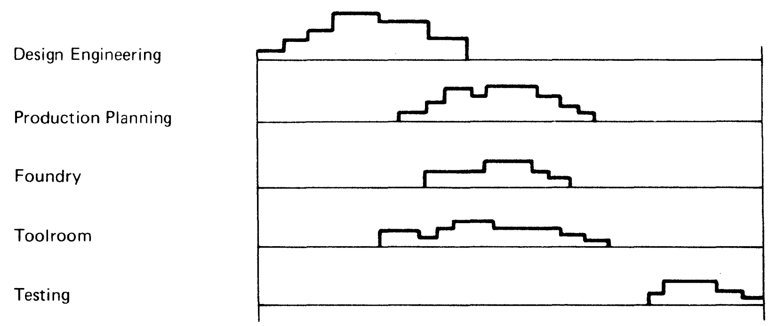


Figure 28. Typical product load profiles for a custom-manufactured product

Since a new product often resembles one produced in the past, it is possible to develop a production estimate from a previous one. For instance, two types of power generator have similar specifications and similar resource requirements. Even if the two are very different in size, their requirements are often in direct proportion and can be derived one from the other (Figure 29). Similarly, a production estimate can be a modification of a previous one.

In summary, product load profiles for products with no detailed specifications are estimated and entered directly into the system. Alternatively, if the loads can be derived from those for another product, only the required modifications are specified.

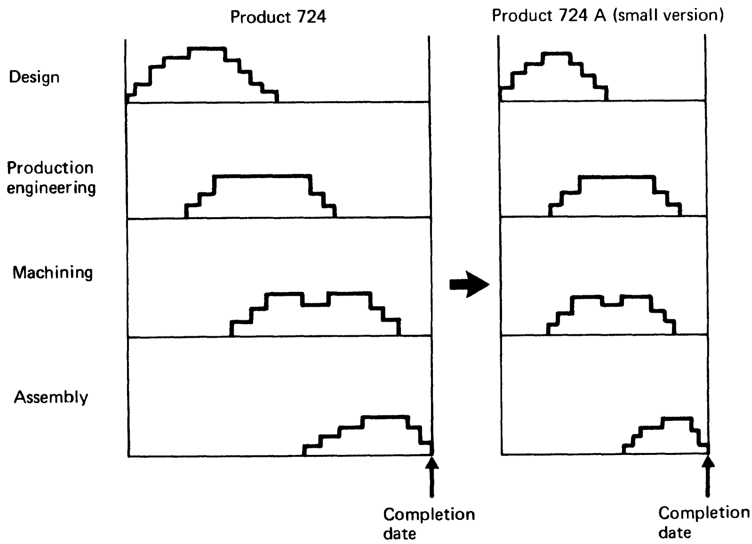


Figure 29. The product load profiles for a product can be derived from those for a similar product. The work content and time span for product 724A are 39% of those for product 724

Learning curves

The loads imposed on resources by a particular product usually change with the passage of time. When the product is newly introduced, the work takes longer. Similarly, material waste is greater and the "yield" is correspondingly low.

The effect on each resource can be represented by a "learning curve" (Figure 30). The example shows how the number of fabrication work hours required varies with the time elapsed since the introduction of the product. Only after several months is the "standard" time achieved.

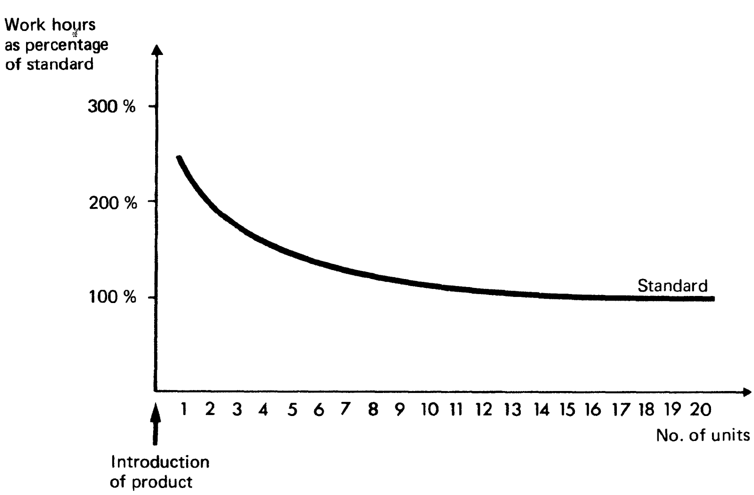


Figure 30. Learning curves can be established for each product. They are used to modify the product load profile

Learning curves are stored by the system and used to modify the product load profiles for each product (Figure 31).

Total Resource Requirements

For any end item, resource requirements across the entire planning horizon are calculated by the system; the quantities in the production schedule for each end item are extended by the hours in its product load profile and the appropriate number of setup hours is added (Figure 32). The resulting resource requirements profile (hours load) shows the resources hours required for the planned production of the end item, including all levels of manufacture. Resource requirements profiles are calculated separately for each end item. However, some products, such as service parts, may be grouped together to provide combined resource requirements.

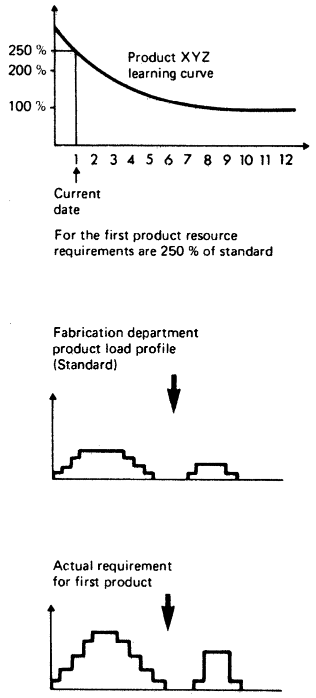


Figure 31. Resource requirements for initial production of a new product

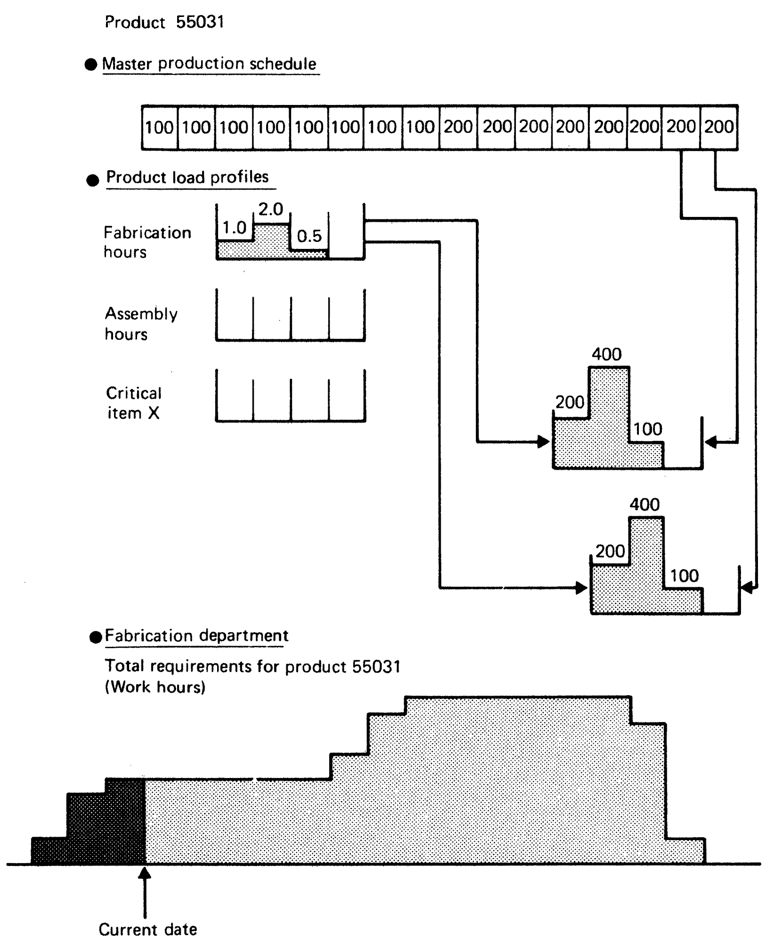


Figure 32. Resource requirements derived from the master production schedule and the product load profiles

Some requirements may fall in the past (Figure 32). This results from the explosion of end item requirements in the early periods of the master production schedule. If production is proceeding according to plan, these past requirements will have been met, and can be ignored. If production is behind schedule, some past requirements will still be outstanding and will have to be met in the future. In the context of long-term planning, their effect on the resource requirement profiles should be negligible. Custom-manufactured products, however, may need special consideration.

By summing requirements across all end items and all service parts, the total resource requirements, period by period, are derived and presented as resource requirements profiles (Figure 33). By studying these profiles, management can decide whether the master production schedule is acceptable. In particular, the system can show how a proposed change to a schedule will affect total requirements.

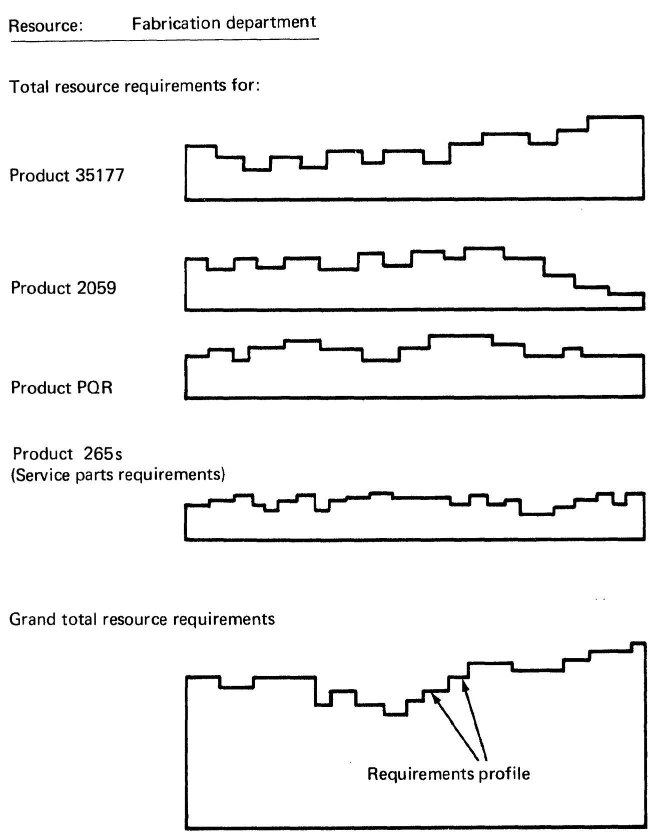


Figure 33. The profile of requirements on a resource is obtained by summing all individual resource requirements

MASTER PRODUCTION SCHEDULE PLANNING has the complementary objectives of planning the long-range resource requirements of the company and producing for each end item a production schedule that can be met with the planned resources. In achieving these objectives, the system can be used for:

- Maintaining the master production schedule on the basis of changes in forecasting demand for repetitive products, and notifying management when the demand exceeds (or falls below) specified limits
- Trial-fitting new additions or changes to the master production schedule
- Rapidly analyzing the effect of unforeseen changes – for example, changes in the market condition, bankruptcy of a major subcontractor, late delivery of planned machine tools, etc.
- Simulating the effect of alternate master production schedules and changes to plant capacity

Maintaining the Master Production Schedule

The master production schedule is the principal input to MATERIAL REQUIREMENTS PLANNING. It should not be overstated, because it would then become impossible to follow the shop order priorities established by the system – the formal priority system would break down and the informal system of expediting to the assembly shortage list would again take over.

The formal priority system will also break down if the master production schedule is not kept up to date so that it reflects the products that can feasibly be built in any planning period. If a critical machine is down, if an interplant shipment is lost in transit, if a quantity of large castings is scrapped in the last machining operation, etc., some scheduled products will, in fact, not be built on time.

In these cases, the master production schedule should immediately be changed to reflect the rescheduling of the affected product. The new schedule is then reprocessed by MATERIAL REQUIREMENTS PLANNING, which *automatically* determines new "dates of need" for *all* released orders affected. Shop priorities can then be changed accordingly and made valid again.

Failure to change the master production schedule in a case like this will cause shop personnel to discover that they are working to the wrong (system-generated) priorities. Once this happens, the formal priorities will, of course, be ignored and the shop will work on what is *really* needed.

To keep the master production schedule in line with factory floor realities is a classic problem in manufacturing management. The problem lies in the fact that with conventional methods it is very difficult (if possible at all) to identify the specific end item or product, and the exact period in the master production schedule, that are affected by an event such as the breakdown or scrap mentioned earlier.

COPICS concepts provide a solution to this problem. The "pegged requirements" capability of INVENTORY MANAGEMENT (see *Chapter 5*) is designed to trace each shop order to the specific requirement that generated it, all the way to the end item production schedule.

When an event occurs that is likely to impact the realism and validity of the master production schedule, Production Control personnel can immediately inquire into an online terminal and trace the effect of the event through the successive levels in the product's structure. Other information, such as the final assembly schedule, data from the customer order file, etc., can be displayed on demand.

This capability can materially assist management in determining what end products should be rescheduled, and how, in cases like the ones mentioned.

Automated master production schedule maintenance

In highly repetitive manufacturing, end-item production schedules can be maintained continuously by the system. Although they are reviewed by management, intervention will usually be necessary only when the system highlights demands outside the set confidence limits, or when some internal development makes it advisable to change the schedule. Of course, changes made by management can be entered whenever needed. Entry of additions and changes by management action will be the preferred method of master production schedule maintenance in many companies.

Periodically the system compares the actual demand for each end item with the demand forecast (see *Chapter 3, Forecasting*). The system calculates a revised demand forecast and extends the forecast horizon further into the future periods.

The system then can generate a production schedule from the new demand forecast and any other demands (such as field warehouse shipping schedules). Inventory policies specified by management, such as manufacturing to stock or holding safety stocks, are incorporated. If desirable, the schedule can be defined as "frozen" over a given time span beyond the current date – say, for the next month (Figure 34).

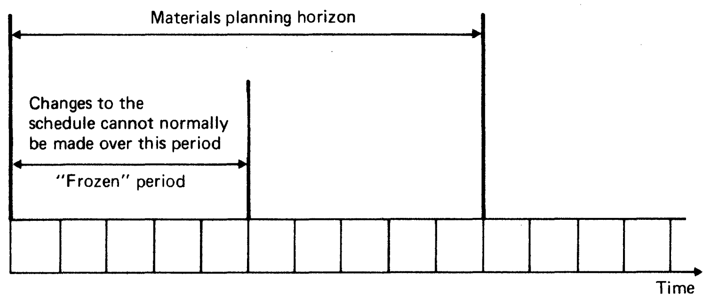


Figure 34. A production schedule can be "frozen" over a given time span

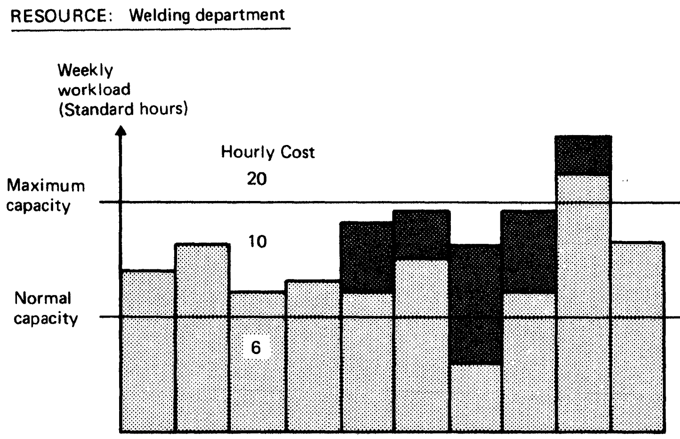
The system maintains resource requirements profiles continuously and can display them on request. It measures the effect of a proposed change to the schedule and shows the associated cost. In the case of manpower resources (Figure 35), standard costs and capacity levels are provided. The system can also determine the extra manpower required to eliminate overtime (assuming that the capacity increase is not restricted by the number of *machines* in the department).

Whenever it is thought that a demand forecast is no longer valid, management can make a new forecast by direct intervention. The system could generate a new schedule, and the effect of the schedule change could be determined again by means of a terminal display.

Schedule adjustments by management action

The importance of the master production schedule to the proper functioning of the rest of the system cannot be overstressed. A master production schedule represents the overall manufacturing program to which all of the subsequent detailed planning will be geared. Inventory management action, procurement action, and manufacturing action will be dictated, directly or indirectly, on the basis of the contents of the master production schedule.

Developing and maintaining the best possible master production schedule is the premise on which the overall success of the COPICS concepts depends. The master production schedule "drives" the several systems that are designed to plan and help in its execution. The master production schedule represents the point of main management entry



						TOTALS
Extra workload	300	200	500	350	150	1500
Extra cost	3000	2000	4200	3500	3000	15700
Extra work at standard cost (1500 x 8)						12000
					Estimated loss	3700

Extra manpower to eliminate overtime	4	6	2	3	8	9	6	9	15	6

Figure 35. The effect of changes (dark shaded areas) to the production schedule can be displayed for management review

into the system. It is through this schedule that management provides direction, initiates changes in production, and exercises control over inventories and manufacturing activities.

Management, therefore, has an important responsibility for keeping the master production schedule realistic, valid, and up to date. In most industries, the schedule of factory requirements will tend to keep changing and so will the master production schedule. These changes, additions, and adjustments to the master production schedule should be *managed*, because of their effect on inventory, manufacturing cost, and delivery performance.

changing the schedule

Each schedule change, whether merely intended or put into effect, represents a desire for flexibility, that is, freedom to change previous decisions. This flexibility is restricted, however, by the realities of *commitment.* The consequences (cost) of a previous decision constitute the practical limits of changing that decision.

If the total manufacturing lead time is six months, there is significant difference in impact and cost between changing something that is six months away from completion and changing something that is five months away from completion. In the former case, the consequences are negligible but in the latter, only one month later, money has already been spent on the processing of the respective production schedules and the placing of orders. In addition, a certain investment has been committed for materials that cannot be canceled.

This evokes the concept of *tentative* and *firm* portions of the master production schedule. Assuming that the schedule covers a period of 18 months ahead, everything that appears within the first six-month segment of that schedule represents the firm portion, that is, products in various stages of commitment and correspondingly difficult to change.

The tentative portion represents merely a plan for the execution of which money has not yet been expended. The firm portion of the schedule is of the same length at any time. It moves along the time scale, with the passage of time, progressively covering what has formerly been the tentative area. At its farthest end, the schedule is added to perhaps monthly or quarterly.

Trial Fitting of Orders

The master production schedule represents production requirements, based primarily on demand forecasts. These may be simply a consolidation of known and predicted customer demands (Figure 36).

When not shipping from stock, orders from customers are normally received in advance of final assembly. Each order received is then allocated against the master production schedule. Provided the demand is covered by the schedule, no further action is necessary.

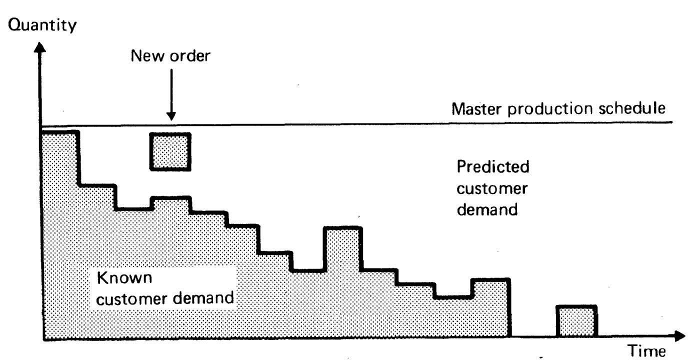


Figure 36. CUSTOMER ORDER SERVICING allocates known customer orders against the master production schedule

When the order does not fit the schedule, as in Figure 37, a decision must be made either to change the schedule or to postpone the delivery date of the order. The criterion again is, "What would be the effect on resource requirements?" Increasing the schedule is possible only if INVENTORY MANAGEMENT confirms that material will be available, and if the additional capacity can be provided.

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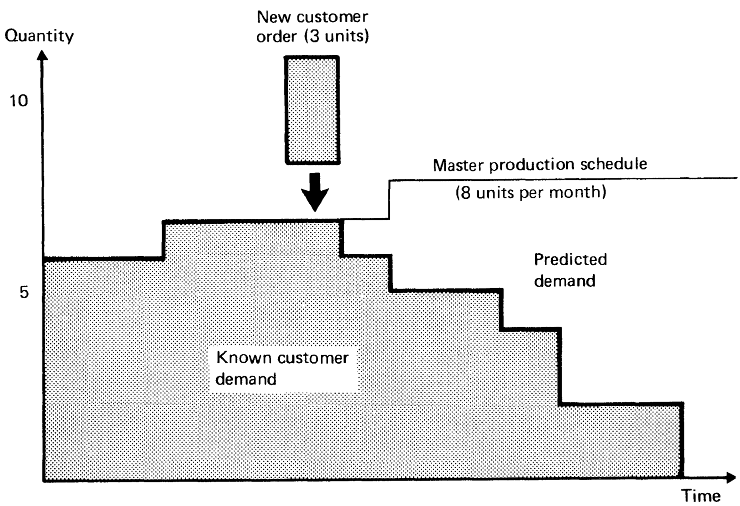


Figure 37. A trial fit must be made on available resources when a new order does not fit the existing master production schedule

The effect of increasing the schedule quantity is simulated by the system. All the affected resource requirement profiles can again be displayed on request; each shows the extra cost that would be incurred, with a comparison against the standard (Figure 38). In this example, most of the additional load on vertical milling is covered by available normal capacity, and consequently the cost of the additional requirement will be below the standard. The system can also accumulate these costs across all *manpower* resources, to show the total labor cost required to produce the order.

If the order is accepted, the system updates the master production schedule. If the order cannot be accepted with the requested delivery date, a new date has to be quoted. The system will, on request, repeat the procedure, using any tentative date chosen.

Trial fitting of orders, as well as of contemplated master production schedule changes, applies also for reasons of manufacturing lead time. Capacity and other required resources may be available but time may not. A simulation of acceptance (via MATERIAL REQUIREMENTS PLANNING) will reveal whether the lead time allowed is sufficient, and if not, by exactly how much. A reliable new delivery date can then be specified.

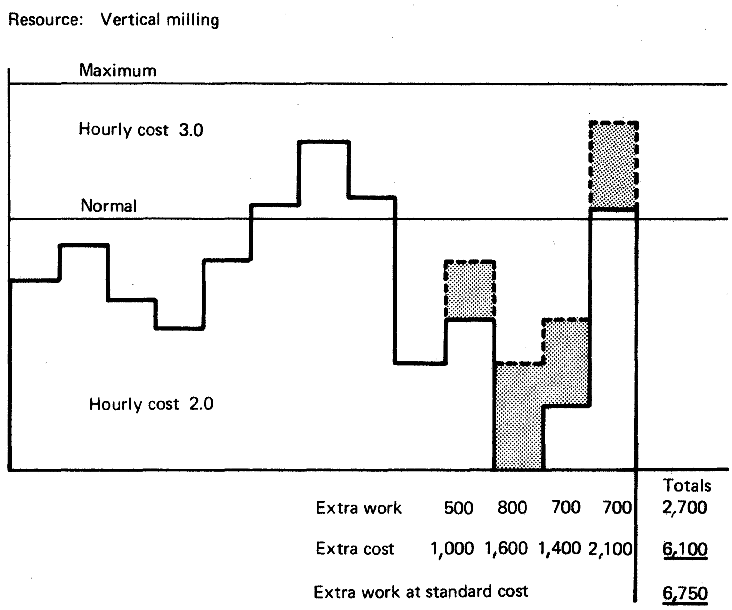


Figure 38. The cost of accepting additional orders can be determined during a trial fit

Scheduling products made to order

In custom manufacturing, where product load profiles are based on production estimates, the scheduling of requirements is often quite flexible. When the product load profiles are developed (see "Requirements for Products with No Specifications"), the requirement schedule represents the optimum situation. To obtain a good "fit", however, certain periods of slack are allowable, even though this extends the total manufacturing time (Figure 39).

The diagrams show simplified requirements for a single order, with only four resources involved. The requirements for each of the four resources can be scheduled across the planning horizon in many possible ways, all of which may be acceptable to management. The system can simulate many allowable schedules, and determine the one representing the minimum labor cost. The effect on all other resources can be studied before the schedule for the specific order is determined.

The number of possibilities is sometimes limited by restrictions imposed by the customer, who might, for instance, insist that engineering be completed by a certain date. The system can also observe time relationships between the schedules for two or more associated products. For example, a customer ordering both a turbine and a generator might demand that the latter be delivered within a certain time after the former.

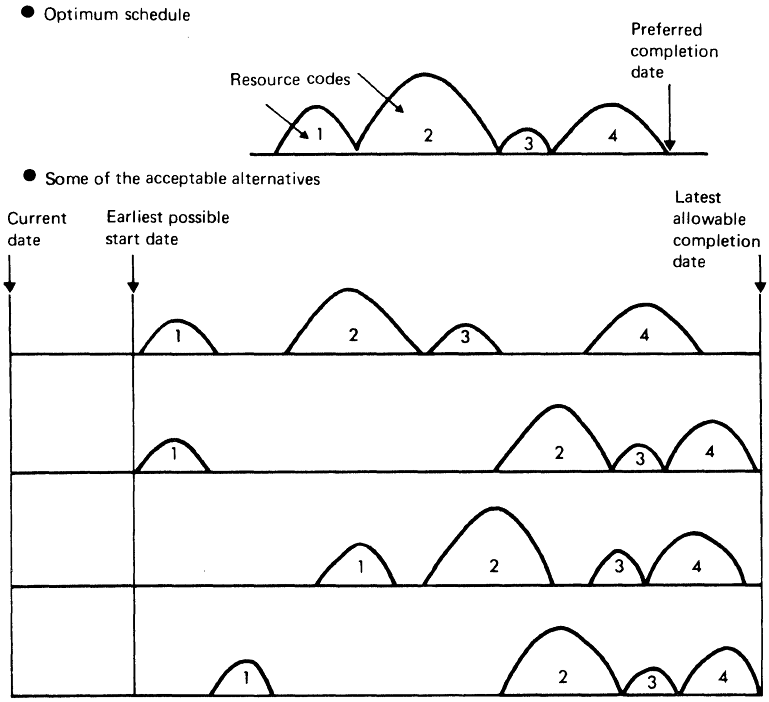


Figure 39. Product load profiles can be adjusted within the earliest and latest start dates to provide the least-cost solution

Analysis of the Effect of Changes

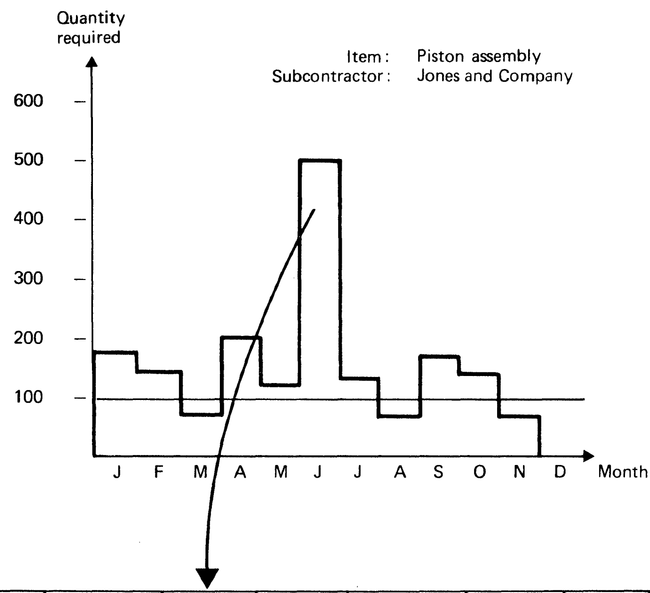
Use of the methods discussed should ensure that resources are adequate to meet the master production schedule. If the planned resources are available, it should be possible to meet every requirement and produce all items on schedule.

Problems arise, however, from unforeseen circumstances. For instance, a subcontractor may accept less work than was planned or employees may leave the company faster than new ones can be trained. As a result, the changed resource requirements profiles show impending "overloads" and are no longer acceptable.

If additional resources cannot be acquired, requirements must be changed in line with the available capacity, and this can be done only by reducing end item production quantities. Some production schedules must be modified, but which ones?

Again the system can provide information on which to base decisions. Suppose, for example, a subcontractor notifies the company that over the next year he can make only 100 items a month (Figure 40); this is much less than the number required, and no other subcontractor can do the job. In particular, there will be a shortage of 400 items in June.

As illustrated, the system analyzes, on request, the total requirements generated and their due dates and shows unit cost, selling price, and inventory information. Management can now decide which end item or items should be deleted or rescheduled, and the system modifies the corresponding production schedule(s). Several simulations may be required before a decision is reached.



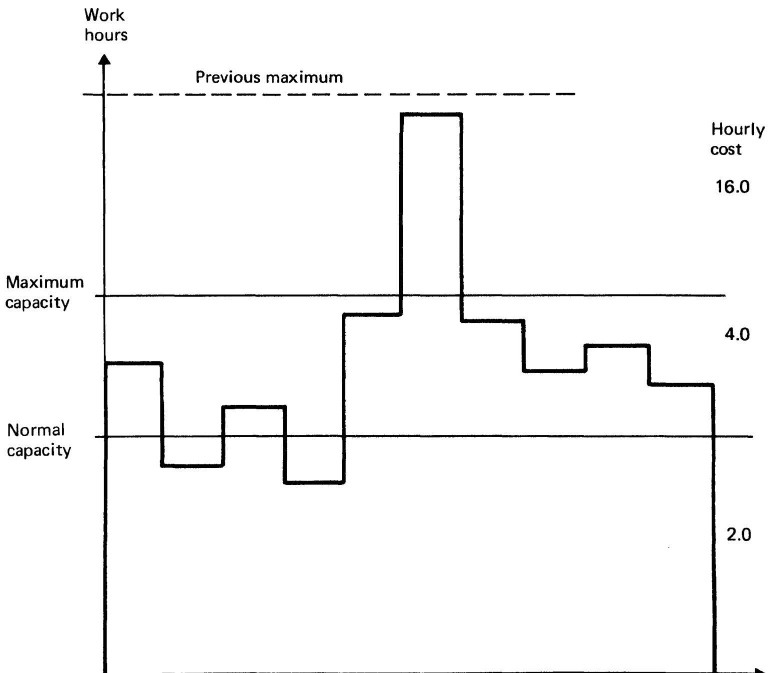
Item Requirement	End Product	Week No.	Quantity	Planned Inventory Surplus	Unit Cost	Selling Price
100	1529	82	25	--	125	150
200	1539	85	50	160	35	50
160	2621	76	40	–	680	1000
40	5887	76	10	–	1020	1200

This requirement can be removed from the master production schedule because it is only being produced as stabilization stock.

Figure 40. Analysis of excessive demand can determine which end item production schedule should be changed

Overloads on manpower resources

If the problem is manpower reduction, the system displays the requirements profile for the resource, showing the new capacity levels (Figure 41). In period 6 the maximum capacity will be exceeded, and subcontracting is highly expensive. The total load (work hours) in that period is analyzed; each load contribution is traced to a requirement for a particular end item in a particular period.



• Period	1	2	3	4	5	6	7	8	9	10
• Labor cost	200	110	160	100	260	1080	240	180	220	180
• Standard	240	175	210	150	285	450	270	225	255	225
• Loss						630				

Figure 41. An unexpected reduction in available manpower causes capacity overloads

The revised cost of producing each of these end item requirements can be derived and compared with the standard. The difference shows the loss that would be incurred. Those end item requirements that would be produced at the greatest loss are the obvious candidates for removal from their respective schedules.

Simulation of Alternative Possibilities

Since demand forecasts are continuously updated to reflect changing demand, *at all times* each forecast represents the best estimate of the quantities required. But even the best estimate can be a bad one; the precise future demand is always unknown. This is particularly true of a new product. Consequently, the ability to simulate the effect on resources of possible errors in forecasts is a valuable planning aid. To do this, it is necessary to simulate the effect of:

- Alternative master production schedules
- Changes to the resources

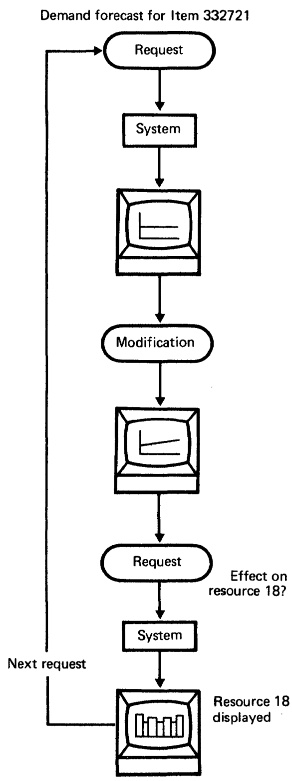


Figure 42. Interactive terminals allow management to simulate the effect of different policy decisions

The simulation of different policies is facilitated by the use of interactive terminals (Figure 42). This allows management to ask "what if" questions and to get prompt answers. The system can provide answers to questions such as:

What additional output could be planned if machining capacity were increased by 10,000 hours per year?

What extra capacity would be required if a new model were introduced in January?

What would be the effect on inventory if sales increased by 15%?

What would happen if the product mix were changed a certain way?

This type of simulation is not normally done at regular intervals; when it is done, however, the answers are usually required almost immediately. The effect of different policy changes, such as sales campaigns, introduction of new products, and planned expansion of production facilities, can be determined during the course of a meeting.

Consider, for example, the effect of changing the product mix. The question might arise because of an apparent change in demand: "What would be the effect on resources if the production of television sets were doubled and the production of radio sets were cut by one-half?" Many different models of both television sets and radios might be involved. To simulate the total effect on resources, the new (tentative) demand forecast for each model should be temporarily entered in the system.

Product groups

To simplify the procedure of simulation, the concept of "product groups" is used. Products can be grouped, provided their product load profiles are similar. For instance, if several different models of radio use the same resources, in similar quantities, they are considered a single product group. This grouping is performed by management, and a corresponding product group code is assigned to each product (end item) and stored in the system.

The system now derives a set of *average load profiles* for each group. Each product within a group has its own product load profile. These are "averaged", each model contributing a different weight in proportion to its average forecast demand (Figure 43).

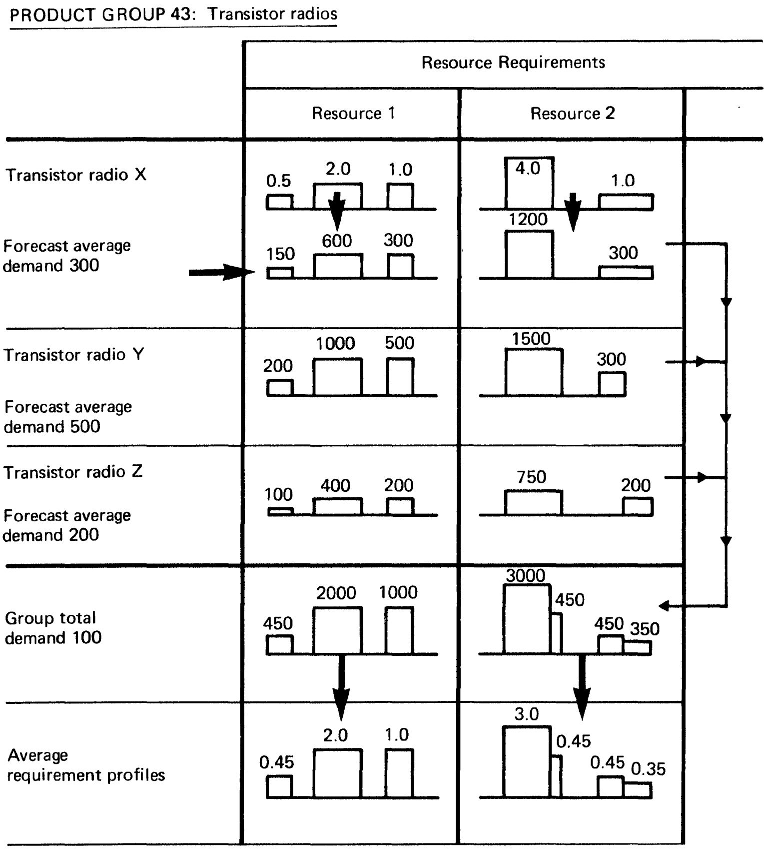


Figure 43. Average load profiles for a product group are derived from the product load profiles for each unique product within the group

Average load profiles are stored in the system and updated when necessary. Whenever a change has to be simulated, the system is provided with the following information for each product group involved:

- Product group code
- Possible percentage deviation from forecast

Then a management estimate of what *could* happen to the demand for the product group is expressed as a "trend" line (Figure 44). Diagram A indicates that the demand for transistor radios *might* in fact be 50% more than predicted. Diagram B indicates that the demand for miniature models *might* "tail off" to only half the expected quantities. Diagram C shows that the demand for short-wave models *might* disappear before the end of the year. Diagram D shows that the demand for portable television sets *might* exceed all expectation.

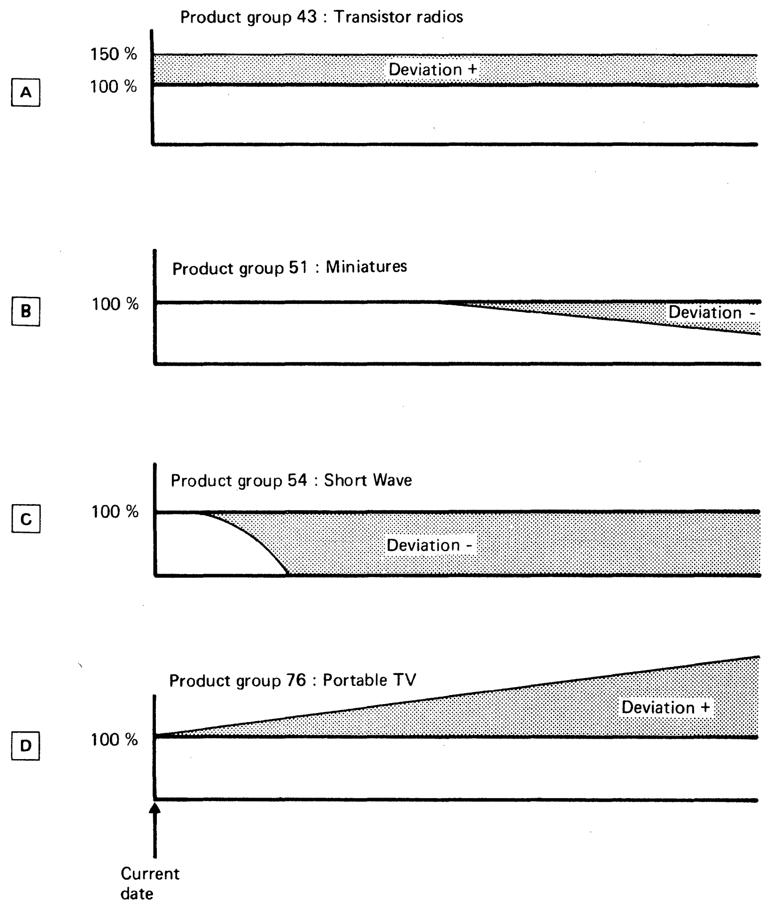


Figure 44. Management estimates of possible deviations to the forecast demand are entered into the system

The system responds with the following procedure, for each of the four groups (Figure 45):

- The *current* demand forecasts for all models within the group are added together.
- The consolidated group forecast is multiplied by the percentage deviation for the group; the result is the simulation deviation from the forecast, expressed as units (number of radios).
- The deviation is extended by the average load profiles for the group. The result is a set of resource requirement profile *increments* (one for each resource).

Increments are thus calculated for each of the four product groups and summed. The results represent the total extra requirements that would be imposed on each resource if all four extreme possibilities materialized (Figure 46).

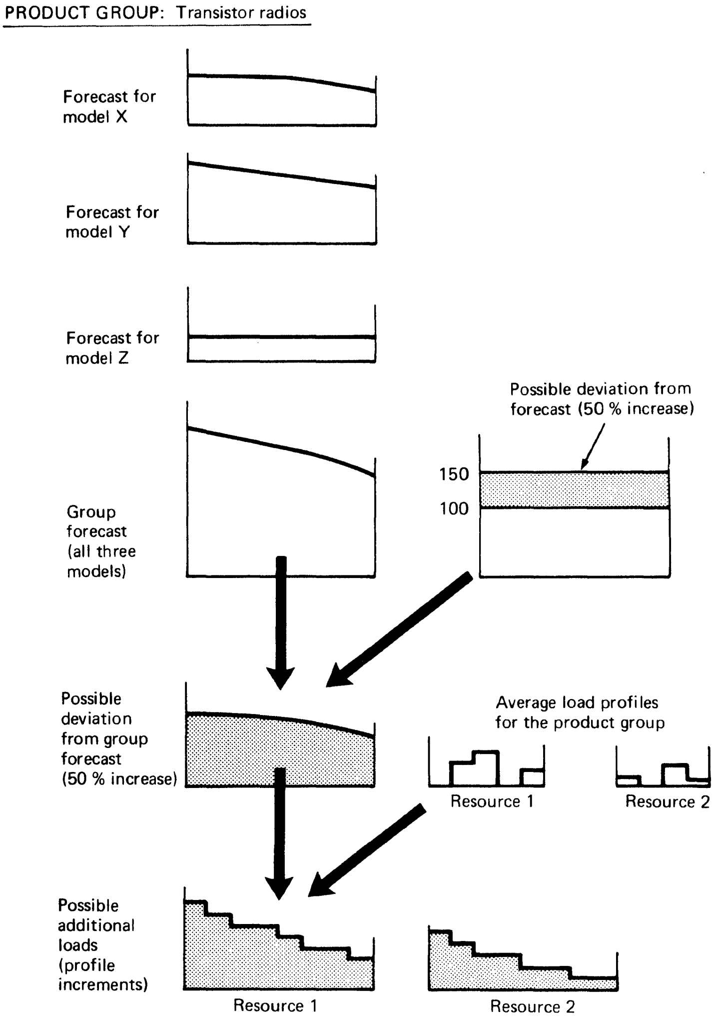


Figure 45. The effect of possible deviations from the forecast on the average resource requirements for the product group

This method allows management to experiment quickly with a wide variety of possibilities. The effect of each possible alternative can be estimated in seconds. The results are approximations – but so too are the predictions!

The value of the technique is that it helps to isolate resources that represent insufficient capacity to meet the combined demand deviations. Management can then balance the cost and time required to provide additional capacity for a combination of demand deviations against the probability that the deviations will occur.

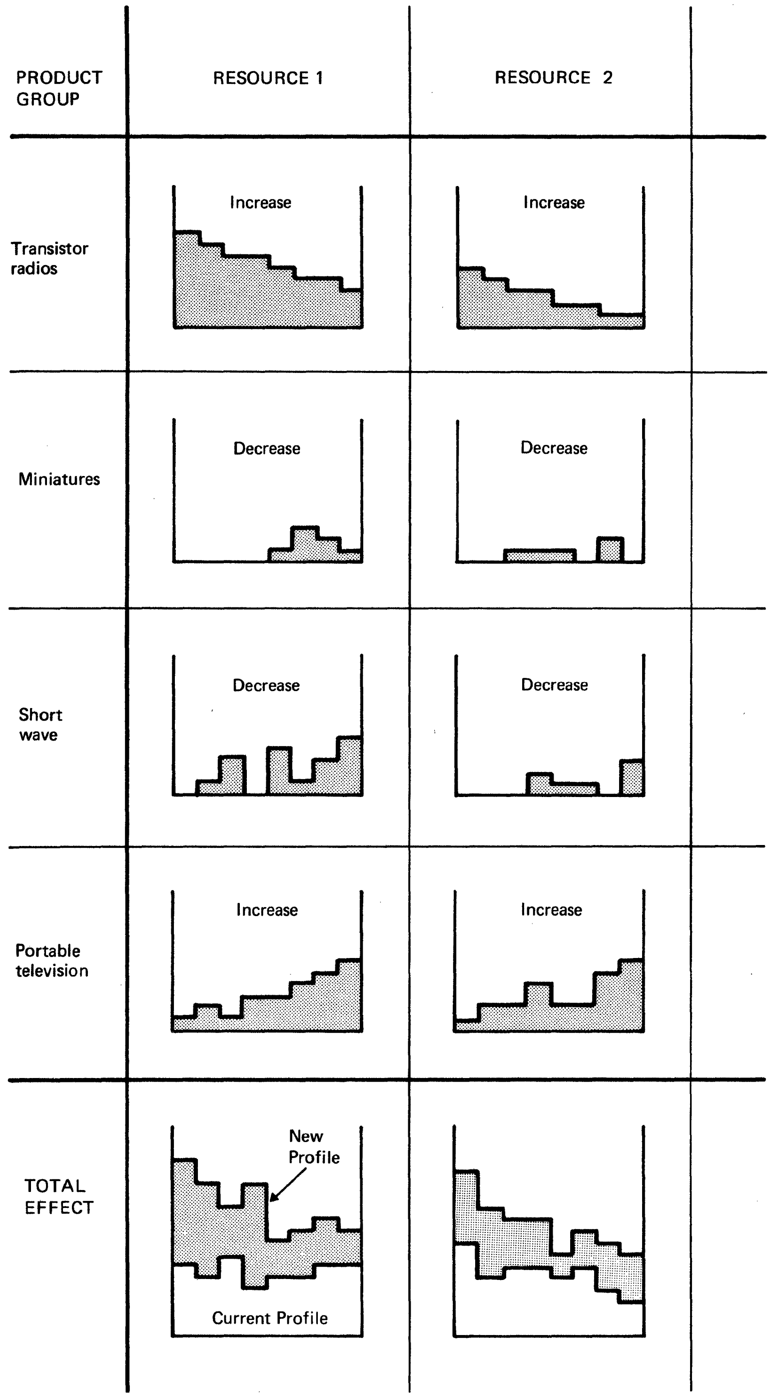


Figure 46. The total effect of possible deviations from the forecast on each product group

Summary

MASTER PRODUCTION SCHEDULE PLANNING is a "gross" planning system that determines for each end item a production schedule based on forecast demand, requirements from field warehouses, interplant orders, and orders direct from the customer. It determines the resources needed to meet the schedules and, using interactive terminals, helps management decide the effect of adjusting the schedules to obtain the best use of available resources.

The output from the system is a revised set of production schedules that are subsequently exploded into detailed material requirements in MATERIAL REQUIREMENTS PLANNING.

The system operates in "net change" mode, so that only changes to the previous schedules need be processed and input to MATERIAL REQUIREMENTS PLANNING.

MASTER PRODUCTION SCHEDULE PLANNING is designed to ensure that the detailed production plans generated to meet this schedule are feasible and can be executed within the available time and capacity.

Notes

Notes

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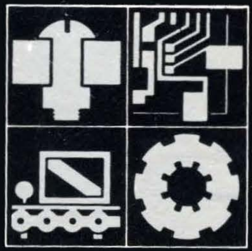

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