
UNIT 10 PLANNING AND CONTROL FOR BATCH PRODUCTION

Objectives

After completion of this unit, you should be able to:

- understand the nature of batch production and the circumstances under which it is used
- appreciate that batch size determination, sequencing and scheduling are the major problems in batch production
- determine the optimum batch sizes for single and multi-product case produced on a single machine
- appreciate the problems of aggregate production planning and master schedule determination
- get an idea of material requirements planning and its function in an organisation
- become familiar with the line of balance as a valuable tool for monitoring and control in batch production
- become aware of new developments like Kanban and Flexible Manufacturing Systems.

Structure

- 10.1 Introduction
- 10.2 Features of Batch Production
- 10.3 How to Determine the Optimum Batch, Size
- 10.4 Aggregate Production Planning
- 10.5 Material Requirements Planning
- 10.6 The Line of Balance (LOB)' for Production Control and Monitoring
- 10.7 Problems and Prospects of Batch Production
- 10.8 Summary
- 10.9 Key Words
- 10.10 Self-assessment Exercises
- 10.11 Further Readings

10.1 INTRODUCTION

When a variety of products is to be made and the volumes of production are not large enough to justify a separate line for each product, production in batches is often resorted to. Batch production implies that general purpose machines are utilised for the production of different products. Material flow tends to be more complex in such systems than in mass production systems.

The layout plan for such systems has to be carefully designed keeping in mind the diversity of products and their individual flow patterns and production volumes, Naturally, in such systems the production times are larger as compared. to those in mass production. Batch production is distinguished from the Job Shop as follows:

In batch production a continuous demand for certain products exists, but because the rate of production exceeds the rate of demand, there is a need to produce products in batches. The scheduling problem here is concerned with determining the batch sizes for products and the order in which they should be produced.

In job production a stream of orders has to be processed on common facilities or production centres, each job having its own unique specifications and requirements in terms of production resources. A job may consist of a single item or a batch of identical items. The scheduling problem here is concerned with setting the sequence in which jobs should be processed at each production centre



Of the various problems in batch production we shall, in this unit, address ourselves to:

- the problem of determining optimal batch sizes
- aggregate production planning
- disaggregation of the aggregate plan to determine the master production schedule
- material requirements planning to achieve a given master production schedule the problem of production control using the line of balance (LOB) in batch production
- some recent concepts in batch and Discrete Parts Systems.

10.2 FEATURES OF BATCH PRODUCTION

Unlike mass production systems which tend to be organised as product layouts with machines or equipment arranged according to the product flow, batch production normally is done employing a process layout. Here similar machines or equipment are grouped in departments and different jobs will follow their own route depending on requirements. Apart from the greater flexibility afforded by process layouts as compared to product layouts some of the advantages and disadvantages of process layouts are summarised below:

Advantages:

- i) Better utilisation of machines is possible; consequently, fewer machines are required.
- ii) A high degree of flexibility exists vis-a-vis equipment or manpower allocation for specific tasks.
- iii) Comparatively low investment in machines is needed.
- iv) There is generally greater job satisfaction for the operator owing to the diversity of jobs handled.
- v) Specialised supervision is possible.

Disadvantages:

- i) Since longer and irregular flow lines result, material handling is more expensive.
- ii) Production planning and control systems are more involved.
- iii) Total production time is usually longer.
- iv) Comparatively large amounts of in-process inventory result.
- v) Space and capital are tied up by work in process.
- vi) Because of the diversity of job in specialised departments, higher grades of skill are required.

In addition to these features which are characteristic of the layout generally adopted in batch production, questions like "what should be the size of the batch?" or "how should various batches be sequenced?" arise typically. Although such decisions may be made in practice, either in an adhoc manner or by using certain rules of thumb

derived from past experience, we demonstrate below a more rational outlook to arrive at the 'optimal' decisions pertaining to batch size.

10.3 HOW TO DETERMINE THE OPTIMUM BATCH SIZE

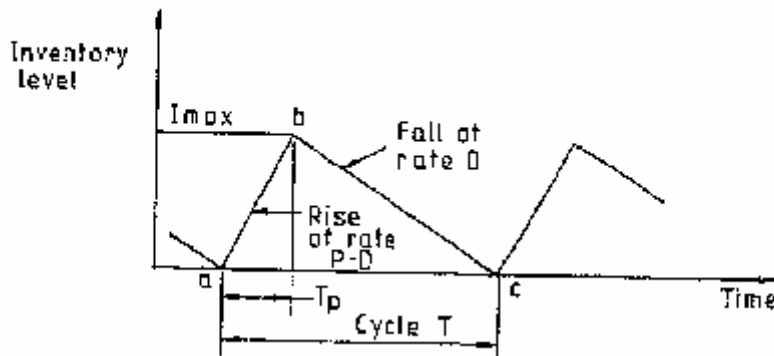
Single Product Case

Let us consider a situation for the production of a single product on a machine under the following set of assumptions.

- there is a continuous demand for the product at rate D units per year
- production rate for the product is P units per year ($P > D$)
- set up cost per batch of size Q is fixed at A (independent of Q)
- unit variable cost of production is C per piece



Figure I: Single Product Model with Constant Demand Rate and no Shortages



- inventory carrying cost per unit per year (Rs./unit/year) = $h = i C$ where i is the annual inventory carrying cost rate
- no shortages are allowed.

Figure I shows the change in inventory level within a cycle T . When production starts at point a , the inventory level will increase at a rate $P-D$ (can you see why?) until the maximum is attained at point h . The inventory level will decrease at a rate D during the rest of the cycle till point c is reached at which a new batch of size Q is initiated and a similar cycle ensues.

It is easy to see from Figure I that

Time to produce a lot Q	$=T_p = Q/P$	(10.1)
Maximum inventory level	$=I_{max} = T_p (P-D)$...
	$=Q/P (P - D)$	(10.2)

The total cost is built up of two conflicting components-the set up cost (which favours large batch sizes) and the inventory holding cost (which favours small batch sizes). Our approach, therefore, is to develop an expression for the total annual cost in terms of the decision variable (which is the batch size Q in this case) and then to mathematically determine the optimum.

This can be done as follows:

The average cost per cycle of length T is the sum of the set up cost, item variable cost and the carrying cost

$$= A + CQ + h T I \quad \dots\dots\dots (10.3)$$

where I is the average inventory over the cycle T .

The average inventory I over the cycle T may be determined from Figure I as the area of the triangle abc divided by T

$$I = \frac{1}{2} \frac{T I_{max}}{T}$$

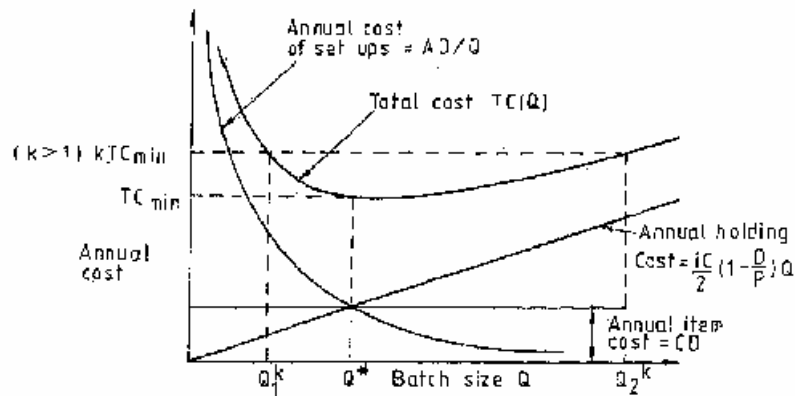
$$= \frac{1}{2} \times Q(1-D/P) \text{ (utilising equation 10.2)} \quad \dots\dots\dots (10.5)$$

The total annual cost $TC(Q)$, is obtained by multiplying equation (10.3) by the number of orders per year, D/Q . By substituting $h=iC$, we obtain

$$Tc(Q) = \frac{AD}{Q} + CD + iCI \quad \dots\dots\dots (10.5)$$



Figure 11: Total Annual Cost as a Function of Batch Size



Substituting for I utilising equation. (10.4)

$$TC(Q) = \frac{AD}{Q} + CD + \frac{iC}{2} Q \left(1 - \frac{D}{P}\right) \quad \dots (10.6)$$

$$\frac{dTC(Q)}{dQ} = 0 \text{ yields the optimal batch size } Q^* \text{ as}$$

$$Q^* = \sqrt{\frac{2AD}{iC(1-D/P)}} \quad \dots (10.7)$$

The total annual cost (equation 10.6) is plotted in Figure II.

The optimum batch size Q^* determined from the above equation 10.7 may have to be modified in practice to suit procurement, storage or machine capacity constraints which have been ignored in the above model. Figure II illustrates how a range of batch sizes (from Q^k_1 to Q^k_2) may be determined so that the total annual cost does not exceed a certain specified cost level (say k times the minimum cost $TC_{min}, k > 1$). Also notice that because of the relatively steep nature of the total cost function to the left of the optimum Q^* , as compared to the right, Q^k_1 is closer to Q^* than Q^k_2 .

Activity A

Determine the optimum batch size for an item produced on a manufacturing facility with the following data:

- Consumption rate: 500 items/month
- Production rate: 1500 items/months
- Storage costs: Rs. 100 per unit per year
- Setup charges per batch: Rs. 2000
- Interest charges: Rs. 50 per unit per year.

What is the breakup of annual item cost, setup cost and holding cost at the optimum?

Activity B

Extend the model discussed above to include the case when shortages are allowed. Assume a linear shortage cost proportional to the quantity of shortage and the time after which it is satisfied. Notice that in this situation there are two decision variables the batch size and the maximum backorder level

Multi-product Case

We shall consider a situation where n items are manufactured on a single machine, with the restriction that there is a common cycle time, T for all the items. The n batches are thus phased within the common cycle. Assuming no shortages, the total annual cost for this multi-item case can be estimated as the sum of the total annual



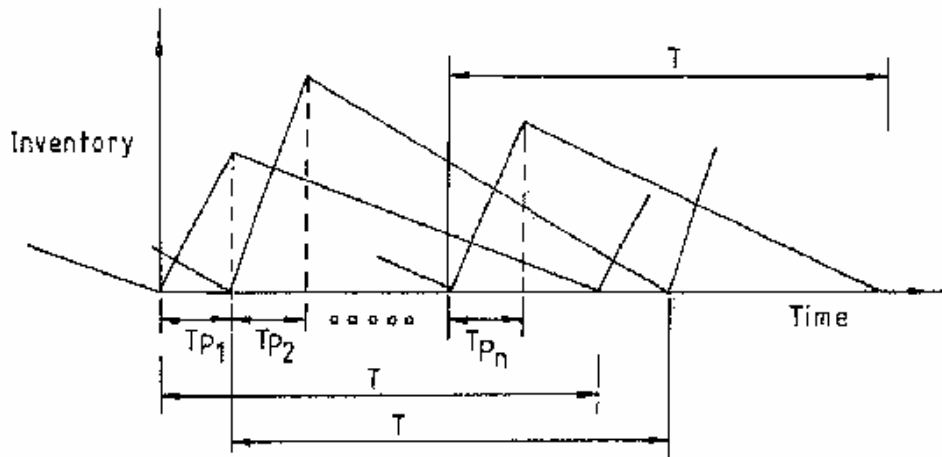
cost of each item independently. Extending the model for the single product case by including a subscript j for the j th product ($j=1,2 \dots n$) we have for the total annual cost (analogous to $TC(Q)$ in eqn. 10.6):

$$TC(Q_1, Q_2, \dots, Q_n) = \sum_{j=1}^n \left(C_j D_j + \frac{A_j D_j}{Q_j} + \frac{i C_j Q_j}{2} (1 - D_j/p_j) \right) \dots \dots \dots (10.8)$$

As seen from Figure III a feasible schedule can be generated with a common cycle T , if the time for production of all batches does not exceed the common cycle time. In the absence of set up time for a lot this is equivalent to:

$$T_{p1} + T_{p2} + \dots + T_{pn} \leq T \dots \dots \dots (10.9)$$

Figure III: Production of Multiple Batches on a Single Machine with a Common Cycle



Since the time required to produce the batch of j th product = $TP_j = Q_j/P_j$ and because $T = Q_j/D_j$, condition 10.9 may be expressed as:

$$\frac{D1}{P1} + \frac{D2}{P2} + \dots + \frac{Dn}{Pn} \leq 1 \dots \dots (10.10)$$

Equation 10.10 may be interpreted as a resource feasibility check to determine if all n items can be scheduled on a single machine. In case the left hand side of eqn. 10.10 exceeds one and equals say 2.4 in a particular case, it indicates that 3 (the integer just exceeding 2.4) is the minimum number of machines needed for scheduling all items under the assumption of a common cycle time.

We can convert the annual total cost expression of eqn. (10.8) into the following by using $Q_j = TD_j$

$$TC(T) = \sum_{j=1}^n \left(C_j D_j + \frac{A_j}{T} + \frac{i C_j D_j}{2} T (1 - D_j/p_j) \right) \dots \dots \dots (10.11)$$

By means of the assumption of a common cycle time we have in effect only one decision variable (T).

The optimum T^* can be found by putting $\frac{d TC(T)}{dt} = 0$, which yields

$$T^* = \sqrt{\left(2 \sum_{j=1}^n A_j \right) \left(i \sum_{j=1}^n C_j D_j (1 - D_j/P_j) \right)} \dots \dots \dots 10.12$$

Once T^* is obtained the optimum batch sizes $Q^*_1, Q^*_2, \dots, Q^*_n$ can easily be found out by using $Q^*_j = T^* D_j, j = 1, \dots, n$.



Example I

A company is concerned with the production of four products on the same equipments The relevant data is shown in Table 1.

- a) Determine the lot sizes of the products individually.
- b) What would be the difficulty in scheduling the above "optimum" lot sizes on the machine?
- c) Under the assumption of a common cycle time, determine the lot sizes.

Table 1
Relevant data for four-product production on a single machine

Product	Demand rate (units/year)	Production rate (units/year)	Inventory Cost Rs./unit/year	Set up cost (Rs.)
j	D _i	P _i	i C _i	A _i
1	1500	12 000	Rs. 50.00	Rs. 90
2	1134	5,000	Rs. 108.00	Rs. 210
3	2016	6,667	Rs. 75.00	Rs. 165
4	2716	8,000	Rs. 67.50	Rs. 135

Assume that there are 240 working days in a year.

Solution

- a) Under this condition the individual lot sizes may be determined by using eqn. 10 that is

$$\left(\frac{D1}{P1} + \frac{D2}{P2} + \frac{D3}{P3} + \frac{D4}{P4} \right) = 0.1250 + 0.2268 + 0.3024 + 0.3395 = 0.9937 < 1$$

The results are summarised in Table 2.

Table 2
Individual Economic Lot Sizes for the four Products

Product	Economic lot size	Production days	Cycle time T*j in days
J	Q* _i	(O* _i /P _i)	= (O* _i /D _i)
1	78.6	1.57	12.6
2	75.5	3.62	15.9
3	112.8	4.06	13.4
4	128.3	3.85	11.3
Total		13.10	

- b) A look at Table 2 indicates that scheduling the four products on the machine in sequence would take a minimum of 13.10 days (the total of the production days for all the lots). Note that an economic lot of product 4 will last only 11.3 days whereas a lot of product 2 will last 15.9 days. Thus there would be uncontrollable shortage; and surplus with this scheme of scheduling.

This difficulty is overcome when we consider a common cycle time for all the products.

- c) Under the common cycle category we obtain the solution by using eqn. 10.12. Computations are simplified if we tabulate the numerator and denominator terms needed under the radical sign on the right hand side in eqn. 10.12. This is shown in Table 3. The common cycle equals 0.0557 year (=0.0557 x 240 =13.37 working days) out of which 13.26 days are utilised for the production of the four product lots as indicated in Table 3.



Table 3
Results under a common of cycle policy

Product	Set up cost	$(1 - D_i/P_j)$	$i C_i D_i (1 - D_i/P_i)$	$Q^*_i = T^* D_i$	Production days per lot
j	A_i				$(\frac{Q^*_i}{P_i})$
1	90	0.8750	65,625.00	84	1.68
2	210	0.7732	94,695.40	63	3.02
3	165	0.6976	105,477.10	112	4.03
4	135	0.6605	121,089.50	151	4.53
Total	600		386,887.00		13.26

You could also check that the feasibility condition of eqn. 10.10 is in fact satisfied

$$\left(\frac{D1}{P1} + \frac{D2}{P2} + \frac{D3}{P3} + \frac{D4}{P4} \right) \\ == 0.1250 + 0.2268 + 0.3024 + 0.3395 = 0.9937 < 1)$$

Activity C

In the multi-product batch size determination under a common cycle we assumed that there was no time required to set up a batch. Think of the consequences in the following two cases:

- If there were set up times but these were independent of the sequence of production.
 - If there were set up times which were dependent on the sequence of production.
- You may like to consult some of the references given at the end (especially 4,5).

10.4 AGGREGATE PRODUCTION PLANNING

The Purpose

Customer demand enters the production system as units of products. Aggregate production planning is concerned with developing the work force and machine time allocation to meet a given demand schedule over the planning horizon (generally the next 3 to 6 months). The purpose of this exercise is to produce an 'aggregate' plan in terms of the overall production of all products combined such as production in tons of steel or litres of paint which would have to be 'disaggregated' to yield individual product schedules.

When planning work force and related activities to conform to a given demand schedule, it is necessary to balance the cost of building and holding inventory against the cost of adjusting activity levels to fluctuations in demand. Figure IV shows a hypothetical cumulative demand pattern and two alternative production strategies.

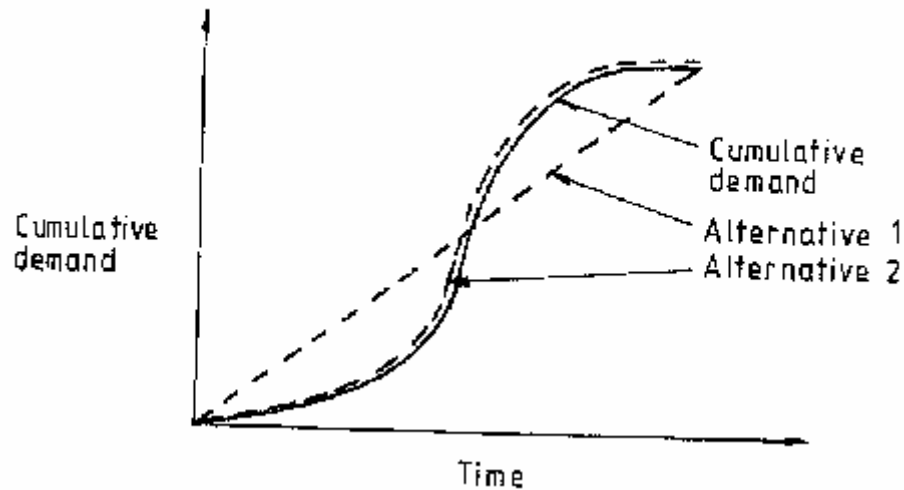
Alternative-1 uses a constant work force level (i.e. constant production output rate). Since the production rate is greater than the expected demand rate in the earlier production periods, cumulative production will exceed cumulative demand resulting in a significant inventory carrying cost. Conversely significant shortage cost may result when the cumulative demand exceeds the cumulative production.

Alternative-2 is a strategy to produce as per demand so that the inventory carrying costs are minimised. This alternative requires constantly adjusting the work force levels or paying significant overtime cost during the high demand periods.

These are two extreme alternatives. The optimal alternative is the one that minimises the total cost of the inventory and the cost of adjusting the work force level. The



Figure IV: Two Alternative Production Schedules for Meeting Demand



primary output of the aggregate planning process is a master schedule, which describes the number of units to be produced during each period and the work forces levels required by period.

A Brief Review of Approaches

Perhaps the simplest approach to aggregate production planning is graphical in which the cumulative demand is plotted as shown in Figure I V and alternative production plans (shown as dotted lines) are compared in terms of their costs and the most economical one is adopted. This approach suffers from the drawback that chooses the best plan from the ones considered and not from 'all' possible plans which in fact could be infinitely large and difficult to conceive.

The above limitation is to some extent taken care of in mathematical optimisation models. The approach for finding the optimal alternative (master schedule and work force level) in such a case is to develop a total cost function which contains the major cost components of the production facility. This cost function is to be minimised while subject to constraints. The linearity or non-linearity of the cost function and constraints determines the solution approach to the problem. Multi-period production planning models can be treated as network flow problems and solved by special procedures (See for instance, Johnson and Montgomery).

Other methods for dealing with the aggregate production planning problem could be heuristic rules or computer search procedures. A review of approaches to aggregate production planning may be found in Buffa, Eilon, Elsayed and Boucher.

Example 2 (adopted from Elsayed and Boucher)

A chemical plant manufactures two types of products A and B with either regular production time or through planned overtime. Products use the same equipment and are scheduled into production one at a time. Demand over the next 4 months is 101, 90, 110 and 100 units for product A and 200, 190, 210 and 200 units for product B.

The initial inventory levels are 36 units of A and 220 units of B. It takes 1 plant hour to produce a unit of product A and 0.40 plant hour to produce a unit of product B.

Associated production costs are:

Cost of regular production, CR

Cost of overtime production, Co = Rs. 150/plant-hour

Inventory carrying cost charge, Ci = Rs. 40/plant-hour/mont

Production capacities for regular time and overtime are:

Regular time = Rs. 160/plant-hour

Overtime = Rs. 40/plant-hour

Determine the aggregate production plan in terms of plant hours for these products. Such that the total production and inventory costs are minimised. The management desire a planed final inventory target of 80 plant hours.



Solution

This problem can be structured as a transportation problem with unit costs as shown in Table 4. Plant hours of demand are computed from the demand data and plant-hours conversion factors. For example, in period I the demand of 100 units of product A and 200 units of product B is equivalent to $(100 \times 1 + 200 \times 0.4) = 180$ plant-hours of aggregate demand. Similar method can be used for other periods.

Table 4
Transportation cost matrix for Example 2

Production period	Period of Demand				Final Inventory	Capacity (Plant-hours)
	1	2	3	4		
Period-1						
Initial Inventory	0	C_i	$2C_i$	$3C_i$	$4C_i$	124
Regular time	C_R	$C_R + C_i$	$C_R + 2C_i$	$C_R + 3C_i$	$C_R + 4C_i$	160
Overtime	C_O	$C_O + C_i$	$C_O + 2C_i$	$C_O + 3C_i$	$C_O + 4C_i$	40
Period-2						
Regular time	—	C_R	$C_R + C_i$	$C_R + 2C_i$	$C_R + 3C_i$	160
Overtime	—	C_O	$C_O + C_i$	$C_O + 2C_i$	$C_O + 3C_i$	40
Period-3						
Regular time	—	—	C_R	$C_R + C_i$	$C_R + 2C_i$	160
Overtime	—	—	C_O	$C_O + C_i$	$C_O + 2C_i$	40
Period-4						
Regular time	—	—	—	C_R	$C_R + C_i$	160
Overtime	—	—	—	C_O	$C_O + C_i$	40
Demand (plant-hours)	180	166	194	180	80	

A planned final inventory of 80 plant-hours is considered a desirable target by management, which still leaves 124 plant-hours surplus over the 4 month planning horizon.

The solution to this very special transportation problem (with no entries below the main diagonal) can be obtained very simply by proceeding to fill the demands of periods 1, 2,.....in order by the cheapest available sources. Applied to the example-problem yields the solution shown in Table 5.

Table 5
Solution for Example 2

Production source	Period Demand				Final Inventory	Unused Capacity	Capacity (Plant hours)
	1	2	3	4			
Period-1							
Initial Inventory	124	40	80	120	160	0	124
Regular time	100	140	180	220	260	40	160
Overtime	150	190	230	270	310	40	40
Period-2							
Regular time		160	140	180	220	0	160
Overtime		150	190	230	270	40	40
Period-3							
Regular time			160	140	180	0	160
Overtime			150	190	230	0	40
Period-4							
Regular time				160	140	0	160
Overtime				150	190	0	40
Demand (plant-hours)	180	166	194	180	80	124	124



Disaggregation to a Master Schedule

The production facility considered in example 2 is a chemical plant which is shared by products A and B. Simultaneous production is not possible. Therefore, we should plan the production of each product by alternating the use of the facility between products. A disaggregation of example 2 requires the determination of the batch size of products A and B that will be produced each time a change-over occurs.

The necessity and desirability of disaggregation is situation dependent. In situation where product demand estimates are likely to differ from actual values, plant management may proceed to set hiring policies based on aggregate plant hour production requirement, with the assumption that forecast errors for individual products will be offset in the aggregate.

In situations where demand estimates are precise it is reasonable to consider a complete disaggregation of their production plan to the individual product level. When such disaggregation is done, the resulting output is called a master schedule, schedule of the time bound completion of production.

Let us assume that in Example 2 the demand forecast by product is reasonably precise and we wish to disaggregate the plan. The aggregate solution has minimised two costs the production cost and the inventory carrying cost. Given the solution the only remaining cost to be considered is the set up cost incurred each time production is switched between products. With only two products to be considered, a simple approach to minimising set up cost is to minimise the total number of set ups scheduled over the planning horizon. One way to achieve this and thus obtain a disaggregated master schedule is to simulate production runs using the following simple decision rule.

Set up and produce one product until the other product's inventory runs out. At that time set up the second product and run it until the first product's inventory runs out.

Application of this procedure to Example 2 yields the Master schedule shown in Figure V.

It should be clear that the simple rule above would not work for the general case with greater than two products. Procedures for disaggregation in such cases may be found in Elsayed and Boucher.

10.5 MATERIAL REQUIREMENTS PLANNING

Overview and. Problem Definition

By using the methods of aggregate production planning and subsequent disaggregation we can determine the weekly master schedule for end-products. The requirements of sub-assemblies, components, and raw stock items related to those end-products can be simply derived from the end-product demands. The manufacturing routing sheets and product bills of materials describe the departmental routings and production times to manufacture the sub-assemblies and components. Using these data bases in conjunction with a schedule of end-product requirements, it is possible to compute the timing of production for each component to meet the given end-product schedule. This, in effect, is the objective of a Material Requirements Planning (MRP) system. Thus, given a master schedule of end (or final) product, MRP computes the timing of all the sub-assembly, component and raw material production and purchasing activities required over the specified production horizon to meet the master schedule of the end-product. Moreover, it does so in such a way as to attempt to minimise work-in-process inventory.

Owing to the large amounts of data storage (a typical batch production facility may purchase/ produce 20,000 to 100,000 components) retrieval and computational requirements practical MRP systems have to be computerised. ,

Parts Explosion Requirements

From the master schedule of end-product production the requirements for purchased and manufactured components and sub-assemblies must be determined. This is referred to as 'parts explosion'



Figure V: Disaggregated Plan and the Resulting Master Schedule for Example 2

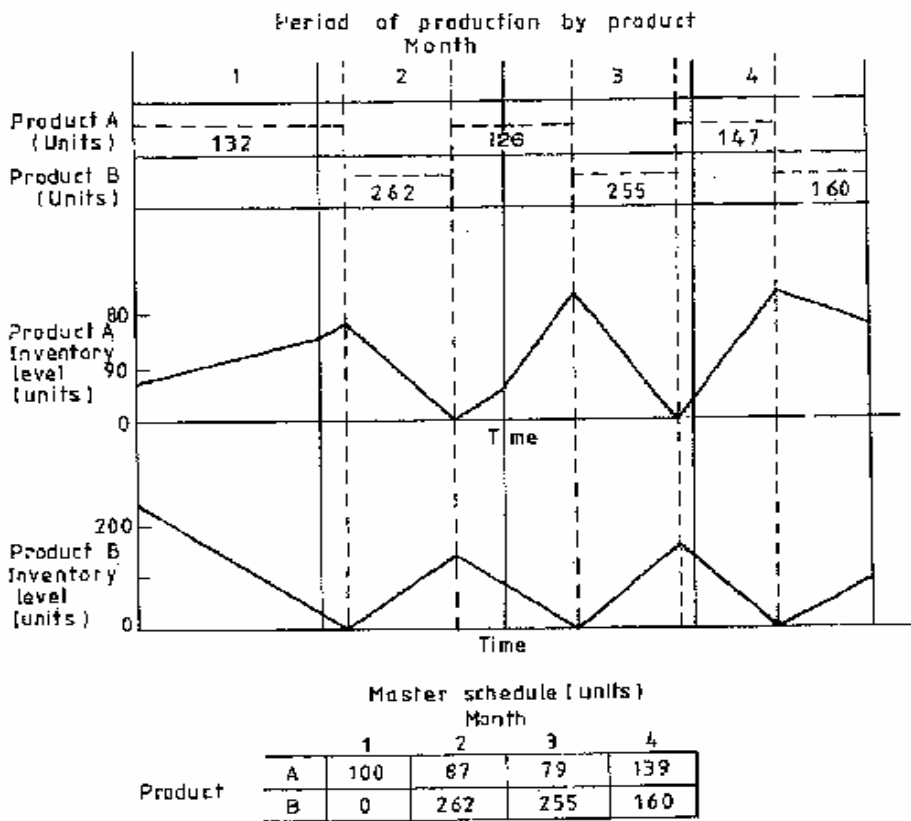
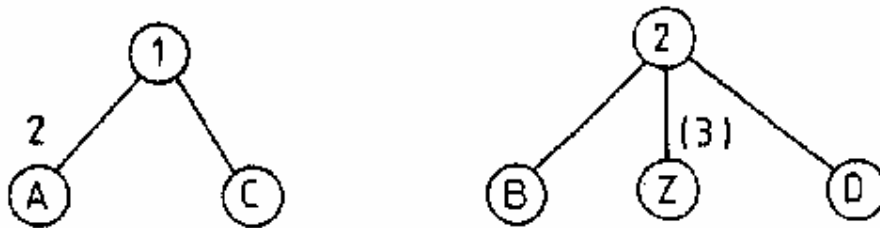
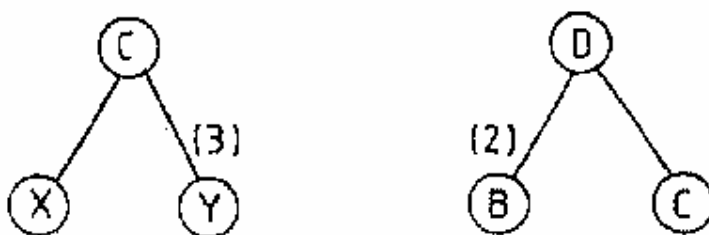
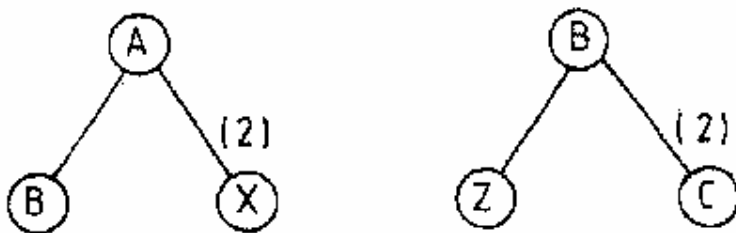


Figure VI: Product Structure for two End Products



Two end products 1 and 2



Four subassemblies (A,B,C,D)

Three parts (X,Y,Z)



Suppose there are 2 end-products (I and 2) which are assembled from four sub-assemblies (A, B, C, D) and three parts (X, Y, Z) as shown in Figure VI, The numbers in parentheses indicate the quantity of an item required, otherwise, the quantity is 1.

We can easily determine the level of an item as follows: Treating the end items at level 0, sub-assemblies A and D are placed at level I since they are directly used for the assembly of level 0 and items I and 2 and are not used at other higher levels. Notice that C, B and Z cannot be placed at level I since they are required as inputs for assembly of D, A and B, respectively, Similarly; level 2 consists of B; level 3 consists of C and Z, and, finally; level 4 consists of X and Y. Based on this level structure the "Bill of Materials Matrix" is shown in Table 6. The rows of this matrix are the 'how constructed files' and the columns are the 'how used files'. For instance, the row corresponding to end-product 2 shows that each unit of this product requires 1 unit each of sub-assemblies D and B and 3 units of the part Z. The column for C shows that C is used in production of end-product I and sub-assemblies D and B in requirements of 1, 1 and 2 respectively.

Table 6
Bill of Materials Matrix

Level	Item	End-Product		Sub-assemblies				Parts (Components)		
		1	2	A	D	B	C	Z	X	Y
0	1			2			1			
0	2				1	1		3		
1	A						1			2
1	D					2	1			
2	B							2	1	
3	C									
3	Z								1	3
4	X									
4	Y									

Now if we need to find out -the sub-assemblies and components needed for making 20 units of end-product I the information that is immediately available from the bill of materials matrix is that 40 units of A and 20 units of C are needed (since from row I we see that 1 unit of end-product I requires 2 units of sub-assembly A and 1 unit of sub-assembly C). This is only the primary, or direct dependent demand. Each of the A and C units would need their components and so on. This is shown schematically in Figure VII where the total requirements of all sub-assemblies and components of end-item 1 are derived. By doing a similar exercise for all the items we can compute total requirements matrix in which a particular row corresponds to the total requirements of that particular item. The total requirements matrix R for the two products example considered earlier is shown in Table 7. Notice that the first row is the total requirements for end-product I as derived in Figure VII. The total requirements matrix has is on the main diagonal.

Figure VII: Computing Total Requirements for End Item 1

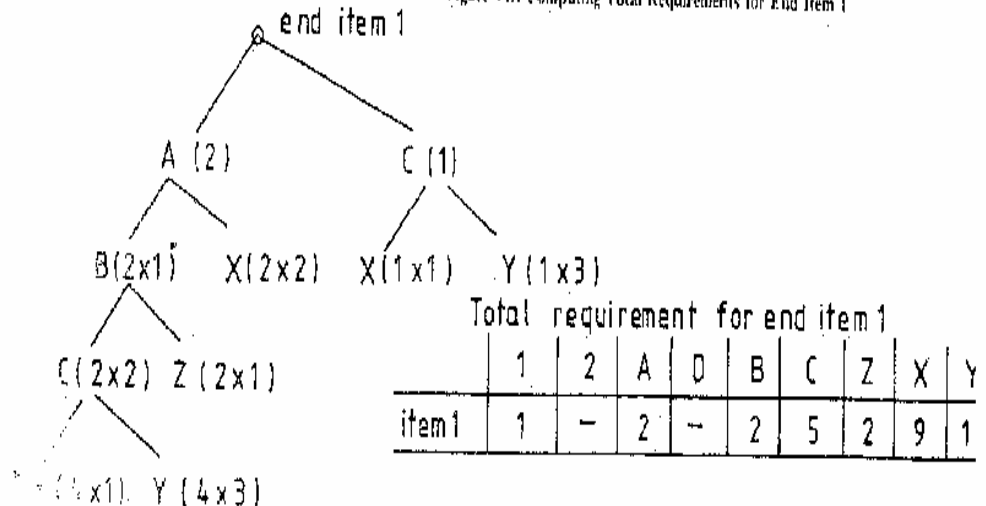




Table 7
Total Requirements Matrix, R

	1	2	A	D	B	C	Z	X	Y
1	1		2		2	5	2	9	15
2		1		1	3	7	6	7	21
A			1		1	2	1	4	6
D				1	2	5	2	5	15
B					1	2	1	2	6
C						1		1	3
Z							1		
X								1	
Y									1

It is this matrix that is used to compute the total production requirements for any given demand. For instance, if at any point of time the demand of items (1, 2, A, D, B, C, Z, X, Y) is (20, 30, 0, 10, 0, 5, 0, 0, 0) the total requirements can be found by multiplying row 1 of the total requirements matrix R by 20, row 2 by 30, row 4 by 10, row 6 by 5 and summing up the columns. This yields the total production vector: (20, 30, 40, 150, 365, 240, 445, 1095)

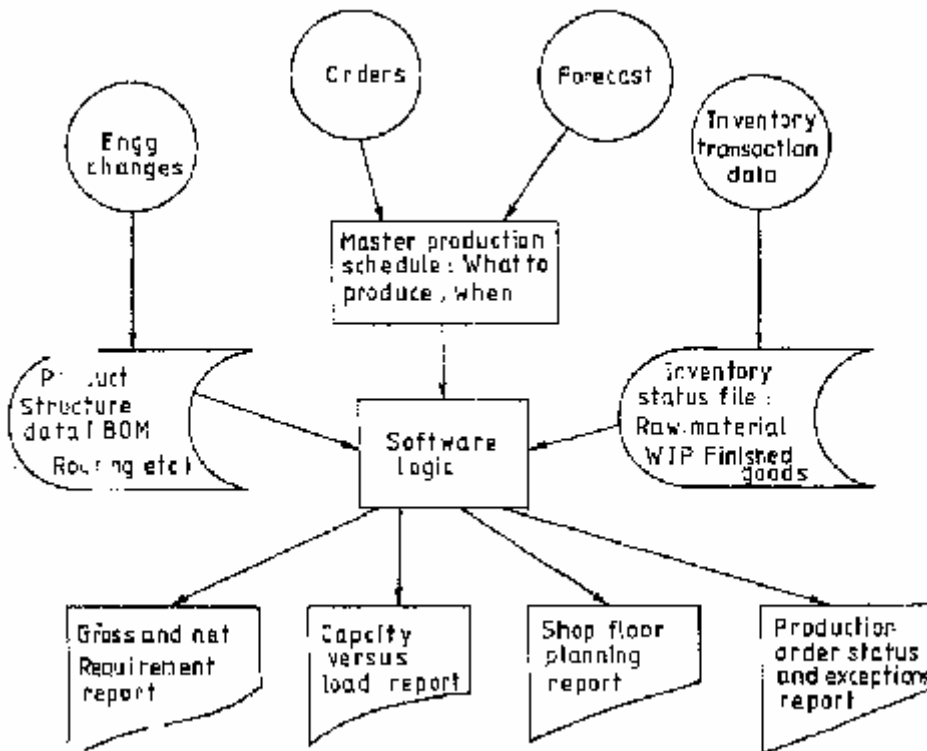
This would be the basic information of how many of which components/ sub-assemblies to have in order to meet the end item demands. However, this information has to be properly dovetailed with current inventory status, production lead times and the end-item demand schedule (or the master schedule) to be able to generate information on which components sub-assemblies should be produced in a given period. This is essentially what an MRP system does.

MRP System in Practice

The major advantage of the MRP approach is its ability to plan discrete parts production for a very complex production system. MRP simply tries to schedule all the activities required to meet a given master schedule, while holding down work in process inventory.

Many commercially available MRP software packages provide a number of informative reports as shown in Figure VIII.

Figure VIII: Typical Structure of an MRP Based Planning System



The major inputs to the system are:
 the master production schedule specifying what to produce and when
 the product structure data including bill of materials, routing files with manufacturing operation lead times.
 the inventory file for raw material work in process, and finished goods.



Among the outputs from the package, the 'gross and net requirements report' indicates the timing of order releases required to meet the master schedule.

The capacity versus load report' determines whether resources required by the w centres are available to produce these orders. This is useful in planning overtime/ sub-contracting.

The 'shop floor planning report' is a listing of jobs by due date where the due date indicates when machining at that department should be completed in order to mf the schedule indicated by the gross and net requirements report. The shop floor supervisor will then release jobs to machines taking into consideration the hours machining required and the due dates for the items.

A typical commercial system provides additional information in the form of Exceptions reports' indicating jobs to be expedited or de-expedited as a consequence of delays in production of components. De-expediting holds down work in process inventory.

In fact an MRP system has to be tailor made to the needs of the organisation, though most of the above features alongwith any special requirements are general] provided for.

10.6 THE LINE OF BALANCE (LOB) FOR PRODUCTION CONTROL AND MONITORING

The line of balance (LOB) is a production control technique suitable for batch production. This technique is used where there is splitting of batches to study the progress of jobs at regular intervals, to compare progress on each operation with the progress necessary to satisfy the eventual delivery requirements and to identify those operations on which progress is unsatisfactory.

The four stages involved in the use of the technique are:

- i) Obtaining the 'delivery schedule for the product as shown, for example, in Table 8.
- ii) Constructing the 'operation programme' to depict the lead times of intermediate operations shown on a chart similar to Figure IX. In this chart, for example, items A and B are assembled (operation 4) 13 days before the final product and this assembly after additional operations is assembled to item (operation 14) 2 days before the final product is ready.

Table 8
Delivery Requirements

Week No.	Delivery of finished items required	Cumulative delivery
0	0	0
1	12	12
2	14	26
3	8	34
4	6	40
5	10	50
6	12	62
7	14	76
8	16	92
9	18	110
10	22	132

- iii) At each review date a 'programme progress chart' is drawn. This shows the number of items that have completed each operation and is obtained by checking inventory levels. For example, at week 4, 40 items should have-been delivered or cleared operation 15 of the example being considered. Figure X shows the programme performance at week no. of 4.



Figure IX: Operation Programme

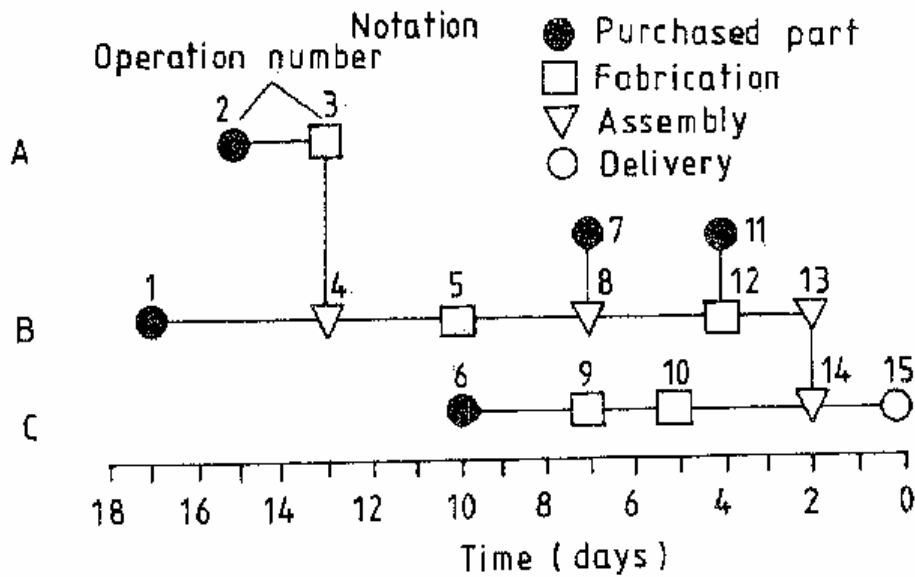
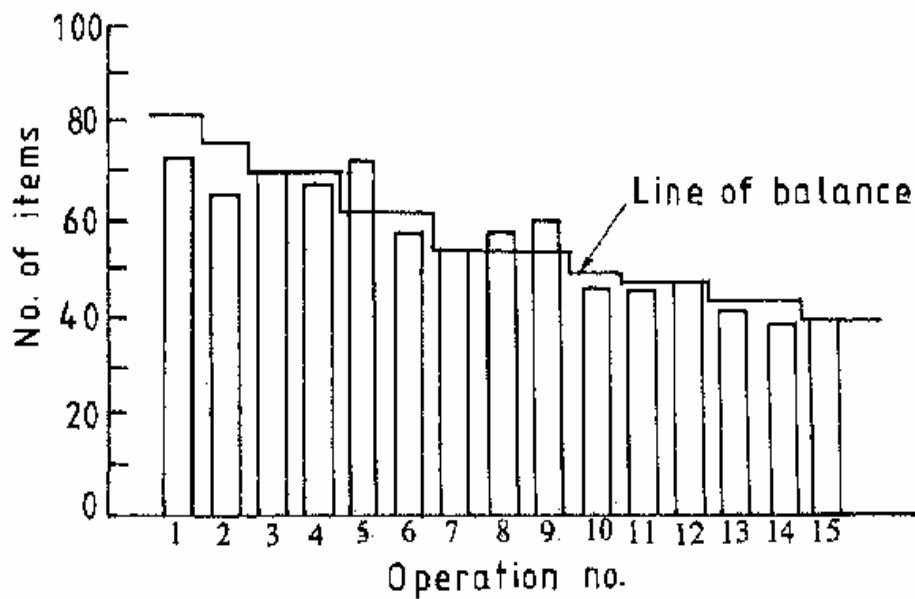


Figure X: Programme Progress Chart (As at week no. 4)

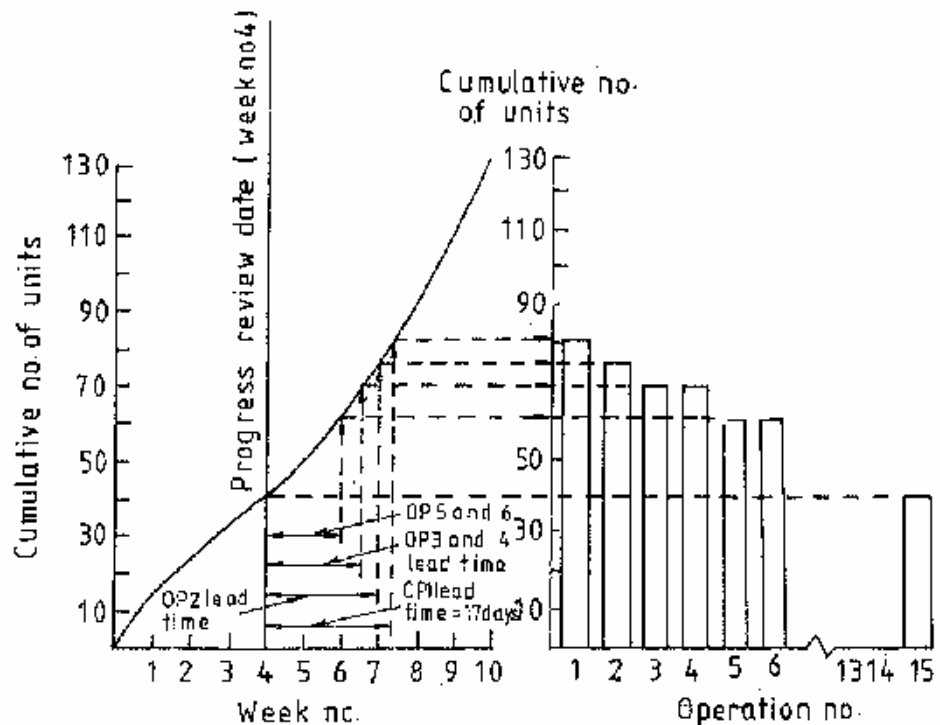


Since the object of the exercise is to compare actual progress with the scheduled or planned progress. The information of Figure X must be compared to the required progress. This is done by constructing a line on the programme progress chart which shows the requisite number of items which should have been completed at each operation at the time of review. This line—the **line of balance** (LOB)—can be constructed by using a graphical procedure as shown in Figure XI. The rationale behind the construction is that at the review date the cumulative number of items ready for each operation must make allowances for the lead time of that particular operation.

- iv) Analysis of progress is finally done to identify shortages and pinpoint the specific operations non-conforming to schedule. For instance, in Figure X the requisite number of completed items have been delivered to the customer (operation 15 = 40), but both operations 13 and 14 are in short supply and unless deliveries during the next week are expedited shortages may occur.



Figure XI: Construction of Line of Balance



The LOB technique is an example of management by exception since it deals only with the important or crucial operations in a job, establishes a schedule or plan for them and attracts attention to those that do not conform to this schedule. It is particularly useful where large batches of fairly complex products, requiring many operations, are to be delivered or completed over a period of time.

10.7 PROBLEMS AND PROSPECTS OF BATCH PRODUCTION

In batch production systems the in-process inventories and the lead times tend to be large. As we have seen MRP is a vehicle to control the discrete parts production planning and also to reduce work in-process inventory. However, the drawback of MRP is that it is expensive to implement as it requires the capability of a mainframe computer, technical support professionals, and MRP software. Instead of designing production control tools for a complex production system, attempts have been made to simplify the system itself. One example of this is Kanban developed in Japan and being implemented at Takahama plant of Toyota, Kanban emphasises the reduction in production lead time and in-process inventory by specifying shorter production runs of any single product. Kanban is characterised by quick change tooling to reduce set up times. Production control is decentralised. Production activity is regulated by Kanban cards. Conflicts are handled by management and supervisory intervention on the shop floor. Further details of Kanban may be found in Elsayed and Boucher.

Another major development with respect to the complicated problems of batch manufacturing has been the development of Flexible Manufacturing Systems (FMS) in an attempt to apply computer controls to production scheduling, the control of machines and the movement of materials in a discrete parts manufacturing environment.

FMS may be defined as general purpose manufacturing machines, which are quite versatile and capable of performing different types of operations, linked together by material handling systems. Both the machines and the material handling systems are under the control of a central computer system. There are two main objectives of employing FMS:

- i) to permit machining of any desired mix of parts in a given time period, and
- ii) to reduce the work in process and increase machine utilisation in small-lot manufacture.



10.8 SUMMARY

In this unit we have presented the features of batch production systems. Normally we resort to batch production of products when there is a continuous demand for products and the production rates exceed the rates of demand. Continuous production would obviously lead to ever increasing inventory build-ups in such cases.

The problems of finding the batch size in both the single product and the multiproduct situation (with the same manufacturing facility) have been considered. Essentially, the approach is to balance two conflicting costs: the cost of set up and the inventory carrying cost, where the former tends to decrease while the latter increases with larger batch sizes.

Aggregate production planning to economically meet a demand schedule over a planning horizon (of say a few months to a year) has been discussed and illustrated through a small example. Disaggregation to obtain the master schedule is also indicated.

A problem, once the master schedule is obtained, is to plan for procurement and production of various components and sub-assemblies in time-this is done through Material Requirements Planning (MRP). How to obtain the demand for parts has been illustrated in parts explosion. Subsequently, the structure of a practical MRP system and the various reports that may be generated are highlighted.

The LOB technique for production monitoring has been discussed. next, pointing out the usefulness of this management by exception tool for production managers.

Finally, some developments in areas of discrete parts manufacturing have been indicated with a brief discussion of Kanban and Flexible Manufacturing Systems.

10.9 KEY WORDS

Aggregate Production Planning: Allocation of work force size and production level to meet the forecasted demands of goods and services over the planning horizon. This is generally done in terms of an aggregate product representing the combined needs of the various products.

Batch Production: A production situation where production takes place in lots or batches as opposed to continuous production. Justified when rate of production exceeds the rate of demand. Determination of batch sizes and sequencing or scheduling of batches in multiple product situation are the key decisions in batch production.

Line of Balance (LOB): A production control device effective in batch production to compare progress on each operation with the progress necessary to satisfy the eventual delivery requirements (not to be confused with 'line balancing' used for designing assembly lines in mass production).

Master. Schedule., A detailed product by product production plan showing the quantities of each product to be produced in each period of the planning horizon.

Material Requirements Planning (MRP): This is generally a computer-based system for drawing up detailed production/procurement schedules for various parts, sub-assemblies needed to meet a given master schedule of the end item. It utilises the product structure, processing, information like production/ procurement lead times and inventory status in a bid to produce the best plan.

Parts Explosion: A particular product is generally composed of sub-assemblies and parts which in turn could be traced to items at the next level in a typical tree-like product structure. The problem of finding the demand of all components, sub-assemblies for a given demand of the end product is referred to as 'Parts Explosion' The problem could be complicated as a component or sub-assembly may be needed at different levels of the same or different end-products.



10.10 SELF-ASSESSMENT EXERCISES

- 1 Distinguish between mass and batch production, under what conditions is batch production justified?
- 2 A product may be made in the plant or purchased from an outside vendor. The inventory carrying cost per unit is Rs. 5 per day and no shortages are to be allowed. Given the information in the following table, what is the best policy for an annual demand of (a) 30,000 units and (b) 20,000 units.

	In-plant	Vendor
Production per day (units)	200	8
Lead time (days)	4	9
Cost per units (Rs)	500	540
Order cost (Rs.)	1000	700

- 3 A company is to produce three products on the same machine using a common cycle policy. What should be the respective batch sizes and the total annual cost given the following data?

	Product-1	Product-2	Product-3
Production per year (units)	6000	12000	4500
Demand per year (units)	2000	3000	1500
Set up cost	Rs. 500	Rs. 400	Rs. 600
<u>Inventory Carrying cost per unit per year</u>	<u>Rs. 400</u>	<u>Rs. 700</u>	<u>Rs. 300</u>

- 4 The packaging division of a paint shop used the same automatic filling machinery for packing 3 grades of paint called A, B and C. Demand for each brand over the next six weeks is as follows:

Units demanded (X10 ³)			
Week	A	B	C
1	100	50	100
2	100	80	80
3	200	100	150
4	150	120	80
5	200	50	80
6	200	100	100
Initial Inventory	200	100	150

The filling machinery is operated for 40 regular time hours per week maximum and overtime is limited to 20% of the scheduled regular time hours.

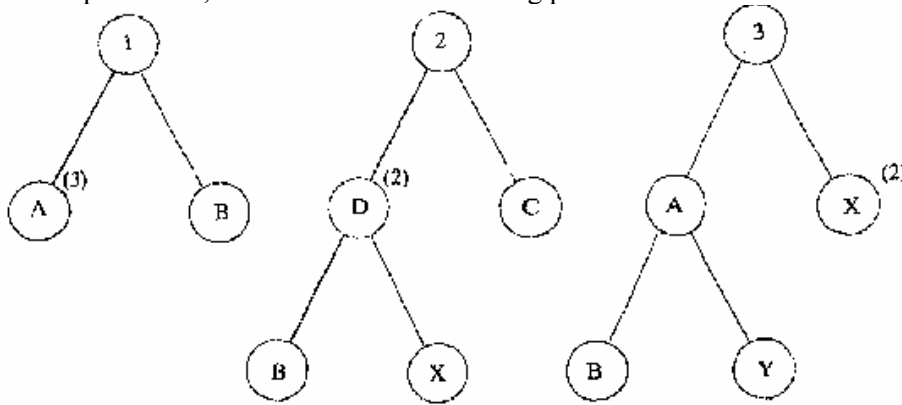
Owing to different viscosities of the paint brands the standard number of tins filled per hour is as follows:

Brand	Standard Tins filled per hour
A	9800
B	7200
C	6900

Costs per hour of regular time an overtime are Rs. 200 and Rs. 400 respectively. The inventory carrying cost rate is 40% per annum. What is the optimal aggregate production plan?



- 5 Three end products 1,2,3 are composed of sub-assemblies A,B;C,D, and components X,Y as shown in the following product structures



3

(numbers in parentheses show the number of units needed for assembly to the next higher level).

- Construct the Bill of Materials matrix
- If 5,2 and 1 units of end items 1,2,3 are required compute the vector of dependent demand resulting directly from end product demand.
- Compute the total requirements matrix for the above case.

10.11 FURTHER READINGS

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