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BUS 801

Operations Management

Module 3

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Module 3

Unit 1 Linear Programming (LP)

1.0 Introduction

In many business situations, resources are limited while demand for them is unlimited. For example, a limited number of vehicles may have to be scheduled to make multiple trips to customers or a staffing plan may have to be developed to cover expected variable demand with the fewest employees. In this unit we describe a method called linear programming (LP), which is useful for allocating scarce resources among competing demands. The resources may be time, money, or materials, and the limitation are known as constraints. Linear programming can help managers find the best allocation solution and provide information about the value of additional resources.

2.0 Objectives

At the end of this unit, you should be able to:

- explain the characteristics and assumption of linear programming model
- formulate models for various problems
- perform graphic analysis for two-variable problems and find the algebraic solution for the corner point found to be optimal
- describe the meaning of slack and surplus variables
- discuss the meaning of sensitivity analysis on the objective function co-efficient and right hand side parameters
- interpret the computer output of a linear programming solution.

3.0 Main Content

3.1 Function and Characteristics of LP

3.1.1 Functions

(i) LP is useful in the specification of optimum organisation of resources in a business organisation such that net returns of maximization of returns is achieved under given condition of resource restriction.

(ii) LP makes long range planning possible in business

(iii) LP gives technical co-efficient based largely on the practices and methods of operation adopted by the manager.

(iv) By-product obtained from results of the LP planning exercises are capable of throwing considerable light on a number of aspects of business management e.g. the surplus or unexhausted resource(s), the rate of interest the manager can justifiably pay on borrowed funds, wages that the manager is willing to pay for labour.

3.1.2 Characteristics

Some assumptions (characteristics) go with the three components of LP outlined in section 3.2, they are:

(i) Linearity:- This implies that the input-output co-efficient are constant and independent of the scale of operation implying constant resource productivity and return to scale.

(ii) Additivity:- This assumption implies that the total quantity of resources used in different activities is equal to the sum of the quantities of different input used in each activity and that the size of any activity is independent of the size of other activities.

(iii)Divisibility:- This means that inputs are infinitely divisible. Thus, an LP solution can specify inputs and outputs in fractional units such as 10.7 units of labour etc.

(iv) Finiteness:-This implies that a limit exists on the number of `activities and resources which can be programmed. This is a practical assumption in the sense that an unlimited number of activities and resources would make an optimum solution impossible to obtain

(v) Single valued expectation:- This characteristics shows that the prices of inputs and outputs, the input-output co-efficient and the levels of resources are known with certainty. Hence, a LP model is deterministic.

(vi) Non-negativity of decision variables:- This is very logical, there is no way you use any negative quantity of any resource, the least you use of any input among series of inputs in a production process is zero i.e. not used at all.

3.2 Components of LP Model

(i) An objective function:- This must be clearly spelt out in mathematical language, and this can take one of several forms e.g. (a) Maximization of net revenue or profit from one or a several combination of enterprises (b) Maximization of production or a transportation cost.

(ii) Competitive enterprises with possible alternative methods of producing each enterprise. This implies that enterprises must be competing for the use of resources and in which case there is a problem of choice among enterprises, (see section under formulation of LP problem).

(iii) Constraint to the attainment of the objective: A linear programming (LP) problem exists only if there are constraints limiting the attainment of an objective

Basically there are 3 types of constraints

(a) Resource constraint:- A manager always have limited levels of such resources as capital, labour, machines, building capacity etc. which limits the scale of his operation.

(b) Institutional constraint: - This is typified by quota system which is a contractual arrangement with say a governmental agency specified minimum or maximum production levels.

(c) Subjective constraint: - The manager imposes this on himself. For example, there may be internal capital rationing due to (i) debt aversion (ii) scale restriction due to skill (iii) consumption habit consideration etc.

3.3 Formulating a LP problem

Linear programming application begins with the formulation of a model of the problem with the general characteristics just described. We illustrate the modeling process here with the product mix problem, a one- period type of aggregate planning problem, the solution of which yields optimal output quantities (or product mix) of a group of product or services, subject to resource capacity and market demand constraints. Formulating a model to represent each unique problem, using the following three-step sequence, is the most creative and perhaps the most difficult part of linear programming.

Step 1: Define the decision variable

Define each decision variable specifically, remembering that the definitions used in the objective function must be equally useful in the constraints. The definitions should be as specific as possible e.g. X, = product 1

or

X, = no of units of product 1 produced and sold at a time.

Step 2: Write out the objective function.

What is to be maximized or minimized? If it is revenue, write out an objective function that makes the revenue a linear function of the decision variables. Identify parameters to go with each decision variable. For example, if each unit of X_1 sold yields a revenue of **N**45, the total revenue realizable from X_1 equal 45 X_1. The objective function often is set to equal to Z, and the goal is to maximize or minimize Z.

What limits the values of the decision variables? Identify the constraints and the parameters for each decision variable in them. To be formally correct, also write out the non-negativity constraints.

Example 1

Lopin factory produces two basic types of plastic pipe. Three resources are taken to be crucial to the output of pipe: extrusion hours, packaging hours, and a special additive to the plastic raw material. The data below represent next production situation.

Product

Resource	Type 1	Type 2	Resource availability
Extrusion	4hr	6hr	48hr
Packaging	2hr	2hr	18hr
Additive mix	2kg	1 kg	16kg

The contribution of profits and overhead per 100 feet of pipe is **N**34 for type 1 and **N**40 for type 2. Formulate a linear programming mode to determine how much of each type of pipe should be produced to maximize contribution to profits and to overhead.

Solution

Step 1: To define the decision variables that determine product mix, we let

X_1 = amount of type 1 pipe to be produced and sold after next production. X_2 = amount of type 2 pipe to be produced and sold after next production.

Step 2: Next define the objective function. The goal is to maximize the total contribution that the two products make to profits and overhead. Each unit of X_1 yields **N**34 and each unit of X_2 yields x **N**40. For specific values of $X_1$and X_2 we find the total profit by multiplying the number of units of each product produced by the profit per unit and adding them. Thus our objective function becomes Maximize **N**34 X_1 + **N**40 X_2 =Z.

Step 3: The final step is to formulate the constraints. Each unit of X_1 and X_2 produced consumes some of the critical resources. In the extrusion department, a unit of X_1 requires 4 hours and a unit of X_2 requires 6 hrs. The total must not exceed the 48hours capacity available, so we use the $\leq$ sign. Thus the first constraint is $4 X_1 + 6 X_2 \leq 48$ (extrusion).

Similarly, we can formulate constraints for packaging and raw materials.

$2 X_1 + 2 X_2 \leq 18$ (packaging)

$2 X_1 + X_2 \leq 16$ (additive mix)

These three constraints restrict our choice of values for the decision variables because the values we choose for $X_1$and X_2 must satisfy all of them. Negative values for $X_1$and X_2 don't make sense, so we add non-negativity restrictions to the model.

$X_1 \geq 0; X_2 \geq 0$

We can now state the entire model, made complete with the definition of variables.

Maximize 1 **N**$34X_1$ + ; **N**$40X_2$ = Z

Subject to $4X_1 + 6X_2 \leq 48$

$2X_1 + 2X_2 \leq 18$

$2X_1 + X_2 \leq 16$

$X_1, X_2 \geq 0.$

3.3.1 Graphic analysis

With the model formulated, we now seek the optimal solution. In practice, most linear programming problems are solved with the computer. However, insight into the meaning of the computer output and linear programming concept in general can be gained by analyzing a two - variable problem with the graphic method of linear programming, even though it isn't a practical techniques for solving problems having three or more decision variables. Five basic steps involved are

(i) Plot the constraint

(ii) Identity the feasible region

(iii) Plot an objective function line

(iv) Find the visual solution

(v) Find the algebraic solution

Each of these five steps are briefly discussed

(1) Plot the constraints

We begin by plotting the constraint equations, disregarding the inequality portion of the constraints. Making each constraint equal converts it to equation for a straight line. The line can be drawn as soon as we identify two points on it. To find the X1 axis intercept, set X_2 equal to 0 and solve the equation for X1. For the Lopin factory in example I, the equation of the line for the extrusion process is

$$4X_1 + 6X_2 = 48$$

for the X1 axis intercept, $X_2 = 0$

and so $4X_1 + 6(0) = 48$

$$X_1 = 12$$

To find X2 axis intercept, $X_1 = 0$

and so $4(0) + 6(X_2) = 48$

$$X_2 = 8$$

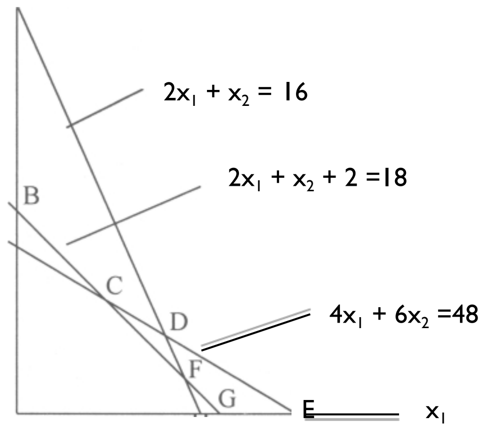
We now connect points (0, 8) and (12, 0) as in Figure 11.1 below.

X_2

$2X_1 + X_2 = 16$

Formal

$4X_1 + 6X_2 = 48$



2 4 6 8 10 12 14 16 X,

Figure 11.1: Graph of the Three Constraints

The solution for packaging process line

$2X_1 + 2X_2 = 18$

for X_1, $:2X_1 + 2(0) = 18$

$X_1, = 9$

For $X_2 : 2(0) + 2(X_2) = 18$

$X_2 = 9$

We now connect points (9,0) and (0,9) on the same graph behind in fig. 1. The equation for the additive mix line is $2X_1, + X_2 = 16$. To find X_1, intercept, set $X_2 = 0$

$2X_1, + X_2 = 16$

$X_1 = 8$

To find X_2, set $X_1 \leq = 0$

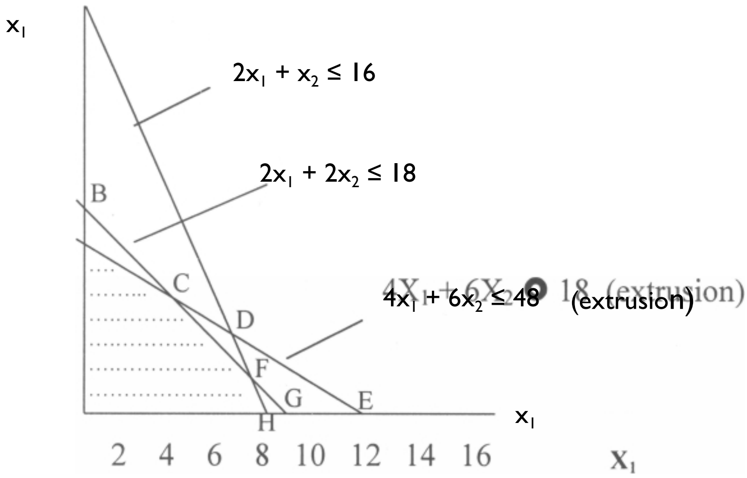
$2(0) + X_2 = 16$

$X_2 = 16.$

We also connect points (0, 16) and (8, 0) for the additive mix on the same graph of Figure 11.1.

(2) Identify the feasible region

The feasible region is the area on the graph that contains the solutions that satisfy all the constraints simultaneously, including the nonnegative restriction. The feasible region for a maximization problem as in this case is that area bounded by all the tree curves and so we would have the curve ICFH as our feasible region as shown in Figure 11.2. Having obtained the feasible region we now seek to locate the point that maximizes the objective function this is achieved by plotting the objective function on the feasible region. The series of lines plotted are called Iso-revenue curves if the objective function is to maximize revenue or Iso-profit curve if the objective is to maximize profit. The optimal point is finally read as the point where the objective function line cuts the tip of the feasible point (farthest point from the origin).



$2\,X_1 + 2\,X_2 \leq 18$ (packaging)

Figure 11.2: The Feasible region

(3) Find the visual solution

From the feasible region ICFH we eliminate corner point OH because better points lie above and to the right. The optimal solution is the last point touching the feasible region when series of lines with slope equal to the slope of the objective are plotted within the feasible region. Due to some errors in reading, the value from the graph or gradation, visual solution isn't exact.

(4) Find the Algebraic Solution

To find an exact solution, we must use algebra. We begin by identifying the pair of constraints that define the corner point at their intersection. We then list the constraints as equations and solve them simultaneously to find the coordinates (XI, X2) of the corner point.

Simultaneously equation can be solved several ways. For small problems the easiest way is as follows.

Step 1: Develop an equation with just one unknown. Start by multiplying both sides of one equation by a constant so that the co-efficient for one of the two variables is identical in both equations. Then subtract one equation from the other and solve the resulting equation for its single unknown variable.

Step 2: Insert this decision variable value into either one of the original constraints and solve for the other decision variable. Find the optimal solution algebraically for the Lopin factory. What is the value of Z when the decision variables have optimal values.'?

Solution

Step 1

$4X_1 + 6X_2 = 48$ (Extrusion)

$2X_1 + 2X_2 = 18$ (Packaging)

Multiply each term in packaging constraint by 2 to give $4X_1 + 4X_2 = 36$. Next, we subtract the packaging constraint from the extrusion constraints.

$4X_1 + 6X_2 = 48$

$(4X_1 + 4X_2 = 36)$

$2X_2 = 12$

$X_2 = 6$

Step 2 substituting the values of X_2 into the extrusion equation, we get

$4X_1 + 6(6) = 48$

$4X_1 = 12$

$X_1 = 3$

The optimal point is thus (3, 6) to give an optimal profit of

34(3) + 40 (6) = N4342

3.4 Slack and Surplus Variables

For a O constraints, the amount by which the left-hand side falls short of the right-hand side is called slack. For a 1:1 constraint, the amount by which the left-hand side exceeds the right-hand side is called surplus. To find the slack for a O constraint algebraically, we add a slack variable to the constraint and convert it to an equality. Then we substitute in the values of the decision variables and solve for the slack. For example the additive mix constraint in Lopin factory is $2X1 + X2 + S1 = 16$.

We then find the slack at the optimal solution (3, 6)

$2(3) + 6 + S_1 = 16$

$S_1 = 4.$

The procedure is much the same to find the surplus for a ◊, constraint, except that we subtract a surplus variable from the left-hand side. Suppose that $X_1 + X_2$ ◊, 6 was another constraint in the Lopin factory problem, representing a lower bond on the number of units produced. We would then rewrite the constraint by subtracting a surplus variable S_2

$X_1 + X_2 - S_2 = 6$

The slack at the optimal solution (3,6) would be

$3+6 - S_2 = 6$

$S_2 = 3$

3.5 Sensitivity Analysis

The parameters in the objective function and constraints are rarely known with certainty. Sometimes they are just estimates of actual values. For example, the available packaging and extrusion hours for the Lopin factory are estimates that do not reflect the uncertainties associated with absenteeism or personnel transfers, and required time per unit to package and extrude may be work standards that essentially are averages. Likewise, profit contribution used for the objective function coefficients do not reflect uncertainties in selling prices and such variable costs as wages, raw materials, and shipping.

In spite of these uncertainties, initial estimates are needed to solve the problem. Accounting, marketing and work-standard information systems usually often provide these initial estimates. After solving the problem using these estimated values, the analyst can determine how much the optimal value of the decision variables and the objective function value Z would be affected if certain parameters had different values. This type of post solution analysis for answering "what if' question is called sensitivity analysis.

3.5.1 Right - Hand - Side Parameters

Now consider how a change in the right-hand-side parameter for a constraint may affect the feasible region and perhaps cause a change in the optimal solution. Let's return to the Lopin factory problem. Consider adding one more hour to the packaging process, increasing it from 18 to 19 hours; i.e.

$4X_1 + 6X_1, = 48$ (extrusion)

$2X_1, + 2X_2 = 19$ (packaging)

The optimal values are $X_1 = 4.5$ and $X_2 = 5$ and the new Z value is N34 (4.5) + N40 (5) = N353. Because the value of Z was N342 with 18 hours of packaging time, the value of one more hour of packaging is N11 (or N353 - N342).

The change in Z per unit of change in the value of the right-hand side parameter of a constraint is called the shadow price, which is the marginal improvement in Z caused by relaxing the constraint by one unit. Relaxations mean making the constraint or decrease it for an O restrictive, which involves increasing the right-hand-side for an O constraint. The shadow price also is the marginal loss in Z caused by making the constraint more restrictive by one unit.

3.6 Computer Solution

Most real-world linear programming problems are solved on a computer, so we will focus our understanding on the use of computer to solving LP problems and the logic behind its use. The solution procedure in computer codes is some form of the simplex method, an iterative algebraic procedure for solving linear programming problems.

3.6.1 Simplex Method

The graphic analysis gives insight into the logic of the simplex method. One corner point of the feasible region will always be the optimum, even when there are multiple optimal solutions. Thus, the simplex method starts with an initial corner point and then systematically evaluates other corner points in such a way that the objective function improves (or at worst, stays at the same) at each iteration. In the Lopin factory example we have being using for illustration; an improvement would be an increase in profits. When no more improvements are possible, the optimal solution has been found.

3.6.2 Computer Output

Computer programmes diagrammatically reduce the amount of time required to solve linear programming problems. Special - purpose programmes can be developed for applications that must be repeated frequently. Such programmes simplify data input and generate the objective function and constraint for the problem.

Printout 1 shows the input data for the Lopin factory problem. The last half of printout 1 gives the values and the type of constraint (O = or O). The user may choose to enter labels for the objective function, constraint, and right hand side values. Here the extrusion constraint is labelled "Ext" and the right-hand -side values are labelled "RHS" Input data can be stored in file for use during subsequent sessions.

Printout 1

Data entered

Number of variables 2

Number of O constraint 3

Number of = constraint 0

Number of O constant 0

Number of	constraint 0	X_2		RHS
Max Z	34	4		
Ext	4	6	O	48
Pac	2	2	O	18
Add	2	1	0	16

Printout 2

Solution

sVariable	Variable	original coefficient

Label	Value	coefficient sensitivity
X1	3	34 0
X2	6	40 0

Constraint	Original	Slack or Shadow
Label	RHV	Surplus Price
Ext	48	0 3
Pac	18	0 11
Add	16	4 0

Objective function value: 342

So far we have solved the Lopin factory problem graphically and algebraically, mention was made of the simplex approach but not performed in this section we shall see manually the series of operations being performed within the input-output system of a computer.

Max Z $= 34\ X_1 + 40\ X_2$

S.t $4X_1 + 6X_2 \leq 48$

$2X_1 + 2X_2 \leq 18$

$2X_1 + X_2 \leq 16$

By converting the inequality to strict equality, we add slack activities to each of the constraints. i.e.

Max Z $= 34X_1 + 40X_2$

S.t $4X_1 + 6X_2 + IS_1 = 48$

$2X_1 + 2X_2 + IS_2 = 18$

$2X_1 + X_2 + IS_3 = 16$

$X_1\ X_2$ O 0

Simplex table

iteration	C	Resources/ Activities	Resources Level	Real Activities 34 40 X, X2	Slack Activities 0 0 0 S, S2 S3	R
	0	S,	48	4 6	1 0 0	8*
	0	S,	18	2 2	0 1 0	9
I	0	S3	16	2 1	0 0 1	16
		Z	0	0 0	0 0 0	
		Z-C	-	-34 -40	0 0 0	
	40	X2	8	213 1	'/6 0 0	12
	0	S2	2	2/3 0	-1/3 1 0	3*
	0	S3	8	11/3 0	-1/6 0 1	6
I I						
		Z	320	262/3 40	62/3 0 0	
		Z-C	-	-71/3 0	62/3 0 0	
	34	X,	3	1 0	-`/2 1 `/2 0	
I I I	40	X2	6	0 1	1/2 -1 0	
	0	S3	4	0 0	1/2 -2 1	
		Z	342	34 40	3 11 0	
		Z-C	-	0 0	3 11 0	

Critical evaluation of the simplex table would show the last value of Z as N342, just as in the computer printout 2, the values 3, 11, 0, last bottom values are defined as shadow prices, just the same as in computer printout 2. In the third iteration S3 featured with a value of 4, showing us that the third resource was not fully consumed, Just the same as computer printout 2. It may be of necessity to practice one or two examples on simplex table, this then call for the need to explain the table.

1. In the first iteration, all resources to be used in the production process are treated as surplus

2. Anything surplus would have a shadow price of zero i.e. how much you are willing to pay to have an additional unit.

3. Consider the resource level column, the level you have would be the total amount you have in store to use in production process.

4. The real activities column would have the co-efficient of the constraint.

5. Slack activities column would have diagonal values as 1 and all off diagonal values as 0, i.e. and identity matrix.

6. Having inputted all these values, underline every column and introduce a Z row

7. To fill the Z row, multiply the cost values corresponding to any entry by the quantity and sum throughout the row.

8. Designate another Z-C row and subtract C, note that C attached to X, and XZ is the coefficient in its objective form as 34 and 40 respectively and C corresponding to Si. SZ

and S3 are all zeros, meaning that whatever is surplus would not command a value from a consumer.

9. Looking at the Z-C row under the real activity column, observe any highest negative value, trace it up and call this the pivot column (incoming activity)

10. Next, divide all resource levels by their pivot column equivalent and fill this in the R column

11. Observe the lowest of all the Rs and trace this sideways (outgoing activity); this is the pivot row.

12. There is a place where the pivot column and pivot row intersect, call this the pivot. That is the end of the first iteration.

13. In the second iteration, first input the incoming activity (XZ in this case)

14. To know the levels of X2 in each cell divide the values of the outgoing activity by its pivot all through.

15. Now, observe something special, just as the pivot divide itself to give 1, observe the two other values under it to be zero. This must be, and so would be helpful when the levels of the other two resources are to be deduced.

16. For the level of S2, we wont just copy the levels iteration 1, but we have to use adjusted levels (observe what was said in point 15 above).

17. To go about that where we peg S2 = 0 under the location where pivot divide itself to give 1 and other values under = 0, we say we want to look for a multiplier effect. This is calculated as initial - multiplier (outgoing) = 0.

18. Look back at iteration 1 and see that the value of S2 directly under pivot value is 2 (that value represents initial).

19. Back in iteration II, the value of S2 under same column was traced down to zero. The outgoing value for that column was 6 (the pivot).

20. Let us now use this combination to find out multiplier as

2 - Multiplier (6) = 0

Let multiplier be x

So that 2-x (6) = 0

$x = {}^{1}/_{3}$

21. To calculate resource level for S2 in iteration II we say 18 which is initial value from iteration I less the product of multiplier and what is going out under same column i.e. 18 - $^{1}/3$ (48) = 2.

Similarly to calculate the value of S_2 under real activity X_1, we say

$2-\frac{1}{3}(4) = \frac{2}{3}$, until the whole array is filled up.

22. We also have to look for multiplier S_3.

23. Underline and evaluate Z and Z-C and observe if negative exists in the real activity column of Z-C row.

24. If negative exists, the highest negative connotes the incoming activity in the next iteration. If not an optimal solution has been reached.

3.7 Dual

The objective of any LP process is called the primal, the process of reversing or transpose of the primal process is called the dual. If the primal is to maximize then the dual is to minimize, whether the primal function is solved or its dual function is used to establish the solution, the answer remain unchanged

3.7.1 Procedure for a dual process

1. Observe the objective function of the primal problem

2. Write out the co-efficients of the constraints of the primal problem in form of matrix.

3. Transpose the matrix of co-efficients of the constraints.

4. Total requirement of each of the constraints of the primal problem now turn coefficients of the objective function of the dual.

5. Co-efficients of the objective function of the primal problem become the resource constraints.

6. The inequality sign is reversed for the dual problem.

4.0 Conclusion

We have been able to see how the knowledge of LP can be of help in management decisions to boost the performance of a business unit or production organisation.

5.0 Summary

We are now able to take some economic and managerial decision on the use of resources, what resource would contribute better to our objective has been pointed out from slack activities column and the Z-C row of the optimal strategy.

The limitations of graphical method compared to the simplex method was seen in that graphical solution cannot handle clearly more than two objective function case, whereas the simplex approach would do us better. The surplus resource(s) or the shadow prices was equality highlighted in the simplex method but cannot be depicted on the graphical solution.

6.0 Self-Assessment Exercise

(1) Maximize $Z = 2X_1 + 3X_2$

S.t $X_1 + 2X_2$ O 30

$3X_1 + X_2$ O 60

$6X_1 + 3X_2$ O 200

$5X_1 + 4X2$ O 200

(2) Maximize $Z = 2X_1 + X_2$

S.t. $X_1 + X_2$ O 5

$X_1 + 3X_2$ O 9

In each case find maximum Z, the slack resources, and the shadow prices.

7.0 References/Further Reading

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Unit 2 Material Requirements Planning

1.0 Introduction

Material requirements planning (MRP) is a computer-based information system for ordering and scheduling of dependent-demand inventories (e.g. raw materials, component parts, and subassemblies). (Recall that dependent-demand is the demand for items that are subassemblies or component parts to be used in the production of finished goods).

What is involved in MRP is the translation of a production plan for a specified number of finished products into requirements for component parts and raw materials working backward, using lead time information to determine when and how much to order.

MRP is as much a philosophy as it is a technique, and as much an approach to scheduling as it is to inventory control. MRP begins with a schedule of finished goods that is converted into a schedule of requirements for subassemblies, components parts, and raw materials needed to produce the finished items in the specified time frame. What this amounts to, is that MRP is designed to answer three questions: What is needed? How much is needed? And when it is needed? The primary inputs of MRP necessary to answer these questions are (i) a bill of material, which tells the composition of a finished product; (ii) a master schedule which tells how much finished product is desired and when; and (iii) an inventory records file, which tells how much inventory is on hand or on order. This information is then processed to determine the planning horizon.

Outputs from the process include planned-order schedule, order releases, changes performance-control reports, planning repots and exception reports. These inputs and output are discussed in more detail in subsequent sections.

2.0 Objectives

At the end of this unit, you should be able to:

- describe the conditions under which MRP is most appropriate
- describe the input, outputs and nature of MRP processing
- explain how requirements in a master production schedule are translated into material requirements for lower-level items
- discuss the benefits and requirements of MRP
- explain how an MRP system is useful in capacity requirements planning
- outline the potential benefits and some of the difficulties users have encountered with MRP
- describe MRP II and how it relates to MRP.

3.0 Main Content

3.1 MRP Inputs

As already mentioned in proceeding section, an MRP system has three major sources of information: a master schedule, a bill- of-material file, and an inventory records file. Let's consider each of these inputs.

3.1.1 The Master Schedule

The master schedule states which end items are to be produced, when they are needed, and in what quantities. Figure 12.1 illustrates a portion of a master schedule that shows planned output for end items X for the planning horizon. The schedule indicates that 100 units of X will be needed (e.g., for shipments to customers) at the start of week 4 and that another 150 units will be needed at the start of week 8.

Week Number

Item X	1	2	3	4	5	6	7	8
Quantity				100				150

Figure 12.1: A portion of master schedule

The quantities in a master schedule come from a number of different sources, including customer orders, forecasts, orders from warehouses to build up seasonal inventories, and external demand.

The master schedule separates the planning horizon into a series of time periods or time buckets, which are often expressed in weeks. However, the time bucket need not be of equal length.

It is important that the master schedule cover the stacked or cumulative lead time necessary to produce the end items. This cumulative lead time is the sum of the lead times that sequential phases of a process require, from ordering of parts or raw materials to completion of final assembly.

Stability in short-term production plans is very important; without it, changes in order quantity and/or timing can render material requirements plans almost useless. To minimize such problems, many firms establish a series of time intervals, called time fences, during which changes can be made to orders. For example, a firm might specify time fences of 4,8, and 12 weeks, with the nearest fence being the most restrictive and farthest fence being less restrictive. Beyond 12 weeks changes are expected; from 8 to 12 weeks, substitutions of one end item for another may be permitted as long as the components are available and the production plan is not compromised; from 4 to 8 weeks, the plan is fixed, but small charges may be allowed; and the plan is frozen out to the four-week fence.

3.1.2 The Bill-of-Material File

A bill of materials (BOM) containing a listing of all the assemblies, sub-assemblies, parts, and raw materials that are needed to produce one unit of a finished product. This means that each finished product has its own bill of materials.

The listing in BOM is hierarchical; it shows the quantity of each item needed to complete one unit of the following level of assembly. The nature of this aspect of a BOM is perhaps grasped most readily by considering a product structure tree, which provides a visual depiction of the subassemblies and components that are needed to assemble a product. Figure 12.2 shows a product tree for a chair.

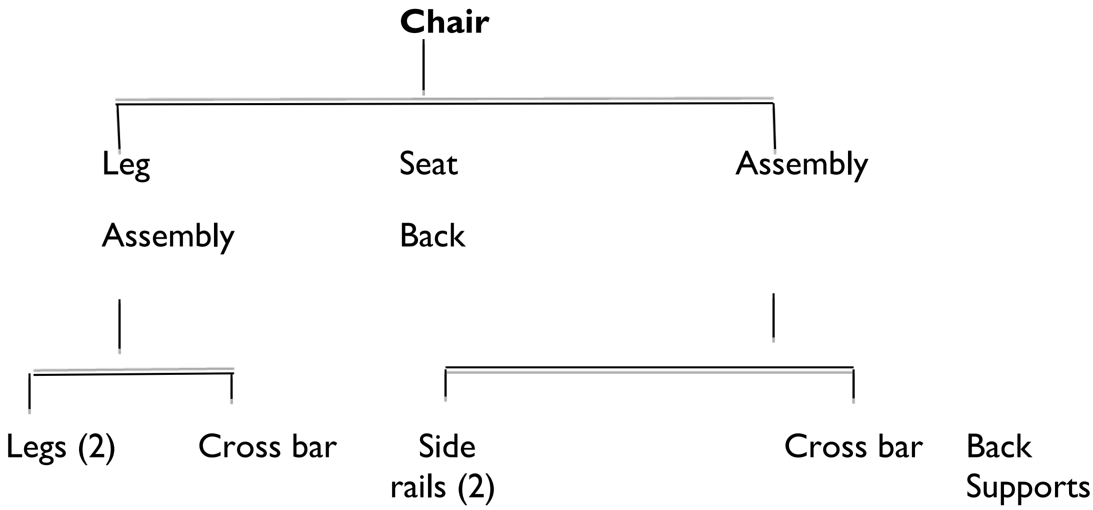


Figure 12.2: Product Structure Tree

A product structure tree is useful in illustrating how the bill of materials is used to determine the quantities of each of the ingredients (requirements) needed to obtain a desired number of end items. Let's consider the product tree shown in figure 12.3.

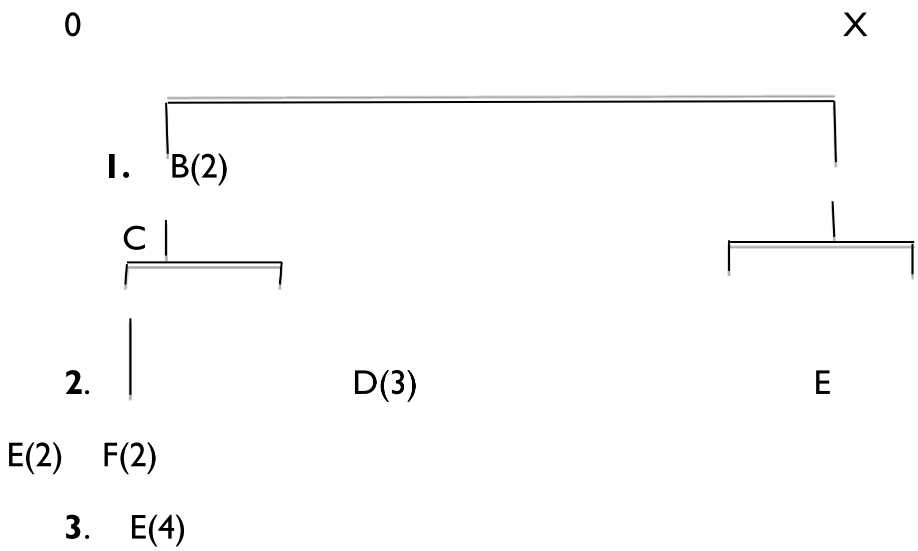


*Figure 12.3:*A product tree for end item X

Note that the quantities of each item in the product structure tree refer only to the amounts needed to complete the assembly in the next higher level. We can use the information presented in figure12.3 to do the following:

(a) Determine the quantities of B, C, D, E, and F needed to assemble one X.

(b) Determine the quantities of these components that will be required to assemble 200Xs

Solution

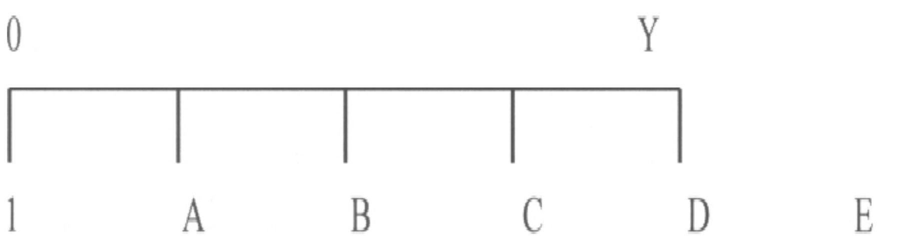
Component	Quantity
B ---------------- 213s	= 2
D----------------30s per B X 213s per X	= 6
E ---------------- 4 Es per D X 3Ds per B X 2Bs per X	= 24
E ----------------IE per B X 213s per X	= 2
C --------------- 1 C per X	= 1
E ----------------- 2 Es per C X 1 C per X	= 2
F --------------- 2 Fs per C X 1 C per X	=2

Note that E appears in three separate places. Its total requirements can be determined by summing the separate amounts, which yields 28.

(b) In order to assemble 200 units of X, the quantities of each component must be multiplied by 200. Hence, there must be 200 (2) = $400X_s$, 200 (6) = 1,200Ds, 200 (28) = 5,600Es, and so on.

When requirements are calculated in an MRP system, the computer scans the product structure level by level, starting at the top. When a component (such as E in figure 12.3 appears on more than one level, its total requirements cannot be determined until all levels have been scanned. From a computational standpoint, this is somewhat inefficient. A simplification sometime used to increase efficiency is low-level coding, which involves restructuring the BOM so that all occurrences of an item are made to coincide with the lowest level in which the item appears. Figure 12.4 illustrates how component E, which appear in three different levels of product Y, can be rearranged so that it appears at only one level.

Level



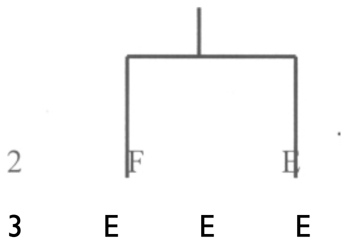


Figure 12.4: Low-level coding for component E

3.1.3 The Inventory Records File

The inventory records file is used to store information on the status of each item by time period. This includes gross amount on hand. It also includes other details for each item, such as supplier, lead time, and lot size - changes due to stock receipts and withdrawal, canceled orders, and similar events also are recorded in this file.

3.2 MRP Processing

MRP processing takes the end-item requirements specified by the master schedule and "explodes" them into time-phased requirements for assemblies, parts, and raw materials using the bull of materials offset by lead times.

The quantities that are generated by exploding the bill of materials are gross requirements. It is the total expected demand for an item or raw material during each time period without regard to the amount on hand. For end items, these quantities are shown in the master schedule; for components, these quantities equal the planned-order releases of their immediate "parents"

Scheduled Receipt: - Open orders scheduled to arrive from vendors or elsewhere in the pipeline by the beginning of a period.

Projected on hand: - The expected amount of inventory that will be on hand at the beginning of each time period; schedule receipts plus available inventory from last period. Net-requirements: - The actual amount needed in each time period.

Planned-order receipts: - The quantity expected to be received by the beginning of the period in which it is shown. Under lot-for-lot ordering, this quantity will equal net requirements. Under lot-size ordering this quantity may exceed net requirements. Any excess is added to available inventory in the next time period.

Planned-order releases: - Indicates a planned amount to order in each time period; equal planned-order receipts offset by lead time. This amount generates gross requirements at the next level in the assembly or production chain. When an order is executed, it is removed from "planned-order releases" and entered under "Scheduled receipts"

Let us illustrate MRP processing with the following example.

Suppose firm that produces wood shutters and bookcases has received two orders for shutters: one for 100 shutters and one for 150 shutters. The 100-unit order is due for delivery at the start of week 4 of the current schedule, and the 150-unit order is due for delivery at the start of week 8. Each shutter consists of four slatted wood sections and two frames. The wood sections are made by the firm, and fabrication takes one week. The frames are ordered and lead time is two weeks. Assembly of the shutters requires one week. There is a scheduled receipt of 70 wood sections in (i .e. at the beginning of) week 1. Determine the size and timing of planned-order releases necessary to meet delivery requirements under each of these conditions:

Lot-for-lot ordering (i e order size equal to net requirements)

Lot-size ordering with a lot size of 20 units for frames and 70 units for wood sections to answer tree question, you first develop a master schedule as follows:

Week number	1	2	3	4	5	6	7	8
Quantity				100				150

Secondly, develop a product structure tree: Shutter

Shutter

Frame (2) wood sections

Next, using the master schedule, determine gross requirements for shutters. Then, compute net requirements. Assuming lot-for-lot ordering, determine planned-order receipt quantities and the planned - order release timing to satisfy the master schedule

Since the master schedule calls for 100 shutters to be ready for delivery, and no shutters are projected to be on hand at the start of week 4, the next requirements are also 100 shutters. Therefore planned receipts for week 4 equals 100 shutters. Some shutters are assembled during week 7 in order to be available for delivery at the start of week 8.

The planned-order release of 100 shutters at the start of week 3 means that 200 frames (gross requirements) must be available at that time. Since more are expected to be on hand, this generates net requirements of 200 frames and necessitates planned receipts of 200 frames by the start of week 3. With a two-week lead time, this means that 200 frames must be ordered at the start of week 1. Similarly, the planned-order release of 150 shutters at week 7 generates gross net requirement 300 frames for week 7 as well as planned receipts for that time. The two-week lead time means frames must be ordered at the start of week 5.

The planned-order release of 100 shutters at the start of week 3 also generates gross requirements of 400 wood sections at that time. However, because 70 wood sections are expected to be on hand, net requirements are 400-70 =330. This means a planned receipt of 330 by the start of week 3. Since fabrication time is one week, the fabrication must start (planned order release) at the beginning of week 2.

Similarly, the planned-order release of 150 shutters in week 7 generates gross requirements of 600 wood sections at that point. Since no on-hand inventory of wood sections is projected, net requirements are also 600, and planned-order receipt is 600 units. Again, the one week lead time means 600 sections are scheduled for fabrication at the start of week 6.

Finally under lot-size ordering, the only difference is the possibility that planned receipts will exceed net requirements. The excess is recorded as projected inventory in the following period. For example, the order size for frames is 320 units. Net requirements for week 3 are 200; thus, there is an excess of 320-200 = 120 units, which become projected inventory in the next week. Similarly, net frame requirements of 180 units are 140 less than the 320 order size; again, the excess become projected inventory in week 9. The same thing happens with wood sections; an excess of planned receipt in weeks 3 and 7 is added to projected inventory in weeks 4 and 8. Note that the order size must be in multiples of the lot size; for week 3 it is 5 times 70 and for week 7 it is 9 times 70.

The importance of computer becomes evident when you consider that a typical firm would have not one but many end items for which it needs to develop material requirements plans, each with its own set of components.

Inventories on hand and on order, schedules, order releases, and so on must all be up dated as changes and rescheduling occurs. Without the aid of a computer, the task would be almost hopeless; with the computer, all of these things can be accomplished with much less difficulty.

Updating the System: The two basic systems to update MRP records are regenerative and net change. A regenerative system is updated periodically; a net-change system is continuously updated.

A regenerative system is essentially a batch-type system, which compiles all changes (e.g. new orders, receipts) that occur within the time interval (e.g. week) and periodically updates the system. Using that information, a revised production plan is developed (if needed) in the same way that the original plan was developed (e.g. exploding the bill of materials level by level).

In a net-change system, the basic production plan is modified to reflect changes as they occur. If some defective purchased parts had to be returned to a vendor, this information is entered into the system as soon as it becomes known. Only the changes are exposed through the system, level by level; the basic plan would not be regenerated.

The regenerative system is best suited to fairly stable systems, whereas the net-change system is best suited to systems that have frequent changes. The obvious disadvantage of a regenerative system is the potential amount of lag between the time information becomes available and the time it can be incorporated into the material requirements plan. On the other hand, processing costs are typically less using regenerative systems; changes that occur in a given time period could ultimately cancel each other, thereby avoiding the need to modify and then remodify the plan. The disadvantages of the net-change system relate to the computer processing costs involved in continuously updating the system and the constant state of flux in a system caused by many small changes. On way around this is to enter minor changes periodically and major changes immediately. The primary advantage of the net-change system is that management can have up-to-date information for planning and control purposes.

3.3 MRP Outputs

MRP systems have the ability to provide management with a fairly broad range of outputs. These are often classified as primary reports, which are the main reports, and secondary reports, which are optional outputs.

3.3.1 Primary Reports

Production and inventory planning and control are part of primary reports. These reports normally include the following:

(1) Planned orders, a schedule indicating the amount and timing of future orders.

(2) Order releases, authorizing the execution of planned orders.

(3) Changes to planned orders, including revisions of due dates or order quantities and cancellations of orders.

3.3.2 Secondary Reports

Performance control, planning, and exceptions belong to secondary reports.

(1) Performance-control repots are used to evaluate system operation. They aid managers by measuring deviations from plans, including missed deliveries and stock-outs, and by providing information that can be used to assess cost performance.

(2) Planning reports are useful in forecasting future inventory requirements. They include purchase commitments and other data that can be used to assess future material requirements.

(3) Exception reports call attention to major discrepancies such as late and overdue orders, excessive scrap rates, reporting errors and requirements for none existent parts.

The wide range of output generally permits users to adapt MRP to their particular needs.

3.3.3 Safety Stock

Theoretically, inventory systems with dependent demand should not require safety stock below the end-item level. This is one of the main advantages of an MRP approach. Supposedly, safety stock is not needed because usage quantities can be projected once the master schedule has been established. Practically, however, there may be exceptions. For example, a bottleneck process or one with varying scrap rates can cause shortage in downstream operations. However, a major advantage of MRP is lost by holding safety stock for all lower-level items. When lead times are variable, the concept of safety time instead of safety stock is often used. This results in scheduling orders for arrival or completion sufficiently ahead of the time they are needed in order to eliminate or substantially reduce the element of chance in waiting for those items. Frequently, managers elect to carry safety stock for end items, which are subject to random demand and for selected lower-level operations when safety time is not feasible.

3.3.4 Lot Sizing

Choosing a lot size to order or for production is an important issue in inventory management for both independent- and dependent-demand items. This is called lot sizing. For independent-demand items, economic order sizes and economic run sizes are often used.

Mangers can realize economies of scale by grouping order or run sizes. This would be the case if the additional cost in covered by holding extra units until they were used led to a saving in set up or ordering cost. This determination can be very complex at times. Let's consider some of the methods used to handle lot sizing.

3.3.4.1 Lot-for-Lot Ordering

The order or run size for each period is set equal to demand for that period. This method was demonstrated in the example in section 3.3. Not only is the order size obvious, but it also virtually eliminates holding casts for parts carried over to other periods. Hence, lot-for-lot ordering minimizes investment in inventory. Its two chief draw backs are that it usually involves many different order sizes and thus cannot take advantage of the economies of fixed order size and it involves a new setup for each run.

3.3.4.2 Economic Order Quantity Model

Sometimes economic order quantity models (EOQ) are used. They can lead to minimum costs if usage is fairly uniform. This is sometimes the case for lower-level items that are common to different parents and for raw materials. However, the more lumpy demand is, the less appropriate such an approach is.

3.3.4.3 Fixed - Period Ordering

This type of ordering provided coverage for some predetermined number of periods (e.g., two or three). A simple rule is; order to cover a two period interval. The rule can be modified when common sense suggests a better way. For example, take a look at the demand shown in Figure 12.5. Using a two-period rule, an order size of 120 units would cover the first two period. The next two periods would be covered by an order size of 81 units. However, the demand, in period 3 & 5 are so small, it would make sense to combine them both with the 80 units and order 85 units.

Demand Period

	1	**2**	**3**	**4**	**5**
Demand	70	50	1	80	4
Cumulative	70	120	121	01	205

Figure 12.5: Demand of part

3.3.4.4 Part-Period Model

The term part-period refers to holding a part or parts over a number of periods. For example, if 10 parts were held for two periods, this would be 10x2 = 20 part periods. The economic part period (EPP) can be computed as:

$$EPP = \frac{\text{Setup Cost}}{\text{Unit holding cost per period.}}$$

In order to determine an order size that is consistent with EPP, various order sizes are examined for a planning horizon, and each one's number of part periods is determined. The one that comes closest to the EPP is selected as the best lot size. The order sizes that are examined are based on cumulative demand. The following example illustrates this approach.

Now use the part-period method to determine order sizes for this demand schedule: set cost is N80 per run for this item, and unit-holding cost is N95 per period.

Solution

Period 1 2 3 4 5 6 7								
Demand	60	40	20	2	30 -	70	50	
Cumulative demand	60	100	120	122	152 1	2 222	272	

(1) First compute the EPP: EPP = N80/=N95 = 84.21 which rounds to 84 part period.

(2) Next, try the cumulative lot sizes beginning with 60, until the port periods approximate the EPP. Continue this process for the planning horizon. This leads to the following:

Period Size carried		Lot Extra inventory X	Period carried = period		Part cumulative part periods	
	1	60	0	0	0	0
100	40	1	40	40	120	20
2	40	80	122	2	3	6
86	5	30	0	0	0	0
100	70	2	140	140	50	0
0	0	0	0	0	0	0

The computations of part periods indicate that 122 units should be ordered to be available at period 1, and 100 units should be ordered to be available at period 5. The next lot will be ordered for period 8, but there is insufficient information now to determine its size.

The lot sizes considered for 1 correspond to cumulative demand. Once the best lot size has been identified, the cumulative demand is set equal to zero and then summed beginning with the next period. In this case, the lot size of 122 covers the first four periods, so cumulative demand is started next for period 5. The next lot size covers through period 7, and the count begins again at period 8.

The process works well for the first lot size because then cumulative number of part periods is close to the EPP, but the effect of Lumpy demand is apparent for the second lot size of 100 (140 part periods is not very close to 84 part periods).

3.4 Capacity Requirements Planning

One of the most important features of MRP is its ability to aid manager in capacity planning. As noted, a master production schedule that appears feasible on the surface may turn out to be far less feasible in terms of the resources requirements needed for fabrication and /or subassembly operations of lower-level items.

Capacity requirement planning is the process of determining shortage capacity requirements. The necessary inputs include planned-order releases for MRP, the current shop load, routing information and job times. Outputs include load report for each work center. When variances (under loads or over loads) are projected, managers might consider remedies such as alternative routing, changing or eliminating lot splitting. Moving production forward or back ward can be extremely challenging because of precedence requirements and availability of components.

The capacity planning begins with a proposed or tentative master production schedule that must be tested for feasibility and possibly, adjusted before it becomes permanent. The proposed schedule is processed using MRP to ascertain the material requirements the schedule would generate. These are then translated into resource (i e capacity) requirements often in the form of a series of load reports for each department or work p center, which compares known and expected future capacity requirement with projected capacity availability.

An important aspect of capacity requirements planning is the conversion of quantity requirements into labour and machine requirements. This is accomplished by multiplying each period's quantity requirements by standard labor and/or machine requirements per unit. For instance, if 100 units of product A are scheduled in the fabrication department, and each unit has a labor standard time of 2 hours and a machine standard time of 1.5 hours, then 100 units of A convert into these capacity requirements.

Labor:- 100 units x 2 hours/unit = 200 labor hours

Machine: 100 units x 1.5 hours/unit = 150 machine hours

These capacity requirements can then be compared with available department capacity to determine the extent to which this product utilizes capacity. For example, if the department has 200 labour hour, and 200 machine hours available, labor utilization will be 100 percent because of all of the labor capacity will be required by this product. However, machine capacity will be underutilized.

$$\frac{\text{Required}}{\text{Available}} \times 100 = \frac{150\text{hours}}{200\text{ hours}} \times 100 = 75 \text{ percent.}$$

Underutilization may mean that unused capacity can be used for other jobs; over utilization indicates that available capacity is insufficient to handle requirements. To compensate, production may have to be rescheduled or overtime may be needed.

3.5 Benefits and Requirements of MRP

3.5.1 Benefits

MRP offers a number of benefits for the typical manufacturing or assembly type of operation, including:

1. Low levels of in-process inventories
2. The ability to keep track of material requirements.
3. The ability to evaluate capacity requirements generated by a given master schedule.
4. A means of allocating production time.

A range of people in a typical manufacturing company are important users of information provided by an MRP system. Production mangers who must balance workloads across departments and make decisions about scheduling work, and plant foremen, who are responsible for issuing work orders and maintaining production schedules, also rely heavily on MRP output. Other users include customer service representatives, who must be able to supply customers with projected delivery dates, purchasing managers, and inventory managers. The benefits of MRP depend on large measure on the use of a computer to maintain up-to-date information on material requirements.

3.5.2 Requirements

In order to implement and operate an effective MRP system, it is necessary to have:

(1) A computer and the necessary software programs to handle computations and maintain records.

(2) Accurate and up-to-date

(a) Master schedule

(b) Bills of materials

(c) Inventory records

(3) Integrity of file data

On the whole, the introduction of MRP has led to a major improvement in scheduling and inventory management but it has not proved to be the cure-all that many hoped it would be. Consequently, manufacturers are beginning to take a much broader approach to resource planning one such approach is referred to as MRP 11.

3.6 MRP II

MRP II refers to manufacturing resources planning. It represents an effort to expand the scope of production resource planning and to involve other functional areas of the firm in the planning process. A major purpose of MRP His to integrate primary functions and other functions such as personnel, engineering and purchasing in the planning process.

Material requirement planning is at the heart of the process. Process begins with an aggregation of demand from all sources (e.g. firm orders, forecasts, safety stock requirement). Production, marketing and finance personnel work toward developing a master production schedule. Although manufacturing people will have a major input in determining the schedule and a major responsibility for making it work, marketing and finance will also have important inputs and responsibilities. The rationale for having these functional areas work together is the increase likelihood of developing a plan that works and with which everyone can live. Moreover, because each of these functional areas has been involved in formulating the plan, they will have reasonably good knowledge of the plan and more reason to work toward achieving it.

In addition to the obvious manufacturing resources needed to support the plan, financing resources will be needed and must be planned for, both in amount and timing. Similarly, marketing resources will also be needed in varying degree throughout the process. In order for the plan to work, all of the necessary resources must be available as needed. Often, an initial plan must be revised based on an assessment of the availability of various resources. Once these have been decided, the master production schedule can be firmed up.

At this point, material requirement planning comes into play generating material and schedule requirements. More detailed capacity requirement planning must be made next to determine whether these more specific requirements can be met. Again some adjustment in the master production schedule may be required.

As the schedule unfold, and actual work begins, a variety of reports help managers to monitor the process and to make any necessary adjustments to keep operations on track.

In effect, this is a continuing process where the master production schedule is updated and revised as necessary to achieve corporate goals. The business plan that governs the entire process usually undergo changes too although this tend to be less frequent than the changes made at lower levels (i. e. the master production schedule).

Finally, it should be noted that most MRP 11 systems have the capability of performing simulation, enabling managers to answer a variety of "what if” questions so they can gain a better appreciation of available options and their consequences.

4.0 Conclusion

In this unit, you have learnt the meaning of MRP and the conditions under which it is appropriate; its inputs and outputs as well as the nature of MRP processing; the benefits, requirements and the difficulties encountered with its use.

5.0 Summary

Material requirements planning (MRP) is an information system used to handle ordering of dependent-demand items (i e, components of assembled products). The planning process begins with customer orders, which are used along with any back order to develop a master schedule that indicates the timing and quantity of finished items. The end items are exploded using the bill of materials, and material requirements plans are developed that show quantity and timing for materials, and timing for ordering or producing components.

The main features of MRP are the time-phasing of requirements, calculating component requirements, and planned-order releases. To be successful, MRP requires a computer program and accurate master production schedules, bills of materials, and inventory data. Firms that have not had reasonably accurate records or schedules have experienced major difficulties in trying to implement MRP.

MRP 11 is a second-generation approach to planning which incorporates MRP but adds a broader scope to manufacturing resource planning because it links business planning, production planning, and the master production schedule.

6.0 Self-Assessment Exercise

Compare and contrast MRP with MRP II and state the advantage MRP offers as also compared to “Order Point” control.

7.0 References/Further Reading

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Bonini, C.P.; Hansman, W.H. and Bierman, H. Jr (1997). *Quantitative Analysis for Management.* Chicago: Irwin.

Unit 3 Just-In-Times System

1.0 Introduction

The term just-in-time (JIT) is used to refer to a production system in which both the movement of goods during production and deliveries from suppliers are carefully timed so that at each step of the process the next (usually small) batch arrives for processing just as the preceding batch is complete-thus, the name just-in-time. The result is a system with no idle items waiting to be processed and no idle workers or equipment waiting for items to process.

The just-in-time phenomenon is characteristic of lean production system, which operates with very little "fat" (e.g. excess inventory, extra workers, and wasted space). JIT pertains to the timing of the flow of parts and material through the systems, and the timing of services. Companies that employ the JIT/lean production approach have lower processing costs, fewer defectives, and greater flexibility; and are able to bring new or improved products to the market more quickly.

The JIT approach was developed at the Toyota Motor Company of Japan by Taiichi Ohno (who eventually became vice president of manufacturing) and several of his colleagues. JIT regards scrap and rework as waste, and inventory as an evil because it takes up space and ties up resources. JIT represents a philosophy that encompasses every aspect of the process, from design to after the sale of a product. The philosophy is to pursue a system that functions well with minimal levels of inventories, minimal space, and minimal transactions. It must be a system that is not prone to disruptions and is flexible in terms of the product variety and range of volume that it can handle. The ultimate goal is to achieve a balanced system that permits a smooth, rapid flow of materials through the systems.

Companies that use JIT have achieved a level of quality that enables them to function with small batch sizes and tight schedules. JIT systems have high reliability: major sources of inefficiency and disruption have been eliminated, and workers have been trained not only to function in the system but also to consciously improve it.

2.0 Objectives

At the end of this unit, you should be able to:

- explain what is meant by the term just-in time (JIT) production system
- list each of the goals of JIT and explain its importance
- list and briefly describe the building blocks of JIT
- list the benefits of the JIT systems.

3.0 Main Content

3.1 JIT Goals

The ultimate goal of JIT is a balanced system; that is, one that achieves a smooth, rapid flow of materials through the system. The idea is to make the process time as short as possible by using resources in the best possible way. The degree to which the overall goal is achieved depends on how well certain supporting goals are achieved. These goals are:

1. Eliminate disruptions.
2. Make the system flexible.
3. Reduce setup times and lead times
4. Minimise inventory.
5. Eliminate waste.

Disruptions are caused by a variety of factors, such as poor quality, equipment breakdowns, changes to the schedule and late deliveries. These should be eliminated as much as possible. Inefficiency and disruption have been eliminated, and workers have been trained not only to function in the system but also to consciously improve it.

A flexible system is one that is robust enough to handle a mix of products, often on a daily basis, and to handle changes in the level of output while still maintaining balance and throughput speed.

Setup times and delivery lead times prolong a process without adding any value to the product. Moreover, long setup times and long lead times negatively impact the flexibility of the system. Hence, reduction of setup and lead times is important, and is one objective of continuous improvement.

Inventory is an idle resource, taking up space and adding cost to the system. It should be minimized or even eliminated wherever possible.

Waste represents unproductive resources: eliminating waste can free up resources and enhance production. In the JIT philosophy, waste includes.

- Overproduction
- Waiting time
- Unnecessary transporting
- Inventory storage
- Scrap
- Inefficient work methods

- Product defects

The existence of these wastes is an indication that improvement is possible. Alternatively, the list of wastes identifies potential targets for continuous improvement efforts.

3.2 Building Blocks

The design and operation of a JIT system provide the foundation for accomplishing the aforementioned goals. The foundation is made up of four building blocks:

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

Let us discuss these blocks in turn.

3.2.1 Product Design

Three elements of product design are key to JIT systems:

1. Standard parts
2. Modular design
3. Quality

The first two elements relate to speed and simplicity.

The use of standard parts means that workers have fewer parts to deal with, and training times and costs are reduced. Purchasing, handling, and checking quality are more routine and lend themselves to continual improvement. Another importance benefit is the ability to use standard processing.

Modular design is an extension of standard parts. Modules are clusters of parts treated as a single unit. This greatly reduces the number of parts to deal with, simplifying assemble, purchasing, handling, training, and so on. Standardization has the added benefit of reducing the number of different parts contained in the bill of materials for various products, thereby simplifying the bill of materials.

Disadvantage of standardization are less product variety and resistance to change in a standard design. These disadvantages are partly offset where different products have some common parts or modules. Using a tactic that is sometimes referred to as delayed differentiation; a decision concerning which products will be produced can be delayed while the standard portions are produced. When it becomes apparent which products are needed, the system can quickly respond by producing the remaining unique portions of those products.

Quality is the sine qua non ("without which not") of JIT. It is crucial to JIT systems because poor quality can create major disruptions.

JIT system uses a three-part approach to quality: One part is to design quality into the product and the production process. High quality levels can occur because JIT systems produce standardized products that lead to standardized job methods, workers who are very familiar with their jobs, and the use of standardized equipment. Moreover, the cost of product design quality (i.e., building quality in at the design stage) can be spread over many units, yielding a low cost per unit. It is also important to choose appropriate quality levels in terms of the final customer and of manufacturing capability: Thus, product design and process design must go hand in hand.

3.2.2 Process Design

Seven aspects of product are particularly important for JIT systems:

(1) Small lot sizes

(2) Setup time reduction

(3) Manufacturing cells

(4) Limited work in process

(5) Quality improvement

(6) Production flexibility

(7) Little inventory storage.

Small lot sizes in both the production process and deliveries from suppliers yield a number of benefits that enable JIT systems to operate effectively: First, with small lots moving through the systems, in-process inventory is considerably less that it is with large lots. This reduces carrying costs, space requirements, and clutter in the workplace. Second, inspection and rework costs are less when problems with quality occur, because there are fewer items in a lot to inspect and rework.

Small lots also permit greater flexibility in scheduling. This flexibility enables JIT systems to respond more quickly to changing customer demands for output: JIT systems can produce just what is needed, when it is needed.

Small lots and changing product mixes require frequent setups. Unless these are quick and relatively inexpensive, the time and cost to accomplish them is prohibitive. Often, workers are trained to do their own setups. Moreover, programs to reduce setup time and cost are used to achieve the desired results; a deliberate effort is required, and workers are usually a valuable part of the process.

One characteristic of many JIT systems is multiple manufacturing cells. The cells contain the machine and tools needed to process families of parts having similar processing requirements. In essence the cells are highly specialized and efficient production centres. Among the important benefits of manufacturing cells are reduced changeover times, high utilization of equipment, and ease of cross-training operators. The combination of high cell efficiency and small lot sizes results in very little work-in-process inventory.

JIT systems sometimes minimize defects through the use of autonomation (note the extra syllable 'no' in the middle of the word). This refers to the automatic detection of defects during production. It can be used with machines or manual operations. It consists of two mechanisms: one for detecting defects when they occur and another for stopping production to correct the cause of the defects. Thus, the halting of production force immediate attention to the problem, after which an investigation of the problem is conducted, and corrective action is taken to resolve the problem.

Because JIT systems have very little in-process inventory, equipment breakdowns can be extremely disruptive. To minimize breakdowns, companies use preventive maintenance programs, which emphasize maintaining equipment in good operating condition and replacing parts that have a tendency to fail before they fail. Workers are often responsible for maintaining their own equipment.

Guidelines for increasing production flexibility are as follows:

1. Reduce downtime due to changeovers by redoing changeovers time

2. Use preventive maintenance on key equipment to reduce breakdowns and downtime.

3. Cross-train workers so they can help when bottlenecks occur or other workers are absent. Train workers to handle equipment adjustments and minor repairs.

4. Use many small units of capacity: many small cells make it easier than a few units of large capacity to shift capacity temporally and to add or subtract capacity.

5. Use off-line buffers. Store infrequently used safety stock away from the production area to decrease congestion and to avoid continually turning it over.

6. Reserve capacity for important customers.

One way to minimize inventory storage in a JIT system is to have deliveries from suppliers go directly to the production floor, which completely eliminates the need to store incoming parts and materials. At the other end of the process, completed units are shipped out as soon as they are ready, which minimize storage of finished goods. Coupled with low work-in-process inventory; these features result in systems that operate with very little inventory.

Among the advantages of lower inventory are less carrying cost, less space needed, less tendency to rely on buffers, less rework if defects occur, and less need to "work off' current inventory before implementing design improvements. But carrying fewer inventories also has some risks. The primary one is that if problems arise, there is no safety net. Another is that opportunities may be lost if the system is unable to respond quickly enough.

3.2.3 Personnel Organizational Elements

There are five elements of personnel and organizational that are particularly important for JIT systems:

1. Workers as assets.
2. Cross-trained workers
3. Continuous improvement
4. Cost accounting
5. Leadership project management.

Worker as Assets:- A fundamental tenet of the JIT philosophy is that workers are assets. Well-trained and motivated workers are the heart of a JIT system. They are given more authority to make decisions than their counterparts in more tradition systems, but they are also expected to do more.

Cross-Trained Worker:- Worker are cross-trained to perform several parts of a process and operate a variety of machines. This adds to system flexibility because workers are able to help one another when bottlenecks occur or when a co-worker is absent.

Continuous Improvement:- Workers in a JIT system have greater responsibly for quality than worker in traditional systems, and expected to be involved in problem solving and continuous improvement. JIT workers typically receive extensive training in statistical process control, quality improvement, and problem solving.

Problem solving is a cornerstone of any JIT interest are problems that interrupt, or have the potential to interrupt, the smooth flow of work through the system.

A central theme of a true just-in-time approach is to work toward continual improvement of the system-reducing inventories, reducing setup cost and time, improving quality; increasing the output rate, and generally cutting waste and inefficiency. Toward that end, problem solving becomes a way of life a "culture" that must be assimilated into the thinking of management and workers alike. It becomes a never ending quest for improving operations as all members of the organization strive to improve the system.

Cost Accounting:- Another feature of some JIT systems is the method of allocating overhead. Traditional accounting methods sometimes distort overhead allocation because they allocate it on the basis of direct labour hours. However, that approach does not always accurately reflect the consumption of overhead by different jobs.

One alternative method of allocating overhead is activity-based costing. This method is designed to more closely reflect the actual amount of overhead consumed by particular job or activity. Activity-based costing first identifies traceable costs and then assigns those costs to various types of activities such as machine setups, inspection, machine hours, direct labour hours, and movement of material. Specific jobs are then assigned overhead based on the percentage of activities they consume.

Leadership/Project Management:- Another feature of JIT systems relates to leadership. Managers are expected to be leaders and facilitators, not order givers. Two-way communication between workers and managers is encouraged.

Project managers are often given full authority over all phases of a project. They remain with the project from beginning to end; in the more traditional forms of project management, the project manager often has to rely on the cooperation of other managers to accomplish project goals.

3.2.4 Manufacturing Planning and Control

Five elements of manufacturing planning and control are particularly important for JIT systems:

1. Level loading
2. Pull system
3. Visual system
4. Close vendor relationships
5. Reduced transaction processing.

Level Loading: JIT systems place a strong emphasis on achieving stable level daily mix schedules. Toward that end, the master production schedule is developed with level capacity loading. That may entail a rate-based production schedule instead of the more familiar quality -based schedule. Moreover, once they are established, production schedules are of short time horizon, which provide certainty to the system. This is needed in day-to-day schedules to achieve level capacity requirements.

Pull Systems: The terms push and pull are used to describe two different systems for moving work through a production process. In push systems, when work is finished at a workstation, the output is pushed to the next station: or, in the case of the final operation, it is pushed on to final inventory Conversely, in a pull system, control of moving the work rests with the following operation: each workstation *pull* the output from the preceding station as it is needed; output of the final operation is pulled by customer demand or the master schedule. Thus, in a pull system, work is moved response to demand from the stage in the process, whereas in push system, work is pushed in as it is completed, without regard to the next station's readiness for the work. Consequently, work may pile up at workstations that fall behind schedule because of equipment failure or the detection of a problem with quality.

JIT systems use the pull approach to control the flow of work, with each workstation gearing its output to the demand presented by the next workstations. Traditional production systems use the push approach for moving work through the system. JIT system communication moves backward through the system from station to station. Work moves "just in time" for the next operation; the flow of work is thereby coordinated, and the accumulation of excessive inventories between operations is avoided. Of course, some inventory is usually present because operations are not instantaneous.

Visual Systems: Another way to describe the pull system is that work flow is dictated by "next-step demand". Such demand can be communicated in a variety of ways, including a shout or a ware, but by far the most commonly used device is the kanban card. Kanban is a Japanese word meaning "signal" or "visible record". When a worker needs materials or work from the preceding station, he or she used a kanban card. In effect, the kanban card is the authorization to move or work on parts. In Kanban system, no part or lot can be moved or worked on without one of these cards. The ideal number of Kanban cards can be computed using this formula:

N= DT(l+X) C

Where

N = Total number of containers

D = Planned usage rate of using work centre

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

X = Policy variable set by management that reflects possible inefficiency in the system (the closer to 0. the more efficient the system

C = Capacity of a standard container (should be no more than 10 percent of daily usage of the part).

Note that D and T must use the same time units (e.g., minutes, days).

Let's illustrates the use of the formula with the following example:

Suppose the usage at a work centre is 300 parts per day, and a standard container holds 25 parts. It takes an average of 12 day for a container to complete a circuit from the time a kanban card is received until the container is returned empty. Compute the number of kanban cards need if X = 20.

N = ?

D = 300 parts per day

T = 12day

C = 25 parts per container

X = 20

N = 300(12)(1 +20)(25) = 1,890,000 containers

Close Vendor Relationships: JIT systems typically have close relationship with vendors, who are expected to provide frequent small delivers of high-quality goods. Traditionally, buyers have assumed the role of monitoring the quality of purchased goods, inspecting shipments for quality and quantity, and returning poor-quality goods to the vendor for rework. JIT systems have little slack, so poor-quality goods cause a disruption in the smooth flow of work. Moreover, the inspection of incoming goods is viewed as inefficient because it does not add value to the product. For these reasons, the burden of ensuring quality shifts to the vendor. Buyers work with vendors to help them achieve the desired quality levels and to impress upon them the importance of consistent, high-quality goods. The ultimate goal of the buyers is to be able to certify a vendor as product A producer of high-quality goods. The implication of certification is that a vendor can be relied on to deliver high quality goods without the need for buyer inspection.

Suppliers must also be willing and able to ship in small lots on regular basis.

Under JIT purchasing, good vendor relationships are very important. Buyers take measures to reduce their list to suppliers, concentrating on maintaining close working relationships with a few good ones. Because of the need for frequent, small delivers many buyers attempt to find local vendors to shorten the lead time for deliveries and to reduce lead time variability. An added advantage of having vendors nearby is quick response when problems arise.

Suppliers: A key feature of many lean production systems is the relatively small number of suppliers used. Lean production companies may employ a tiered approach for suppliers. They use relatively few first-tier suppliers who work directly with the company or who supply major subassemblies. The first-tier suppliers are responsible for dealing with second-tier suppliers who provide components for the subassemblies, thereby relieving the final buyer from dealing with large numbers of suppliers.

A good example of this situation is found in the automotive industry. Suppose a certain model has an electric seat. The seat and motor together might entail 250 separate parts. A traditional producer might use more than 50 suppliers for the electric seat, but a lean producer might use a single (first-tier) supplier who has the responsibility for the entire seat unit. The company would provide specifications for the overall unit, but leave to the supplier the details of the motor, springs and so on. The first-tier supplier, in turn, might subcontract the motor to a second-tier supplier, the track to another second-tier supplier, and cushions and fabric to still another. The second-tier suppliers might subcontract some of their work to third-tier suppliers, and so on. In this "team of suppliers" approach, all suppliers benefits from a successful product, and each supplier bears full responsibility for the quality of its portion of the product.

Reduced Transaction Processing:- The transactions can be classified as logical, balancing, quality, or change transactions.

Logical Transactions:- Include ordering, execution, and confirmation of materials transported from one location to another. Related costs cover shipping and receiving personnel, expediting orders, data entry, and data processing.

Balancing transactions:- Include forecasting, production control, procurement, scheduling, and order processing. Associated costs relate to the personnel involve in these and supporting activities.

Quality transactions:- Include determining and communicating specifications, monitoring, recording, and follow-up activities. Costs relates to appraisal, prevention, internal failures (e.g., scrap, rework, retesting, delay, administration activities) and external failure (e.g., warranty cost, product liability, returns, potential loss of future business).

Change transactions:- Primarily involve engineering changes and the ensuing changes generated in specifications, bills of material, scheduling, processing instructions and so on. Engineering changes are among the most costly of all transactions.

JIT systems cut transaction costs by reducing the number and frequency of transactions. For example, supplier deliver goods directly to the production floor, by passing the store-room entirely, thereby avoiding the transactions related to receiving the shipment into inventory storage and later moving the materials to the production floor. In addition, vendors are certified for quality, eliminating the need to inspect incoming shipment for quality. The unending quest for quality improvement that pervades JIT systems eliminates many of the above mentioned quality transactions and their related costs. The use of bar coding (not exclusive to JIT systems) can reduce data entry transactions and increase data accuracy.

3.3 Benefits of JIT Systems

JIT systems have a number of important benefits that are attracting the attention of traditional companies. The main benefits are:

1. Reduced level of in-process inventories, purchased goods, and finished goods.
2. Reduced space requirements.
3. Increased product quality and reduced scrap and rework.
4. Reduced manufacturing lead times.
5. Greater flexibility I changing the production mix.
6. Smoother production flow with fewer disruptions caused by problems due to quality, shorter setup times, and multi-skilled workers who can help each other and substitute for other
7. Increased productivity levels and utilization of equipment
8. Worker participation in problem solving.
9. Pressure to build good relationships with vendors
10. Reduction in the need for certain indirect labour, such as material handlers.

4.0 Conclusion

This unit has described the JIT/lean production approach, including the basic elements of these systems, and what it takes to make them work effectively. It has also pointed out the benefits of these systems.

5.0 Summary

Just-in-time (JIT) is a system of lean production used mainly in repetitive manufacturing, in which goods move through the system and tasks are completed just in time to maintain the schedule. JIT systems require very little inventory because successive operations are closely coordinated.

The ultimate goal of a JIT system is to achieve a balanced, smooth flow of production. Supporting goals include eliminating disruptions to the system, making the system flexible, reducing setup and lead times, eliminating waste, and minimizing inventories. The building blocks of a JIT system are product design, process design, personnel and organization, and manufacturing planning and control.

Lean systems require the elimination of sources of potential disruption to the even flow of work. High quality is stressed because problems with quality can disrupt the process. Quick, low-cost setups, special layouts, allowing work to be pulled through the system rather that pushed through, and a spirit of cooperation are important features of lean systems. So too, are problem solving aimed at reducing disruptions and making the system more efficient, and an attitude of working toward continual improvement.

Key benefits of JIT/lean systems are reduced inventory levels, high quality, flexibility, reduced lead times, increased productivity and equipment utilization, reduced space requirements.

6.0 Self-Assessment Exercise

"One reason for Japan's high manufacturing productivity is the cost reductions it achieved through its Just-in-Time".

1. Define the conceptual framework of JIT as a philosophy to bring out its fundamental characteristics.

2. Discuss fully the foundations building block of Just-In-Time.

7.0 References/Further Reading

Krajewski, L. J. and Ritzman, L.P. (1999) Operations Management: *Strategy and Analysis.* Reading, Massachutes: Addison Wesley

Bonini, C.P.; Hansman, W.H. and Bierman, H. Jr. (1997). *Quantitative Analysis for Management.* Chicago: Irwin.

Unit 4 Project Management

1.0 Introduction

Managers typically oversee a variety of operations. Some of these involve routine, repetitive activities, but other involves non routine activities. Under the non-routine are projects: unique, one-time operations designed to accomplish a set of objectives in a limited time frame. Examples of projects include constructing a shopping complex, drainage system, installing a new computer system, introducing a new product or service to the market place.

Projects may involve considerable cost. Some have a long time horizon, and some involve a large number of activities that must be carefully planned and coordinated. Most are expected to be completed within time, cost, and performance guidelines. To accomplish these, goals must be established and priorities set. Tasks must be identified and time estimates made. Resource requirements must also be projected and budget prepared. Once commenced, progress must be monitored to ensure that project goals and objectives are achieved.

2.0 Objectives

At the end of this unit, you should be able to:

- discuss the behavioral aspects of projects in terms of project personnel and the project manager
- discuss the importance of a work breakdown structure in project management
- give a general description of PERT / CPM techniques
- construct simple network diagrams
- list the kinds of information that a PERT or CPM analysis can provide
- analyse networks with deterministic times
- analyze networks with probabilistic times
- describe activity "crashing" and solve typical problems.

3.0 Main Content

3.1 Behavioural Aspect of Project Management

Project management differs from management of more traditional activities which gives rise to a host of rather unique problems. This section will emphasize the nature of projects and their behavioural implications. Emphasis will be laid on the role of the project manager.

3.1.1 The Nature of Projects

Projects go through a series of stages, a life cycle, which include planning, execution, and project phase out. During this life cycle, a variety of skillful requirements are involved.

In effect, projects unit personnel are with diverse knowledge and skills, most of whom remain together for less than the full life of the project. Some personnel go from project to project as their contributions become needed, some on a full-time or part-time basis, from their regular jobs. Certain kinds of organisation tend to be involved with project on a regular basis; examples include consulting firms, architects, writers and publishers.

3.1.2 The Project Manager

The central figure in a project is the project manager. He or she bears the ultimate responsibility for the success or failure of the project manager. The role of the project is one of an organizer - a person who is capable of working through others to accomplish the objectives of the project.

Once the project is underway, the project manager is responsible for effectively managing each of the following:

(i) The work, so that all of the necessary activities are accomplished in the desired sequence.

(ii) The human resource, so that those working on the project have direction and motivation.

(iii) Communications, so that everybody has the information they need to do their work.

(iv) Quality, so that performance objectives are realized

(v) Time, so that the project can be completed on a time.

(vi) Costs, so that the project is completed within budget.

The job of project manager can be both difficult and rewarding. The manager must coordinate and motivate people who sometimes owe their loyal support to other managers in their functional areas. In addition, the people who work on a project frequently possess distinct knowledge and skill that the project manager lacks. Nevertheless, the manager is expected to evaluate and guide their efforts.

The rewards of the job of project manager come from the challenges of the job, the benefits of being associated with a successful project, and the personal satisfaction of seeing it through to its conclusion.

3.1.3 The Merits and De-merits of Working on Projects

People are chosen to work on special projects because the knowledge or abilities they possess are needed. In some instances, however, their supervisor may be unwilling to allow them to interrupts their regular jobs, even on a part time basis, because it may require training a new person to do a job that will be temporary. Moreover, managers don't want to lose the output of good workers. The workers themselves are not always eager to participate in projects because it may mean working for two bosses who impose differing demands and may cause disruption of friendships and daily routines, and the risk of being replaced on the current job.

In spite of the potential risks of being involved in a project, people are attracted by the potential rewards. One is the dynamic environment that surrounds a project, often a marked contrast to the more staid environment in which some may feel trapped. Then, too, projects may present opportunities to meet new people and to increase future job opportunities, especially if the project is successful. In addition, association with a project can be a source of status among fellow workers.

3.2 Project Life Cycle

The length, size and scope of projects vary widely according to the nature and purpose of the project. Nevertheless all projects have something in common. They go through a life cycle, which typically consists of five phases.

(i) Concept at which point the organisation recognizes the need for a project or responds to a request for a proposal from a potential client.

(ii) Feasibility analysis, which examines the expected costs, benefits and risk of undertaking the project.

(iii) Planning, this spells out the details of the work and provides estimates of the necessary human resources, time and cost.

(iv) Execution, during which the project itself is done. This phase often accounts for the majority of time and resources consumed by a project.

(v) Termination, during which closure is achieved.

It should be noted that the phases can overlap, so that one phase may not be fully completed before the next phase begins. This can reduce the time necessary to move through the life cycle, perhaps generating some competitive advantage and cost saving.

3.3 Work Breakdown Schedule

Because large projects usually involve a very large number of activities, planners need some way to determine exactly what will need to be done so that they can realistically estimate how long it will take to complete the various elements of the project and how much it will cost. This is often accomplished by developing a work breakdown structure (WBS), which is a hierarchical listing of what must be done during the project. This methodology establishes a logical framework for identifying the required activities for the project. The framework is illustrated below. The first step in developing the work breakdown structure is to identify the major elements of the project. These are the level 2 boxes in the structure below. The next step is to identify the major supporting activities for each of the major elements the level 3 boxes. Then, each major supporting activity is broken down into a list of the activities that will be needed to accomplish it, the level 4 boxes. Figure 14.1 below.

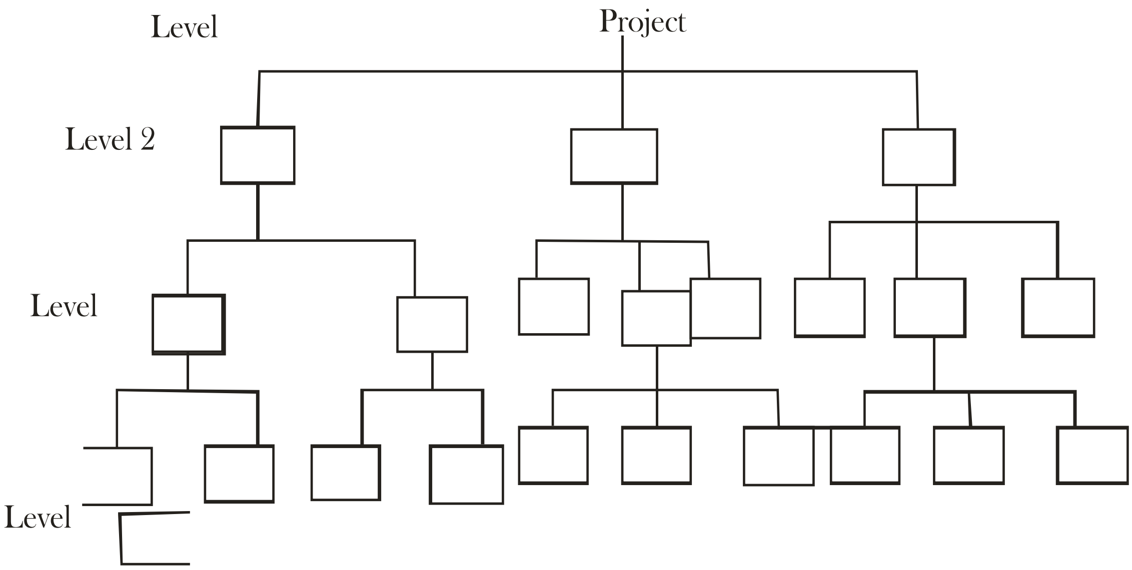

Figure 14.1:

3.4 Planning and Scheduling with Gantt Charts

The Gantt chart is a popular tool for planning and scheduling simple projects. It enables a manager to initially schedule project activities and then to monitor progress over time by comparing planned progress to actual progress. A Gantt chart for a bank's plan to establish a new direct marketing department is given in the figure below. To prepare the chart, the personnel in charge of the project first identify the major activities that would be required. Next, time estimates for each activity is made, and the sequence of activities is determined. Once completed, the chart would indicate which activities will occur, their planned duration, and when they will to occur. Then, as the project progresses, the manager would be able to see which activities were ahead of schedule and which were delaying project. This enables the manager to direct attention where it was needed most to hasten the project in order to finish on schedule.

Activity Weeks after start

	Start	2	4	6	8	10	12	14	16	18	20
Locate new facilities											
Interview prospective staff											
Hire and train staff											
Select and order furniture											
Remodel and install phones											
Furniture received and setup											
More in start up											

Figure 14.2:

The obvious advantage of a Gantt chart is its simplicity, and this accounts for its popularity. However, Gantt Charts fails to reveal certain relationships among activities that can be crucial to effective project management. For instance, if one of the early activities in a project suffers a delay, it would be important for the manager to be able to easily determine which later activities would result in a delay.

3.5 PERT and CPM

PERM (Program Evaluation and Review Technique) and CPM (Critical Path Method) are two of the most widely used techniques for planning and coordinating large -scale projects. By using PERT and CPM, managers are to obtain:

(i) A graphical display of project activities

(ii) An estimate of how long the project will take

(iii) An indication of which activities are the most critical to timely project completion.

(iv) An indication of how long any activities can be delayed without lengthening the project.

3.6 The Network Diagram

One of the main features of PERT and related techniques is their use of a network or precedence diagram to depict major project activities and their sequential relationships. Recall the bank example that used a Gantt chart (Figure14.2).

A network diagram for the same problem is shown in Figure14.3 below. The diagram is composed of a number of arrows and nodes. The arrows represent the project activities. Note how much clearer the sequential relationship of activities is with a network chart than with a Gantt chart. For instance it is apparent that ordering the furniture and remodeling both require that a location for the office has been identified. Likewise, interviewing must precede training. However, interviewing and training can take place independently of activities associated with locating a facility, remodeling, and so on. Hence, a network diagram is generally the preferred approach for visual portrayal of project activities.

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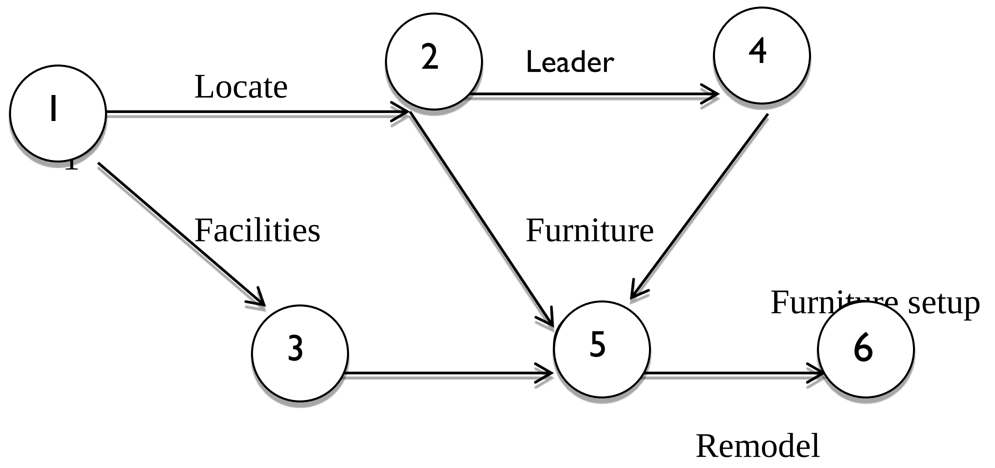


Interview

3 Hired and 5 Move 6

Trained In

Figure 14.3:

There are two slightly different conventions for constructing these network diagrams. Under one convention, the arrows designate activities: under the other convention, the nodes designate activities. These conventions are referred to as activity - on- arrow (A-O-A) and activity –on-node (A-O-N), we will concentrate on the activity -on-arrow convention. For now, we shall use the arrows for activities. Activities consume resources and/or time. The nodes in the A-O-A approach represent the starting and finishing of activities, which are called events. Events are points in time. Unlike activities, they consume neither resources nor time.

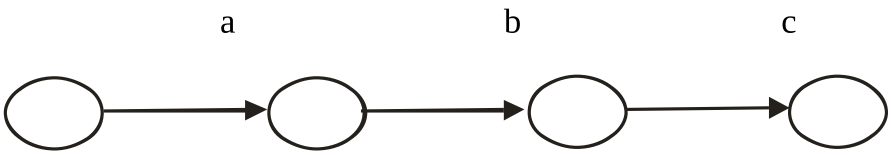
Activities can be referred to in either of two ways. One is by endpoints and the other is by a letter assigned to an arrow. Both methods are illustrated in this unit.

The network diagram describes sequential relationship among major activities on a project. For example activity 2-4 cannot be started, according to the network until activity 1-2 has been completed (Figure 14.3 behind). A path is a sequence of activities that leads from the starting node to the finishing node. Thus, the sequence 1-2-4-5-6 is a path. There are two other paths in this network: 1-2-5-6 and 1-3-5-6. The path with the longest time is of particular interest because it governs project completion time. Project life cycle equals the expected time of the longest path; the longest path is referred to as the critical path, and its activities are referred to as critical activities. The allowable slippage for any path is called slack, and it reflects the difference between the length of a given path and the length of the critical path.

3.6.1 Network Conventions

Developing and interpreting network diagrams requires some familiarity with networking conventions. Although many could be mentioned, the discussion will only itemize some of the most basic and most common features of network diagrams. This will provide us sufficient background for understanding the basic concepts associated with precedence diagrams and allow us to solve typical problems.

One of the main features of a precedence diagram is that it reveals which activities must be performed in sequence and which can be performed independently of each other. For example, in the following diagram, activity "a" must be completed before activity "b" can begin and activity "b" must be completed before activity "c" can begin (Figure 14.4 below).



If the diagram had looked like the one below (Figure 14.5), both activities "a" and "b" would have to be completed before activity "c" could begin, but "a" and "b" could be performed simultaneously, performance of "a" is independent of performance of "b".

Figure 14.4:

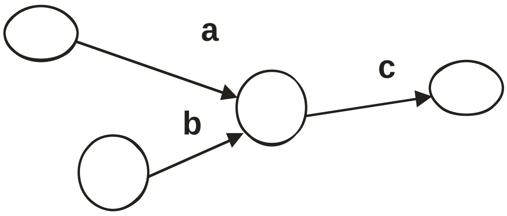


Figure 14.5:

If activity a must precede "b" and "c", the appropriate network would look like this:

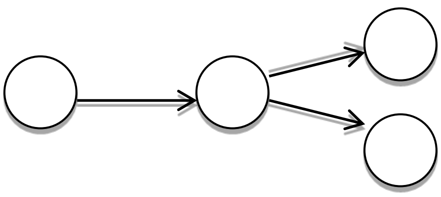


Figure 14.6:

When multiple activities enter a node, this implies that all those activities must be completed before any activity that is to begin at that node can start. Hence, in this next diagram, activities "a" and "b" must both be finished before either activity "c" or activity "d" can start.

Figure 14.7:

When two activities both have the same beginning and ending nodes, a dummy note and activity is used to preserve the separate identity of each activity. In the diagram below, activities "a" and "b" must be completed before activity "c" can be started.

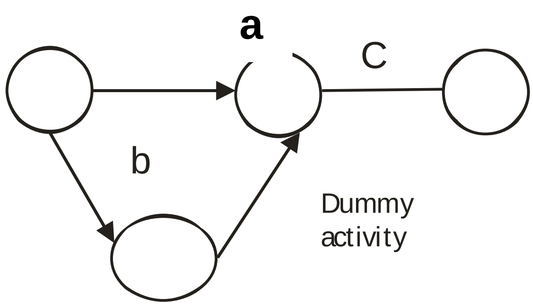


Figure 14.8:

3.7 Deterministic Time Estimates

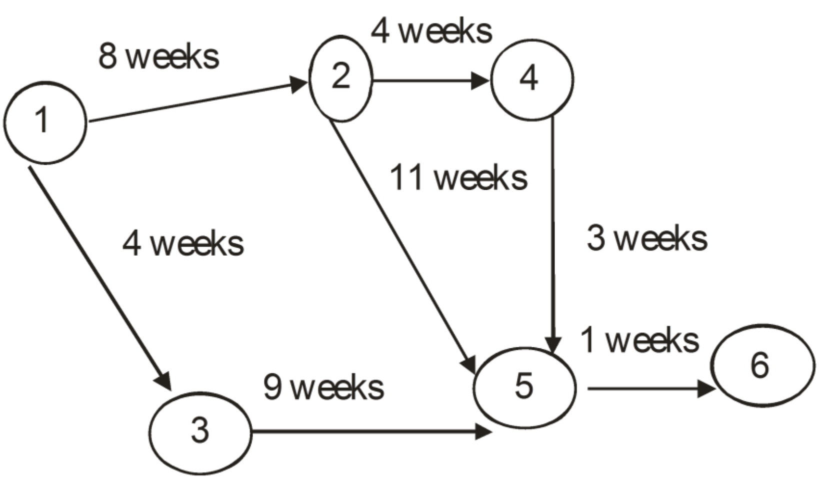
The main determinant of the way PERT and CPM networks are analyzed and interpreted is whether activity time estimates are probabilistic or deterministic. If time estimates can be made with a high degree of confidence the actual times will not differ significantly, we say the estimates are deterministic. If estimated times are subject to variation, we say the estimates are probabilistic. Probabilistic time estimates must include an indication of the extent of probable variation.

This section describes analysis of networks with deterministic time estimates. A later section deals with probabilistic times.

We would most understand the nature of network analysis with the following simple example.

Example 1

Given the following information



Determine

(a) The length of each path

(b) The critical path

(c) The expected length of the project

(d) Amount of slack time for each path.

Solution

(a) As shown in the following table, the path lengths are 18 weeks, 20 weeks and 14 weeks

(b) The longest path (20 weeks) is 1-2-5-6, so it is the critical path.

(c) The expected length of the project is equal to the length of the critical path (i.e. 20 weeks)

(d) We find the slack for each path by subtracting its length from the length of the critical path, as is shown in the last column of the table.

Path	Length (weeks)	Slack
1-2-4-5-6	8+6+3+1 = 18	20-18 = 2
1-2-5-6	8+11+1 =20*	20-20 = 0
1-3-5-6	4+9+1 =14	20 -14 = 6

*Critical path length

3.7.1 A Computing Algorithm

Many real-life project networks are much larger than the simple network illustrated in the preceding example; they often contain hundreds or thousands of activities. Because the necessary computations can become exceedingly complex and time -consuming, large networks are generally analyzed by computer programmes instead of being done manually. The intuitive approach just demonstrated does not lend itself to computerization because, in many instances, path sequences are not readily apparent. Instead, an algorithm is used to develop four pieces of information about the network activities:

ES, the earliest time activity can start, assuming all preceding activities start as early as possible. EF, the earliest time the activity can finish.

LS, the latest time the activity can start and not delay the project LF, the latest time the activity can finish and not delay the project Once these values have been determined they can be used to find:

(i) Expected project duration

(ii) Slack time

(iii) Those activities on the path.

With reference to example 1, compute the earliest starting time and earliest finishing time for each activity in the diagram.

The earliest starting time, ES is the time at the start off of an activity. Thus, activities 12 and 1-3 are assigned ES values of 0.

The earliest finishing time is the time taken for an activity added to ES and so,

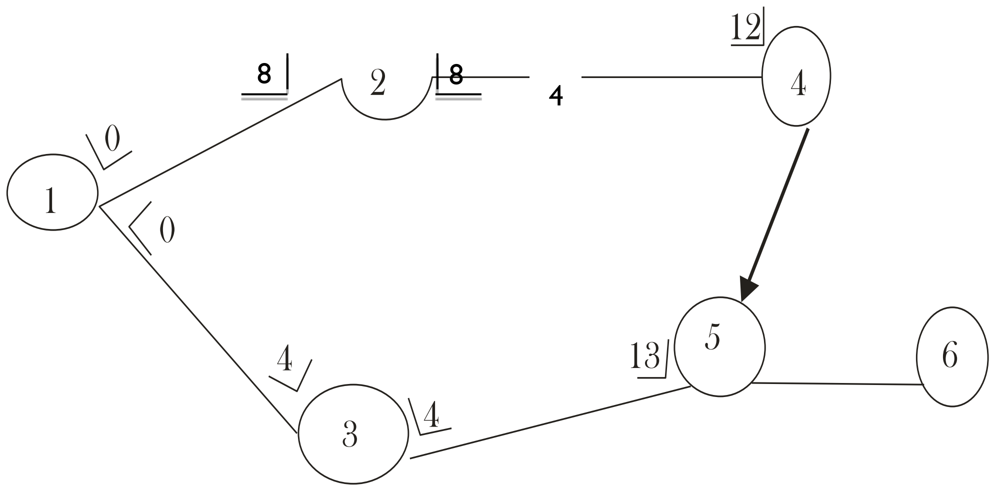
EF_{1-2} = 0+8 = 8

EF_{1-3} = 0+4 = 4

EF_{3-5} = 4+9 = 13

By placing brackets at the two ends of each starting activity, wet get:

If we reference our example 1 as shown below



We observe that ES of the starting point is 0 and EF is the time from the origin of the project, but note that ES for activity 2-4 would be the EF of activity 1-2 (8 weeks would have been exhausted in the history of the project before we want to commence activity 2-4) and EF of activity 2-4 would be 8+4 to give 12 weeks. This 12 weeks is equivalent to time taken from path 1- 2-4.

3.7.1.1 Computing ES and EF Times

Computation of earliest starting and finishing times is aided by two simple rules:

(i) The earliest finish time for any activity is equal to its earliest start time plus it expected duration t. EF = ES + t.

(ii) ES for activities at nodes with one entering arrow is equal to EF of the entering arrow. ES for activities leaving nodes with multiple entering arrows is equal to the largest EF of the entering arrow.

3.7.1.2 Computing LS and LF Times

Computation of the latest starting and finishing times is aided by the use of two rules:

(i) The latest starting time for each activity is equal to the latest finishing time minus its expected duration LS = LF- t

(ii) For nodes with one leaving arrow, LF for arrows entering that node equals the LS of the leaving arrow. For nodes with multiple leaving arrows, LF for arrows entering that node equals the smallest LS of leaving arrows.

Finding ES and EF times involve a "forward pass" through the network: finding LS and LF times involves a "backward pass" through the network. Hence, we must begin with the EF of the last activity and use that time as the LF for the last activity and use that time as the LF for the last activity. Then we obtain the LS for the last activity by subtracting its expected duration from its LF.

3.7.1.3 Computing Slack Times

The slack time can be computed in either of two ways:

Slack = LS - ES

or

LF-EF

The critical path using this computing algorithm is denoted by activities with zero slack time.

Probabilistic time estimates

The preceding discussion assumed that activity times were known and not subject to variation. While the assumption is appropriate in some situations there are many others where it is not. Consequently, those situations require a probabilistic approach.

The probabilistic approach involves three time estimates for each activity instead of one:

1. **Optimistic time: -** The length of time required under optimum conditions; represented by the letter o.
2. **Pessimistic time:** The length of time required under the worst conditions: represented by the letter p.
3. **Most likely time:** The most probable amount of time required: represented by the letter m.
4. These time estimates can be made by managers or others with knowledge about the project.

The beta distribution is generally used to describe the inherent variability in time estimates. Although there is no real theoretical justification for using the beta distribution, it has certain features that make it attractive in practice: the distribution can be symmetrical or skewed to either the right or the left according to the nature of a particular activity: the mean and the variance of the distribution can be readily obtained from the three times estimates listed above: and the distribution is unimodal with a high concentration of probability surrounding the most likely time estimate.

Of special interest in network analysis are the average or expected time for each activity t_e and the variance of each activity time δ^2 The expected time is computed as a weighted average of the three time estimates.

$$t_e = \frac{0+4M+P}{6}$$

The standard deviation of each activity time is estimated as one-sixth of the difference between the pessimistic and optimistic time estimates. The variance is found by squaring the standard deviation.

$$\delta^2 = \left\{\frac{P-0}{6}\right\}^2$$

The size of the variance reflects the level of uncertainty associated with an activity time: the larger the variance, the greater the uncertainty.

It is al so desirable to compute the standard deviation of the expected time for each path. This can be accomplished by summing the variances of the activities on a path and then taking the square root of that number: that is,

$$\text{Path} = \sqrt{(\text{variances of activities on path}}$$

For simplicity the following example illustrates clearer.

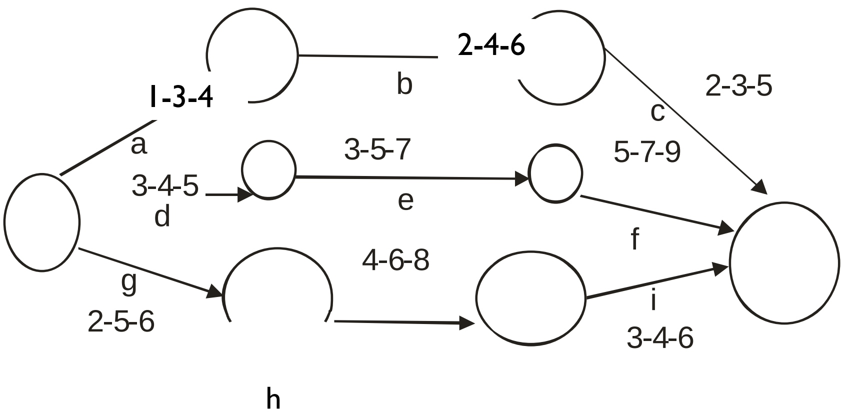
The network diagram for a project is shown in the accompanying figure. With three time estimates for each activity. Activity times are in months.

Do the following:

a. Compute the expected time for each activity and the expected duration for each path.

b. Identify the critical path.

c. Compute the variance of each activity and the variance of each path.



Key: The left hand figure of each three digit is the optimistic time.

The middle figure, most likely time

The right hand figure, pessimistic time

Solution

Path	Activity	Times O M P	$T_e = \frac{0+4m+p}{6}$	Path total
a-b-c	A	1 3 4	2.83	
	B	2 4 6	4.00	10.00
	C	2 3 5	3.17	
d- e-f	D	3 4 5	4.00	
	E	3 5 7	5.00	16.00
	F	5 7 9	7.00	
g-h-I	9	2 3 6	3.33	
	H	4 6 8	6.00	13.50
	I	3 4 6	4.17	

(a) The path that has the longest expected duration is the critical path. Since path d-e-f has the largest path, it is the critical path.

(b)

Path	Activity	Times O M P	Ω^2 act = $(P-O)^2$	Ω^2path	Ω^2path
a-b-c	a	1 3 4	$(4-1)^2/_{36}$	=-3-4	0.97
	b	2 4 6	$(6-2)^2/_{36}$	36 =0.944	
d-e-f	D	3 4 5	$(5-3)^2/_{36}$	=36	
	e	3 5 7	$(7-3)^2/_{36}$	36= 1.00	1.00
	f	5 7 9	$(9-5)^2/_{36}$		
g-h-I	g	2 3 6	$(6-2)^2/_{36}$	=41	
	h	4 6 8	$(8-4)^2/_{36}$	36 = 1.139	1.07
	I	3 4 6	$(6-3)^2/_{36}$		

If we use the information from this preceding example, we may consider the following question.

(a) What is the probability that the project can be completed within 17 month of its start?

(b) What is the probability that the project will be completed within 15 months of its start?

(c) What is the probability that the project will not be completed within 15 months of its start?

Solution

(a) To answer this question, you must first compute the value of Z using the relationship

$$Z = \frac{\text{Specified time} - \text{Expected time}}{\text{Path standard deviation}}$$

In this instance, we have

$$Z = \frac{17-16}{1.00} = 1.00 \text{ for project d-e-f}$$

From the normal distribution table, the area under the curve to the left of Z is 0.8413. Hence, the probability of the project finishing within 17 months of its start is 0.8413.

Projects a-b-c and g-h-I are both sure to be completed within 17 months of its start.

Hence, their probabilities would be 1 each.

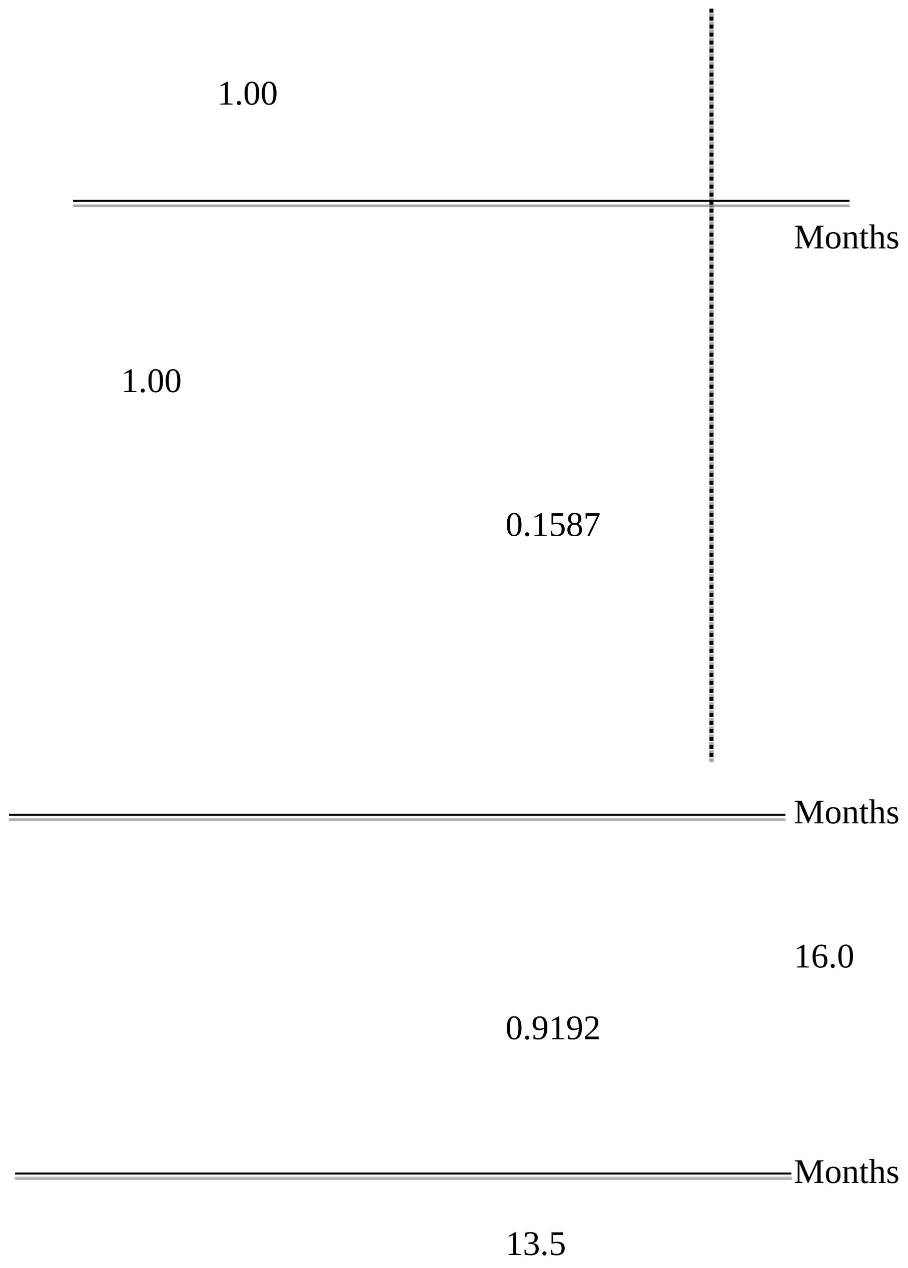
(b) If on the other hand we consider the probability of the project being completed within 15 months, we then have to compute Z values for each project.

Path Z $= \dfrac{15 - \text{Expected path duration}}{\text{Path standard deviation}}$ = probability of completion in 15 months

a-b-c $\dfrac{15 - 10.00}{0.97} = +5.15$ 1.00

d-e-f $\dfrac{15 - 16.00}{1.00} = -1.00$ 0.1587

g-h-i $\dfrac{15 - 13.50}{1.07} = +1.40$ 0.9192



Although the figure is useful in expressing the concept of overlapping paths, you need a more rigorous approach to determine which paths to consider and what the probability of completion is for each path. This requires computing Z values; any Z value that is greater than + 2.50 is treated as having a completion probability of 100 percent.

Time -cost trade -offs: Crashing

Estimates of activity times for projects usually are made for some given level of resources. In many situations, it is possible to reduce the length of a project by injecting additional resources. The necessity to shorten projects may reflect efforts to avoid late penalties, to take advantage of monetary incentives for timely or early completion of a project. In new product development, shortening may lead to a strategic benefit: beating the competition to the market. Managers often have certain options at their disposal that will allow them to shorten, or crash, certain activities. Among the most obvious options are the use of additional funds to support additional personnel or more efficient equipment and the relaxing of some work specifications.

In order to make a rational decision on which activities, if any to crash and on the extent of crashing desirable, a manager needs certain information.

1. Regular and time crash estimates for each activity.

2. A list of activities that are on the critical path

3. Regular cost and crash cost estimates for each activity.

Activities on the critical path are highly subjected to crashing, since shortening non critical activities would not have an impact on total project duration. From an economic standpoint, activities should be crashed according to crashing costs: crash those with lowest cost first.

Moreover, crashing should continue as long as the cost to crash is less than the benefits received from crashing.

4.0 Conclusion

We have been able to see the need for a manager to be versatile and have creative and imaginative thought to the smooth running of business. The need to be evaluative and analytical has been greatly emphasized. Working round clock has been able to bring his dread a reality.

5.0 Summary

Projects are made up of special activities established to realize a given set of objectives in a short while. The non-routine nature of project activities places a set of demands on the project manager that are different in many respects from those the manager of more routine operations activities require.

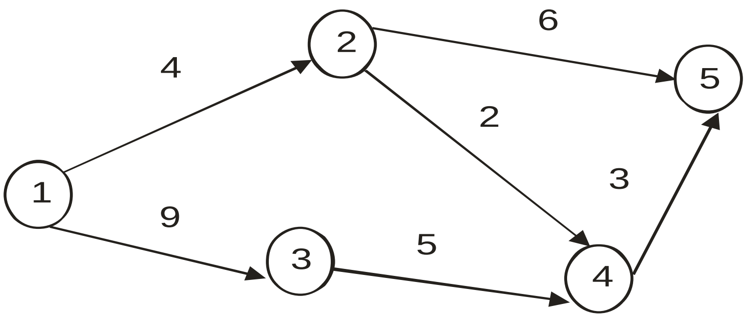
PERT and CPM are two commonly used techniques for developing and monitoring projects. Although each technique was developed independently and for expressly different purposes, time and practice have erased most of the original differences, so that now there is little distinction between the two. Either provides the manager with a rational approach to project planning and a graphical display of project activities. Both show the manager the sequence of events which must be completed on time to achieve timely project completion.

Two slightly different conventions can be used for constructing network diagram. One designates the arrows as activities: the other designates the nodes as activities. This unit has emphasized only the activity-on-arrow model.

In some situations, it may be possible to shorten, or crash, the length of a project by shortening one or more of the project activities. Typically, gains are achieved by the use of resources, although in some cases, it may be possible to transfer resources among project activities. Generally, projects are shortened to the point where the cost of additional reduction would exceed the benefit of additional reduction, or to a specified time.

6.0 Self-Assessment Exercise

1. Given the following information



(a) Determine the number of paths by writing them out

(b) Determine the critical path

(c) Expected length of the project (all unit in months)

(d) Amount of slack time for each path. Tabulate your answers.

2. Identify the term being described for each of the following:

(a) A sequence of activities in a project.

(b) The longest time sequence of activities in a project

(c) The difference in time length of any path and the critical path.

(d) Used to denote the beginning or end of an activity.

(e) Shortening an activity by allocating additional resources.

7.0 References/Further Reading

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Unit 5 Productivity

1.0 Introduction

This unit discusses issues concerned with productivity. Productivity itself relates to how effective an organisation is in the use of its resource. Here you will learn how to differentiate between efficiency and productivity. Other things to learn in this unit include the impact of human behaviour on productivity, and how productivity can be measured as well as improved.

2.0 Objectives

At the end of this unit, you should be able to:

- define the term productivity
- explain why it is important to organizations
- determine partial, multi-factor and total productivities
- explain how productivity can be improved.

3.0 Main Content

3.1 Productivity and Human Behaviour

One of the primary responsibilities of an operations manager is to achieve productive use of an organisations resource. The term "productivity" is used to describe this. Productivity is actually an index that measures output (i.e. goods and services) relative to the input (e.g. labour, materials, energy, cost of equipment, and other appropriate resources) used to produce them. It is usually expressed as the ratio of output to input

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

The ratio can be computed for a single operation, a department, an organisation, or even the whole country productivity measures can be based on single input (i.e. partial productivity) on more than one in (i.e. multi-factor productivity), or on all inputs (i e total productivity) some of these measures are given in Table 1.

The choice of particular measure depends primarily on the purpose of the measurement. For example, if the purpose is to track improvements in labour productivity, then labour becomes the obvious input measurement

Table 1: Examples of different types of measures of productivity

TYPE	FORMULAR
Partial	Output Output Output Output
Measures	Labour Machine Capital Energy
Multifactor	Output Output
Measures	Labour + Machine Labour + Capital + Energy
Total	Goods or Services Produced
Measures	All inputs used to produce them

Operations managers are more interested in partial measures of productivity. Examples of such measure include the following;

(a) Labour Productivity

Units of output per labour hour

Units of output per shift

Value-added per labour hour

Naira value of output per labour hour

(b) Machine productivity

Units of output per machine hour

Naira value of output per machine hour

(c) Capital Productivity

Units of output per Naira input

Naira value of output per Naira input

(d) Energy Productivity

Units of output per kilowatt- hour

Naira value of output per kilowatt -hour

Productivity measures are of prime importance at different levels. For instance, in the case of an individual department or organization, such measures can be used to track performance over time this provides opportunities for operations managers to judge performance, and to decide where improvements are needed.

Productivity can also be used to determine the performance of an entire industry or even the national productivity of country as a whole. In a nutshell, productivity measurements serve as scorecards of the effective use of resources.

Operations manager plays a key role in determining productivity. Their challenge is to increase the value of output, relative to the cost of input. For example, if they can generate more output of better quality by using the same amount of input productivity will definitely increase. Again if they can maintain the same level of output while reducing the use resources productivity will also increase.

At the national level, productivity is usually measured as the naira value of output per unit of labour. This measure depends on the quality of the products and services generated in a nation, as well as the efficiency with which they are produced.

Productivity is actually the prime determinant of a nation's standard of living. If the output per work hour goes up, the nation benefits from higher income levels, since the productivity of human resources determines employee wages. On the other hand, lagging or declining productivity lowers the standard of living. For instance, wage or price increases not accompanied by productivity increases usually lead to inflationary pressures rather real increases in the standard of living.

Examples on the Calculation of Productivity

Calculate the productivity for the following operations:

(a) Three employees processed 600 insurance policies last week. They worked 8 hours per day, 5 days per week.

(b) A team of workers made 400 units of a product, which is valued by its standard cost of 10 each (before markups for other expenses and profit). The accounting department reported that for this job, the actual costs were **N**400 for labour, **N**1,000 for materials, and **N** 300 for overhead.

Solutions

(a) Labour productivity $= \dfrac{\text{Policies processed}}{\text{Employee hours}}$

$= \dfrac{600}{(3 \text{ employees})(40 \text{ hours/Employee})}$

$=$ 5 policies/hour

(b) Multi-factor productivity $= \dfrac{\text{Quantity of standard cost}}{\text{Labour Cost + material cost + overhead cost}}$

$= \dfrac{(400 \text{ units})(\textbf{N}10\text{/unit})}{\textbf{N}400 + \textbf{N}1{,}000 + \textbf{N}300} = \dfrac{\textbf{N}4{,}000}{\textbf{N}\ 1{,}700} = \textbf{N}2.35$

3.2 Labour Productivity

Many companies today are pushing hard to improve their labour productivity. For man of these companies, direct labour cost remains a significant cost. Some manufacturing operations are not yet automated, and never will be because either it is not cost effective or insufficient capital is available. In addition, many services remain direct-labour-intensive. For these reasons, the cost of labour and the need to improve the productivity of labour continues to receive management attention. We are therefore going to focus on labour productivity in this section.

The major factors that affect labour productivity are contained in Figure 15.1. The figure clearly shows that the causes of labour productivity are many. Unfortunately, there are currently no sets of formulars that precisely predict human behaviour, in general and productivity in particular. It is however gratifying to note that we can have enough understanding of employee behaviour, so as to remove some of the uncertainty about why employees are productive.

Another look at Figure 15.1 should reveal to you that three major factors affect labour productivity. These are the physical work environment; employee job performance; and product quality. In this realisation, various staff groups are making efforts such as industrial, process product and systems engineering to develop better automation, machines, tools, and work methods to enhance labour productivity. The belief is their increasing productivity through technology development is at least as important as employee job performance in increasing productivity. The productivity of all factors of production can also be directly increased through reduction in defects, scrap, and re-work.

You need to realise that employee job performance is a complex topic because no two people are exactly the same. Hence, their abilities, personalities, interests, ambitions, energy levels, education, training, and experience are bound to vary considerably. Operations managers often consider these factors since blanket or common approaches to improving job performances may not be effective for all and sundry.

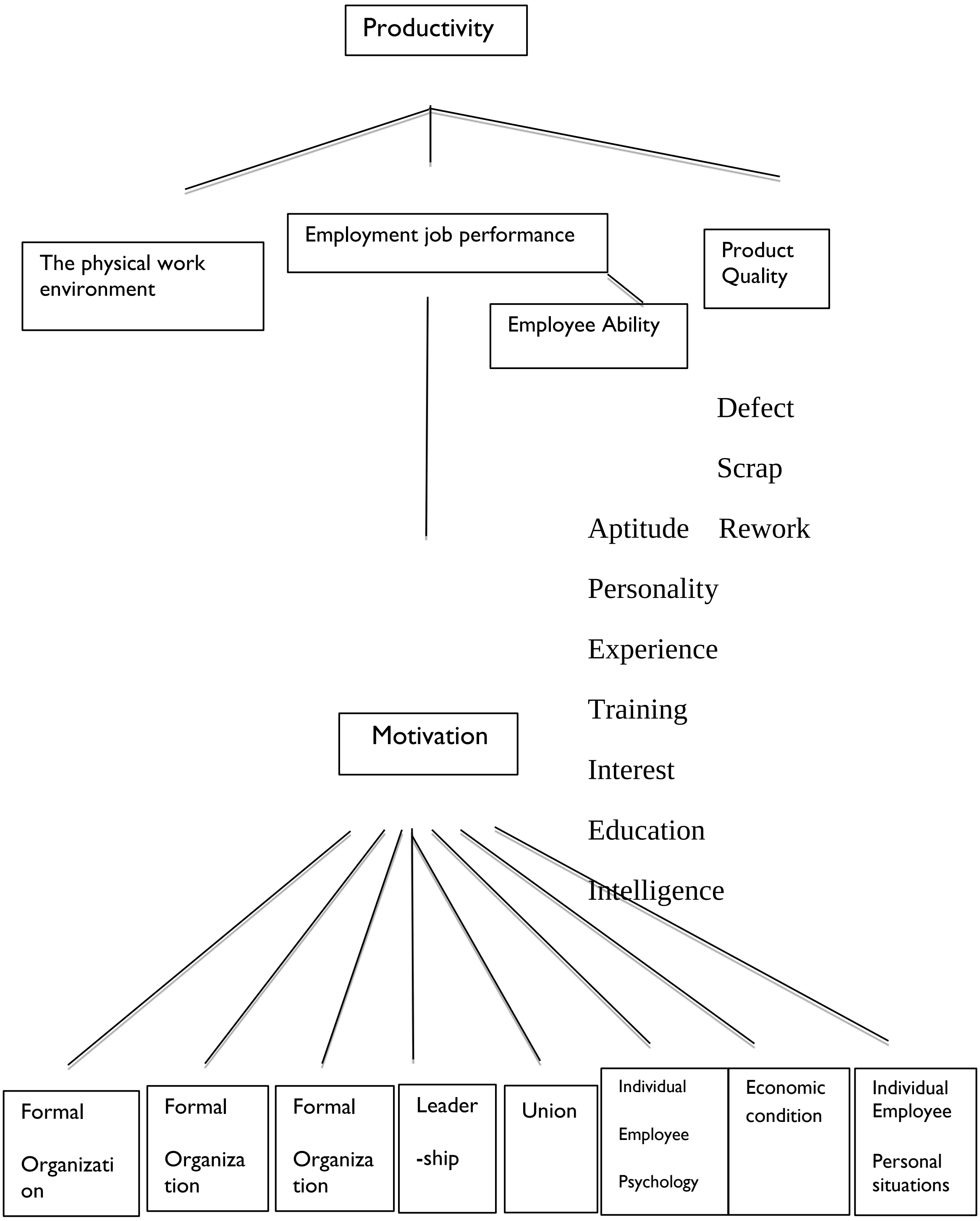

Figure 15.1: Variables Affecting Labour Productivity

Source: Gaither, M. (1996). *Production and Operations Management*, (7th Ed). Belmont, Duxary Press, p. 608.

It is in recognition of these differences that efforts are being made by personnel, departments to select employees who have the desired abilities to develop training programmes for the improvement of employee skills.

There is a growing importance of employee training and education all over the world. Many organisation are aggressively increasing their employee training programmes for competitive advantage, and this has been off in boosted production and morale.

Motivation has been discovered to be the most complex variable in the equation of productivity. As Berelson and Steiner (1964) have defined the term, a motive "is an inner state that energises, activates, or moves (hence 'motivation'), and that directs or channels behaviour toward goals". In other words, "motivation" is a general term applying to the entire class of drives, desires, needs, wishes, and similar forces.

One of the widely referred-to theories of motivation is the "hierarchy of needs" theory developed by Abraham Maslow. He saw human needs in the form of a hierarchy, starting in an ascending order from the lowest to the highest needs, and concludes that when one set of needs was satisfied, this kind of need ceased to be a motivator. In this sense, therefore, only unsatisfied needs are motivators, or cause people to act.

The basic human needs identified by Maslow in an ascending order of importance are the following:

1. Physiological needs

These are the basic needs for sustaining human life itself - food, water, clothing, shelter, sleep, and sexual satisfaction. Maslow took the position that until these needs are satisfied to the degree necessary to maintain life, other needs will not motivate people.

2. Security or Safety needs

These are the needs to be free from physical danger, and the fear or loss of a job property, food, clothing or shelter.

3. Affiliation or Acceptance needs

Since people are social beings, they need to belong and to be accepted by others. In other words, this means sense of belonging and love.

4. Esteem needs

According to Maslow, once people begin to satisfy their need to belong, they tend towant to be held in esteem both by themselves, and by others. This kind of need produces such satisfactions as power, prestige, status, and self-confidence.

5. Self-Actualisation needs

Maslow regards this as the highest need in his hierarchy. It is the desire to become what one is capable of becoming, i.e. to maximise one's potential and to accomplish something.

In Nigeria today, many employees' lower-level needs (physiological and safety) have been mostly taken care of by the recent minimum wage law. For all workers in the country, The higher-level needs (social, esteem and self-actualisation) may therefore hold more promise for managers in their attempt to motivate employees.

To what extent can we use the understanding of employees' needs to design a work environment that encourages productivity?. Using Maslow's theory, if we can determine what class of needs is currently important to our employees, then we can apply the following framework given by Graither (1996).

If productivity is seen by employees as a means of satisfying their needs, high productivity is likely to result. Once employees have their needs satisfied through rewards that have been conditional upon productivity, the process is likely to be repeated.

Labour unions and work groups can influence employees to be either productive or unproductive. For instance, if employees think that their work groups may treat them as outcasts because they have been productive, they may not cooperate with management in this productivity-reward-productivity cycle. This is the reason why operations managers should recognise the influence that work groups have on labour productivity. They therefore need to develop cooperative work groups. They also need to influence group norms through effective cooperation and communication.

3.3 How Productivity can be improved

An organisation or a department can take a number of key steps toward improving productivity. Here are some of them as suggested by Stevenson (1996):

1. Develop productivity measures for all operations. This is based on the premise that measurement is the first step in managing and controlling an operation.

2. Look at the system as a whole in deciding which operations are most critical. This is based on the fact that it is the overall productivity that is important. This concept is illustrated by Figure 15.2, which shows several operations feeding their output into a bottle neck operation. The capacity of the bottle neck operation is less than the combined capacities of the operations that provide input, so units queue up waiting to be processed. Productivity improvements to any non-bottleneck operation will not affect the productivity of the system. However, improvement in the bottleneck operation will lead to increases productivity, up to the point where the output rate of the bottleneck equals the output of the operations feeding it.

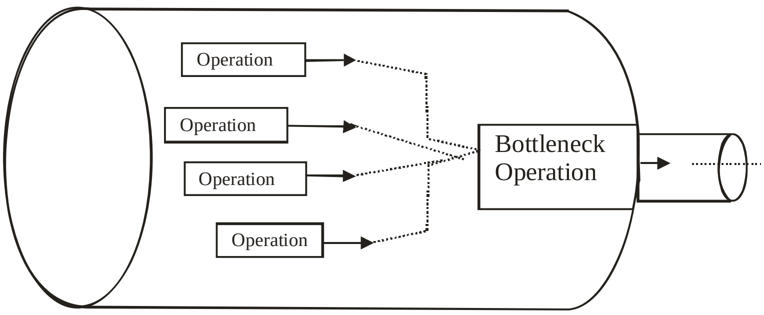

Figure 15.2: Bottleneck Operation

Source: Stevenson, W.J. (1996). *Production/Operations Management,* (5th ed). Burr Ridge, Ill.: Richard D. Irwin. p. 45.

3. Develop methods achieving productivity improvements, such as soliciting ideas from workers (e.g. organising teams of workers, engineers, and managers) studying how similar firms have increased productivity, and re-examining the way work is done.

4. Estimate reasonable goods for improvement

5. Make it clear that management supports and encourages productivity improvement. It is also important to consider incentive to reward workers for contributions.

6. Measure improvement and publicise them.

7. Don't confuse productivity with efficiency. This is because efficiency is a narrower concept that pertains to getting the best out of a given set of resources. Productivity, on the other hand, is a broader concept that pertains to effective use of overall resources. For example, an efficiency perspective on mowing a lawn given a hand mower would focus on the best way to use the hand mower; a productivity perspective would include the possibility of using a power mower.

Self-Assessment Exercise

1) If labour productivity is low in a company, does it necessarily mean that the labour resource is under performing?

2) A company that processes fruits and vegetables is able to produce 400 cartoons of canned peaches in one-half hour with two workers. What is labour productivity?

3) A wrapping paper company produced 2,000 rolls of paper one day. Labour cost was N60, material cost was N50, and overhead was N320. Determine the multi-factor productivity.

4.0 Conclusion

In this unit, you have learned what productivity is and why it is important. You have also learned how organisations can improve productivity. You should now be able to compute partial, multi-factor and total measures of productivity.

5.0 Summary

One basic fact you have learned in this unit is that it is necessary for organisations, especially the operations managers to achieve productive use of resources. This unit has taken you through a general discussion on productivity and human behaviour and labour productivity in particular. The unit that follows is also in line with attempts to increase the efficiency, as well as productivity of organisations.

6.0 Self-Assessment Exercise

(1) Student tuition a university in an oil-rich state is **N**100 per semester credit hour. The state supplements school revenue by matching student tuition, naira for naira. Average class size for a typical three-credit course is 50 students. Labour costs are **N**4, 000 per

class, material cost are **N**20 per students per class, and overhead costs are **N**25, 000 per class.

(a) What is the multi-factor productivity ratio?

(b) If instructors work an average of 14 hours per week for 16 weeks for each three credit class of 50 students, what is the labour productivity ratio?

(2) Natty Dresses makes fashionable garments. During a particular week, employees works 360 hours to produce a batch of 132 garments, of which 52 were "seconds" (meaning that they were flawed). Seconds are sold for **N**90 each at Natty's Factor outlet store. The remaining 80 garments are sole to retail distributor, at **N**200 each. What is the labour productivity ratio?

7.0 References/Further Reading

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