
UNIT 9 PLANNING AND CONTROL FOR MASS PRODUCTION

Objectives

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

- understand the nature of mass/flow production
- identify the situations under which mass production is justified
- appreciate both the desirable and undesirable features of mass production
- see how assembly lines and fabrication lines are designed
- get an idea of how modular production and group technology could be used to advantage in mass production
- understand the role of automation including robotics in mass production.

Structure

- 9.1 Introduction
- 9.2 When to Go For Mass Production
- 9.3 Features of a Mass Production System
- 9.4 Notion of Assembly Lines and Fabrication Lines
- 9.5 Design of an Assembly Line
- 9.6 Line Balancing Methods
- 9.7 Problems and Prospects of Mass Production
- 9.8 Modular Production and Group Technology
- 9.9 Automation and Robotics
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9.1 INTRODUCTION

Kinds of Production Systems: Flow Shops, Job Shops and Projects

As you already know, production involves the transformation of inputs (such as men, machines, materials, money, information and energy) to desirable outputs in the form of goods and services. It is customary to divide production systems into three categories: the flow shop, the job shop and the project. The flow shop exists when the same set of operations is performed in sequence repetitively; the job shop exists where the facilities are capable of producing many different jobs in small batches; the project is a major undertaking that is usually done only once. It consists of many steps that must be sequenced and coordinated.

The flow shop employs special purpose equipment (designed specifically for the mass-scale production of a particular item or to provide a special service). The job shop contains general-purpose equipment (each unit is capable of doing a variety of jobs). The project, like the flow shop, requires a sequence of operations, except that the sequence lacks repetition. Each project operation is unique and seldom repeated. For example, the production line for automobiles is a flow shop; the machine shop that makes hundreds of different gears in batches of 50 at a time is a job shop; building a bridge or launching a satellite in space is a project.

This unit is concerned with the problems of mass production encountered in flow shops. Batch production and its problems are discussed in unit 10, while job shops and projects are handled in units 11 and 12 respectively.

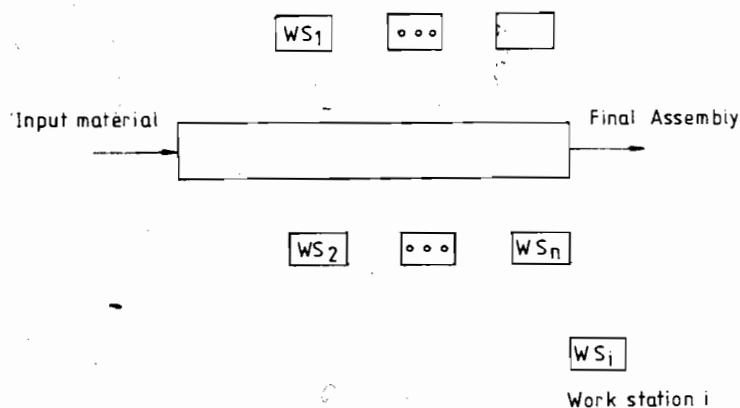
Nature of Mass Production

It was Henry Ford who in 1913 introduced the 'assembly line' and the notion of 'mass production'. It is erroneous to think that mass production means production in millions or for the masses, though this may be an outcome. Mass production refers to the manner in which a product is produced. This involves the decomposition of

the total task into its minutest elements (shown usually on a precedence diagram) and the subsequent regrouping of these elements according to the norms of production. An assembly line consists of work stations in sequence where at each work station the above carefully designed portion of work is done. Mass production requires that all like parts of an assembly line be interchangeable and that all parts be replaceable, characteristics which permit production and maintenance of large quantities.

The assembly line is a production line where material moves continuously at a uniform average rate through a sequence of work stations where assembly work is performed. Typical example of these assembly lines are car assembly, electrical appliances TV sets, computer assemblies and toy manufacturing and assembly. A diagrammatic sketch of a typical assembly line is shown in Figure I. The arrangement of work along the assembly line will vary according to the size of the product being assembled, the precedence requirements, the available space, the work element and the nature of the work to be performed on the job.

Figure I: A Typical Assembly Line



Material movement between work stations could be **manual**, as for instance when operators sitting in a row pick up the part from the output of the previous operator, work on it and leave it in a bin to be picked up by the next operator; or through the use of **conveyors**, which carry the part at a predetermined speed so that there is adequate time for each work station to complete its allocated share of work. There are various types of conveyors that are used in assembly lines; the most widely used are belt, chain, overhead, pneumatic and screw conveyors.

It may be of interest to note that assembly lines could have varying degrees of automation, starting from the purely manual on the one hand to the fully automated line on the other. However, the underlying principle of the assembly line and mass production remains unchanged, although the labour content may be reduced through robotisation.

9.2 WHEN TO GO FOR MASS PRODUCTION

It is generally agreed that mass production is justified only when production quantities are large and product variety small. The ideal situation for mass production would be when large volumes of one product (without any changes in design) are to be produced continuously for an extended period of time. Thus the rate of consumption (or demand) of the product as compared to the rate of production decides whether continuous or batch production is called for. Obviously, only if the rate of demand is greater than or equal to the production rate, mass or continuous production could be sustained. If the rate of demand is less than the production rate, batch production with suitable inventory buildups could be resorted to.

Apart from the above consideration, the economics of the matter would have to be evaluated before deciding as to whether an assembly line is justified or not. This is illustrated by the following example.

Example 1

As a manager of a plant you have to determine whether you should purchase a component part or make it in the plant. You can purchase the item at Rs. 10 per piece. With an investment equivalent to an annual fixed cost of Rs. 20,000 and a variable cost of Rs. 2.50 per piece an assembly line can be set up to manufacture the part. A third option open to you is to make the part at individual stations with an annual fixed cost of Rs. 10,000 and a variable cost of Rs. 5 a piece. Assuming that the annual demand is expected to be around 3500 units which alternative would you suggest?

Solution

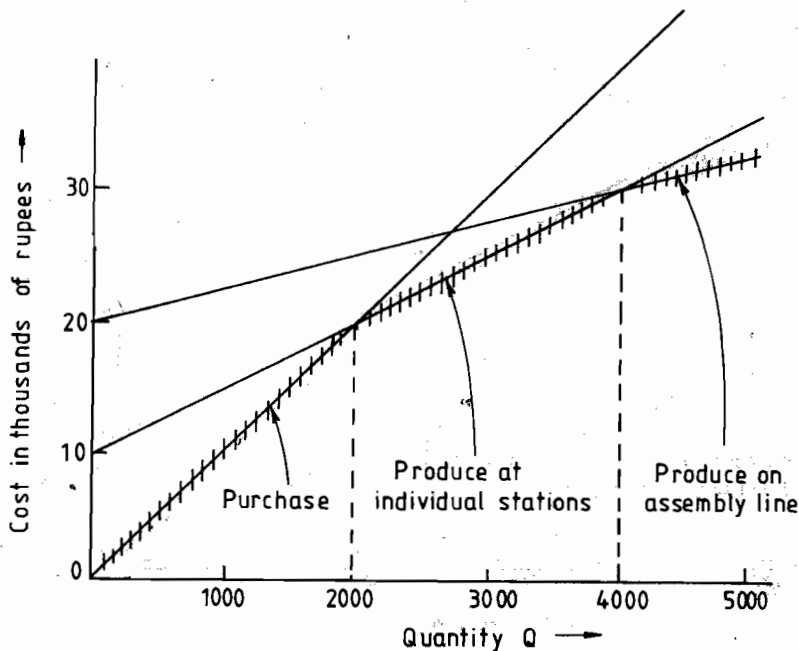
The choice from the three alternatives (purchase, produce at individual stations, or employ an assembly line for production) is simplified by plotting a cost vs. quantity chart for these options. If Q is the quantity purchased or produced then total cost equals Rs. $(10Q)$, if the part is purchased; Rs. $(10,000 + 5Q)$, if the part is made at individual stations; and Rs. $(20,000 + 2.5Q)$ if the part is made on an assembly line. These cost functions are plotted in Figure II and the break-even points at quantity levels of 2000 and 4000 reveal the following decision rules:

For annual requirements in the range 0–2000, it is cheapest to buy,

For annual requirements in the range 2000–4000, it is cheapest to produce on individual stations, and only for annual requirements of 4000 or more, is an assembly line justified.

Thus for an annual requirement of 3500, you should not recommend the installation of an assembly line.

Figure II: Costs of the Three Alternatives



Activity A

Think of situations in your daily life where alternatives of the above types exist. Can you analyse them using break-even analysis?

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9.3 FEATURES OF A MASS PRODUCTION SYSTEM

A mass production system operating as a continuous flow line exhibits certain desirable and undesirable features. These are summarised below:

Advantages

- 1 A smooth flow of material from one work station to the next in a logical order. Although straight line flow is common, other patterns of flow exhibited in Figure III are also employed when constraints on space or movement so indicate.

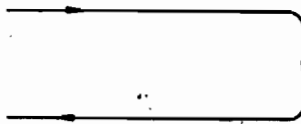
Figure III: Kinds of Flow Patterns



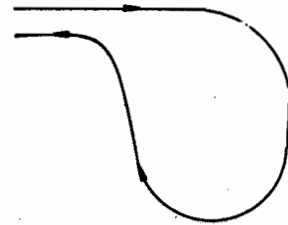
(a) Straight or I flow



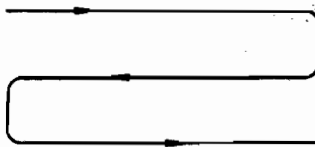
(b) L - flow



(c) U - flow



(d) Circular or O - flow



(e) Serpentine or S - flow

- 2 Since the work from one process is fed directly into the next, small inprocess inventories result.
- 3 Total production time per unit is short.
- 4 Since the work stations are located so as to minimise distances between consecutive operations, material handling is reduced.
- 5 Little skill is usually required by operators at the production line; hence training is simple, short and inexpensive.
- 6 Simple production planning and control systems are possible.
- 7 Less space is occupied by work in transit and for temporary storage.

Disadvantages

- 1 A breakdown of one machine may lead to a complete stoppage of the line that follows the machine. Hence maintenance and repair is a challenging job.
- 2 Since the product dictates the layout, changes in product design may require major changes in the layout. This is often expressed by saying that assembly lines are inflexible.

- 3 The pace of production is determined by the 'slowest' or 'bottleneck' machine. Line balancing proves to be a major problem with mass manufacture on assembly lines.
- 4 Supervision is general rather than specialised, as the supervisor of a line is looking after diverse machines on a line.
- 5 Generally high investments are required owing to the specialised nature of the machines and their possible duplication in the line.

9.4 NOTION OF ASSEMBLY LINES AND FABRICATION LINES

It is useful to consider two types of line balancing problems:

- i) assembly line balancing, and
- ii) fabrication line balancing.

The distinction refers to the type of operation taking place on the line to be balanced. The term 'assembly line' indicates a production line made up of purely assembly operations. The assembly operation under consideration involves the arrival of individual component parts at the work place and the departure of these parts fastened together in the form of an assembly or sub-assembly.

The term 'fabrication line', on the other hand, implies a production line made up of operations that form or change the physical, or sometimes, chemical characteristics of the product involved. Machining or heat treatment would fall into operations of this type.

Although there are similarities between the problem of assembly line balancing and that of fabrication line balancing, the problem of balancing a fabrication line or machine line is somewhat more difficult than the assembly line balancing problem. It is not so easy to divide operations up into relatively small elements for regrouping. The precedence restrictions are usually tighter in the fabrication line. An assembly operator may easily shift from one assembly job to another, but a machine tool may not be utilised for a variety of jobs without expensive changes in setup and tools.

Some methods by which the balance of fabrication operation times can be achieved are as follows:

- 1 changing machine speeds
- 2 using slower machines on overtime
- 3 providing a buffer of semi-finished parts at appropriate places
- 4 using mechanical device for diverting parts
- 5 methods improvement.

9.5 DESIGN OF AN ASSEMBLY LINE

The Broad Objective in Design

As you have just seen the two most important manufacturing developments, which led to progressive assembly are the concept of interchangeable parts and the concept of the division of labour. These permit the progressive assembly of the product, as it is transported past relatively fixed assembly stations, by a material handling device such as a conveyor. The work elements, which have been established through the division of labour principle, are assigned to the work stations so that all stations have nearly an equal amount of work to do. Each worker, at his or her station, is assigned certain of the work elements. The worker performs them repeatedly on each production unit as it passes the station.

The assembly line balancing problem is generally one of minimising the total amount of idle time or equivalently minimising the number of operators to do a given amount of work at a given assembly line speed. This is also known as minimising the balance delay. 'Balance delay' is defined as the amount of idle time for the entire

assembly line as a fraction of the total working time resulting from unequal task time assigned to the various stations.

Kilbridge and Wester after studying the variation in idle times at stations caused by different assembly line balances concluded that high balance delay for an assembly line system for a specific product is caused by

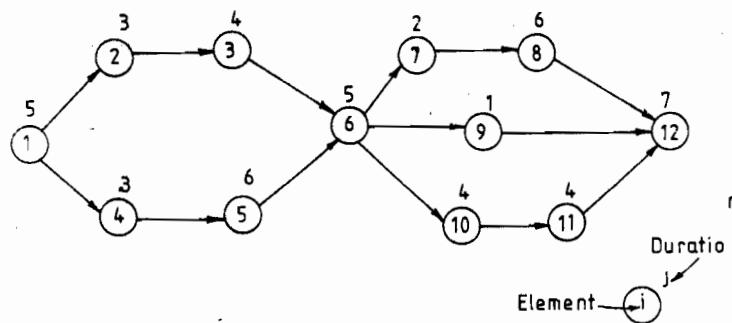
- i) wide range of work element times
- ii) a large amount of inflexible line mechanisation and
- iii) indiscriminate choice of cycle times.

However, as we shall see, the cycle time is often dictated by a specific desired production rate, which may not lead to a low balance delay.

Division of Work into Parts: The Precedence Diagram

The total job to be done or the 'assembly' is divided into work elements. A diagram that describes the ordering in which work elements should be performed is called a 'precedence diagram'. Figure IV shows the precedence diagram for an assembly with 12 work elements. Notice that tasks 2 and 4 cannot begin until task 1 is completed. Moreover, there is no restriction on whether task 2 is done first or task 4. These two tasks are unrelated meaning thereby that they may be done in parallel or even with partial overlap. A task may well have more than one immediate predecessor. For example, in the precedence diagram of Figure IV task 12 has 3 immediate predecessors and cannot begin until all the three work elements 8, 9 and 11 are completed.

Figure IV: Precedence Diagram for An Assembly with 12 Elements



The ordering dictated by the precedence diagram may be the result of technological restrictions on the process or constraints imposed by layout, safety or convenience. The precedence diagram forms the basis for the grouping of work elements into work stations.

Activity B

For a job like mending the puncture of your bicycle tyre identify the work elements and draw a precedence diagram.

[illegible]

Grouping of Tasks for Work Stations and Efficiency Criteria

Depending on the desired production rate of the line, the cycle time (CT) or the time between the completion of two successive assemblies can be determined. This determines the conveyor speed in the assembly line or the time allocated to each operator to complete his share of work in a manual line.

The individual work elements or tasks are then grouped into work stations such that

- i) the station time (ST), which is the sum of the times of work elements performed at that station and should not exceed the cycle time, CT.
- ii) the precedence restrictions implied by the precedence diagram are not violated.

There are many possible ways to group these tasks keeping the above restrictions in mind and we often use criteria like line efficiency, balance delay and smoothness index to measure how good or bad a particular grouping is. These criteria are explained below:

- 1 Line efficiency (LE): This is the ratio of total station time to the product of the cycle time and the number of work stations. We can express this as

$$LE = \frac{\sum_{i=1}^K S T_i}{(K) (CT)} \times 100\%$$

where

- $S T_i$ = station time of station i
 K = total number of work stations
 CT = cycle time.

- 2 Balance delay (BD): This is a measure of the line inefficiency and is the total idle time of all stations as a percentage of total available working time of all stations.

Thus

$$BD = \frac{(K) (CT) - \sum_{i=1}^K S T_i}{(K) (CT)} \times 100\%$$

Balance delay is thus $(100-LE)$ as a percentage.

- 3 Smoothness index (SI): This is an index to indicate the relative smoothness of a given assembly line balance. A smoothness index of 0 indicates a perfect balance. This can be expressed as:

$$SI = \sqrt{\sum_{i=1}^K (S T_{\max} - S T_i)^2}$$

where

- $S T_{\max}$ = maximum station time
 $S T_i$ = station time of station i
 K = total number of work stations.

It may be noted that in designing an assembly line the number of work stations, K cannot exceed the total number of work elements, N (in fact K is an integer such

that $1 \leq K \leq N$). Also the cycle time is greater than or equal to the maximum time of any work element and less than the total of all work element times, that is

$$T_{\max} \leq CT \leq \sum_{i=1}^N T_i$$

Where

T_i is the time for work element i

N is the total number of work elements

T_{\max} is the maximum work element time

CT is the cycle time.

There is yet no satisfactory methodology which guarantees an optimal solution for all assembly line balancing problems. The emphasis has been on the use of heuristic procedures that can obtain a fairly good balance for the problem. For reviews of procedures available for assembly line balancing refer to Buffa and Kilbridge and Wester. Two commonly used methods for obtaining a good balance for an assembly line balancing problem are presented in the next section.

9.6 LINE BALANCING METHODS

Kilbridge and Wester Method

In this procedure proposed by Kilbridge and Wester numbers are assigned to each operation describing how many predecessors it has. Operations with the lowest predecessor number are assigned first to the work stations. The procedure consists of the following steps:

- 1) Construct the precedence diagram for the work elements. In the precedence diagram, list in column I all work elements that need not follow others. In column II, list work elements that must follow those in column I. Continue to the other columns in the same way. By so constructing the columns the elements within a column can be assigned to work stations in any order provided all the elements of the previous column have been assigned.
- 2) Select a feasible cycle time, CT . By a feasible time we mean one for which

$$T_{\max} \leq CT \leq \sum_{i=1}^N T_i$$

- 3) Assign work elements to the station such that the sum of elemental times does not exceed the cycle time CT . This assignment proceeds from column I to II and so on, breaking intra column ties using the criterion of minimum number of predecessors.
- 4) Delete the assigned elements from the total number of work elements and repeat step 3.
- 5) If the station time exceeds the cycle time CT due to the inclusion of a certain work element this work element should be assigned to the next station.
- 6) Repeat steps 3 to 5 until all elements are assigned to work stations.

Example 2

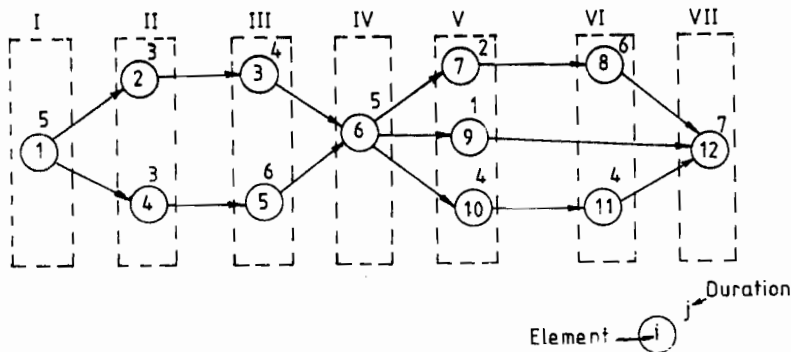
Let us, for illustration, use the Kilbridge-Wester method to balance the assembly line with the precedence diagram shown in Figure IV.

First of all, the 12 elements are assigned to columns as under

element 1	in column	I
elements 2 and 4	in column	II
elements 3 and 5	in column	III
element 6	in column	IV
elements 7, 9 and 10	in column	V
elements 8 and 11	in column	VI
element 12	in column	VII

This is diagrammatically shown in Figure V. Suppose, we want to balance the line for a cycle time, $CT=10$. We count the number of predecessors for each work element and record it in Table 1. Work element 1 is selected first because it has the least number of predecessors. Therefore, we assign element 1 to station 1. Either

Figure V: Grouping of Work Elements into Columns for Kilbridge-Wester Method



element 2 or 4, each of which has an operation time of 3, can be assigned to station 1, which results in a station time of $8 \leq CT$. Element 4 cannot be added to station 1, otherwise the station time will exceed the cycle time; therefore we assign element 4 to station 2 and continue with the above process. The final assignment resulting from an application of this procedure is shown in Table 2.

Table 1
Number of Predecessors for Each Work Element

Work Element i	Number of Predecessors	T_i
1	0	5
2	1	3
3	2	4
4	1	3
5	2	6
6	5	5
7	6	2
8	7	6
9	6	1
10	6	4
11	7	4
12	11	7

Table 2
Assignment of Work Elements to Stations (Kilbridge-Wester Method)

Station	Element i	T_i	Station sum	Idle time
I	1	5	8	2
	2	3		
II	4	3	9	1
	5	6		
III	3	4	9	1
	6	5		
IV	7	2	7	3
	9	1		
	10	4		
V	8	6	10	0
	11	4		
VI	12	7	7	3

$$\text{The line efficiency (LE)} = \frac{50}{6 \times 10} \times 100\% \\ = 83.3\%$$

$$\text{Balance delay (BD)} = 16.7\%$$

$$\text{Smoothness index (SI)} = \sqrt{4+1+1+9+9} \\ = \sqrt{24} = 4.89$$

That the solution obtained above is not the optimal solution can be seen by making some adjustments in the solution of Table 2 to yield the solution of Table 3 for which the cycle time is equal to 9 and the figures for line efficiency and smoothness index are:

$$LE = \frac{50}{6 \times 9} \times 100 = 92.6\%$$

$$SI = \sqrt{1+1+1+1} = 2$$

Table 3
Revised Assignment of Work Elements to Stations (Cycle Time = 9)

Stations	Element i	T _i	Station sum	Idle Time
I	1	5	8	1
	2	3		
II	4	3	9	0
	5	6		
III	3	4	9	0
	6	5		
IV	7	2	8	1
	8	6		
V	10	4	8	1
	11	4		
VI	9	1	8	1
	12	7		

This should cause no concern, for the Kilbridge and Wester method is a heuristic procedure which does not guarantee an optimal solution. It only results in good working solutions with relatively little computational effort. This is also true of the other heuristic procedure to be discussed below.

Helgeson and Birnie Method:

This method proposed by Helgeson and Birnie is also known as the ranked positional weight technique. It consists of the following steps:

- 1 Develop the precedence diagram in the usual manner.
- 2 Determine the positional weight for each work element (a positional weight of an operation corresponds to the time of the longest path from the beginning of the operation through the remainder of the network).
- 3 Rank the work elements based on the positional weight in step 2. The work element with the highest positional weight is ranked first.
- 4 Proceed to assign work elements to the work stations where elements of the highest positional weight and rank are assigned first.
- 5 If at any work station additional time remains after assignment of an operation, assign the next succeeding ranked operation to the work station, as long as the operation does not violate the precedence relationships and the station time does not exceed the cycle time.
- 6 Repeat steps 4 and 5 until all elements are assigned to the work stations.

Example 3

Let us take up for illustration the balancing of the same assembly line considered previously by the Kilbridge-Wester method. For the precedence diagram shown in Figure IV, and a desired cycle time of 10, we first construct the table of positional weights of all elements as Table 4. For example, the positional weight of operation 6 equals the maximum of (5+2+6+7), (5+1+7), (5+4+4+7) = 20, since there are 3 paths (6-7-8-12, 6-9-12, 6-10-11-12) from the concerned operation to the end of the network. Following the above steps 4, 5, 6 we obtain the assignments of work elements shown in Table 5.

The line efficiency and smoothness index for this assignment is:

$$\begin{aligned}\text{Line efficiency} &= \frac{50}{6 \times 10} \times 100 \\ &= 83.3\%\end{aligned}$$

(Or equivalently, the balance delay = 16.7%)

$$\begin{aligned}\text{Smoothness index} &= \sqrt{4+1+1+16+4} \\ &= \sqrt{26} = 5.09\end{aligned}$$

Table 4
Positional Weights for the Work Elements

Element	Positional Weight, PW
1	34
2	27
3	24
4	29
5	26
6	20
7	15
8	13
9	8
10	15
11	11
12	7

Table 5
Assignment of Work Elements to Stations (Helgeson and Birnie Method)

Station	Element i	T _i	Station sum	Idle time
I	1	5	8	2
	4	3		
II	2	3	9	1
	5	6		
III	3	4	9	1
	6	5		
IV	7	2	6	4
	10	4		
V	8	6	10	0
	11	4		
VI	9	1	8	2
	12	7		

Activity C

You should explore the possibility of improving the balance of adjustments between work stations as we have done previously with the solution obtained by the Kilbridge and Wester method.

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9.7 PROBLEMS AND PROSPECTS OF MASS PRODUCTION

Variable Work Element Times

In both the line balancing methods discussed in the previous section it was assumed that the work element times are constant. In practice, these times may be varying randomly owing to factors like human variability, fatigue or carelessness on the

operator's part. Even in the case of machine operations, the set up or positioning time of the part or components could lead to random variations in the individual work element times. Since the assembly line is balanced for a given fixed set of work element times the effects of these variabilities are two-fold.

- i) greater idle time at some work stations, and
- ii) the reduction of the average production rate of the line.

In designing lines for random work element times with given means and variances, some modification of the deterministic line balancing methods is adopted utilising the additional criterion that the probability of the station time exceeding the cycle time should be kept as low as possible. Some methods of probabilistic assembly line balancing are discussed by Elsayed and Boucher.

Breakdowns at Work Stations

The mass production system consists of a number of stages in series at which some operations are being performed. A failure or a breakdown of one stage or work station will result in failure of the entire production system until repair is completed.

The result would be decreased production rate. This problem is handled in practice by providing:

- i) efficient maintenance service so that the broken down units are repaired and put into service as soon as possible.
- ii) buffer storage of semi-finished goods between each pair of stages, so that the entire line does not stop due to the failure of one or more units.

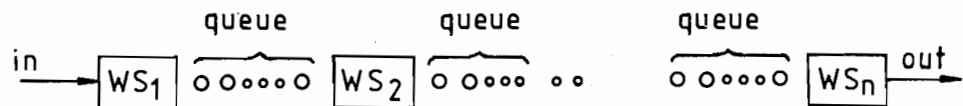
The question of how much buffer storage to allocate between stages is of great practical importance—a higher buffer stock means greater tied up capital but a lower risk of runout and subsequent line stoppage due to breakdowns.

The decision to estimate the size of the buffer can be governed by one or more of the following criteria which consider as to what is the buffer size that:

- 1 maximises the production rate of the system
- 2 minimises the total production cost
- 3 maximises the availability of the production system.

The problem could in general be viewed as a multi-stage queueing system (Figure VI). See for instance Elsayed and Boucher.

Figure VI: An Assembly Line with Buffers as a Multi-stage Queueing System



Multi-product Lines

One of the major disadvantages with assembly lines is their relative inflexibility. A line is usually designed for one product and changes in design of the product are often difficult to accommodate on the line, unless suitable adjustments are made at work stations. But when similar products, in which a large percentage of the tasks are common, have to be manufactured, the possibility of the same production line for the products can be explored. Since tasks are fixed within stations, once balanced, it should be apparent that station times and line efficiencies will vary with the products being produced. A great variety in these efficiencies might dictate that separate lines be utilised. In case a multi-product line is to be designed a common precedence diagram must be developed. For instance precedence diagrams for a two product case are shown in Figure VII. For a cycle time of 10 the optimum solution is shown in Figure VIII. Notice that the line efficiencies are 73% and 100% for products 1 and 2 respectively. A computer assisted approach for multi-product Stochastic Line Balancing is described by Bedworth and Bailey.

Loss of efficiency over single product line but gain in equipment effectiveness is the trade off that must be evaluated in the mixed product line balance.

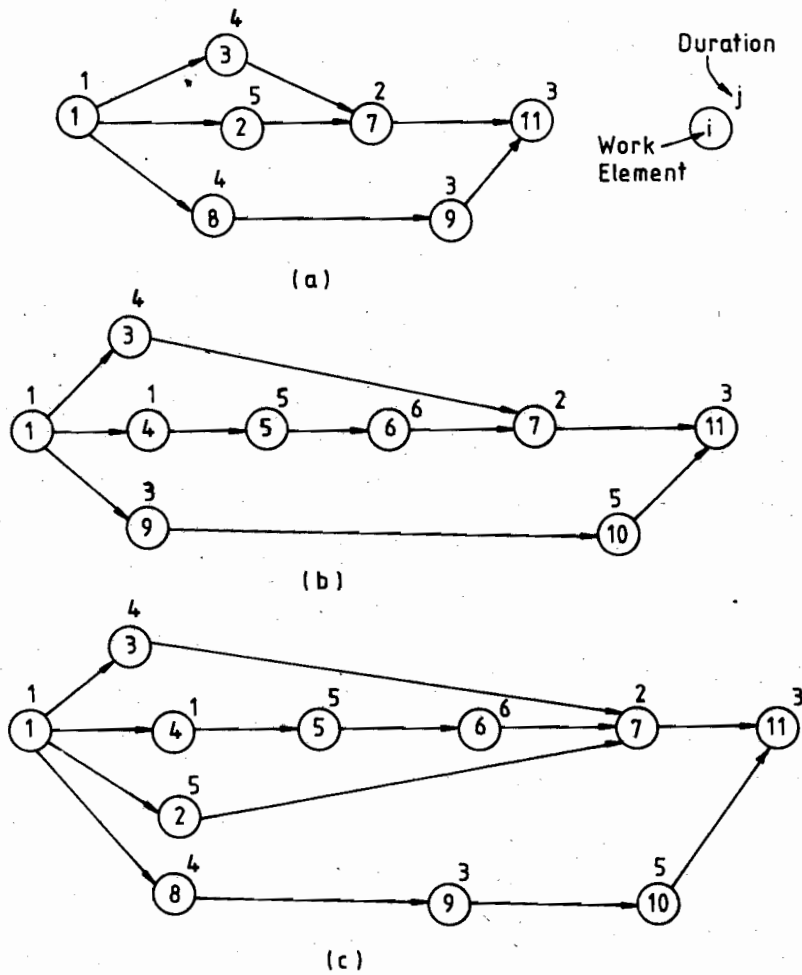
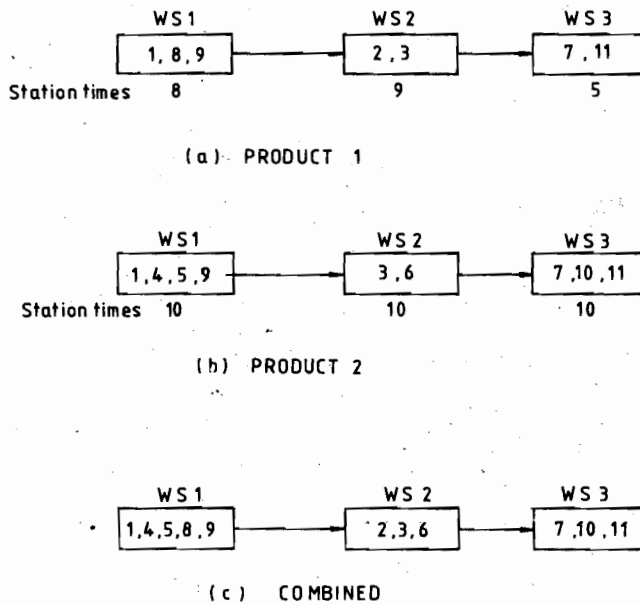


Figure VIII: Work Station Assignment for the Two Product Assembly Line



9.8 MODULAR PRODUCTION AND GROUP TECHNOLOGY

One criticism of manually operated assembly lines has been that they reduce a man to a mere cog in a machine. Surely you can imagine the boredom, monotony and fatigue of a man who spends all his time tightening the same bolt on a part in an assembly line. It has been found valuable to enlarge the scope of work of the worker so that he assembles a complete 'module', which in turn may be used on an assembly line to assemble a product or a number of different products sharing that particular module. This job enrichment results in greater job satisfaction for the operator by reducing the monotony of the job and giving the operator a sense of accomplishment for assembling a complete module. In modular production we tend to specialise in the production of particular parts or activities that can then be included as components of more than one product or service. The reason for wanting to achieve such commonality is that one part or operation, if used in several products or services, can accumulate sufficient demand volume to warrant investment in a flow shop.

Group technology provides another aspect of the same basic idea. It refers to specialisation in families of similar parts. Hence components requiring primarily turning operations, such as shafts, are collected in one group, while components requiring surface grinding and drilling operations, such as plates are assigned to a different group. These groups become the basis on which a traditional process plant layout can be reorganised into a group technology plant layout in which machines are arranged in such a way that each machine is assigned to the production of only one group of parts. Group technology typically affects only component manufacture, not the assembly stage of production.

For illustrative example of assembly lines using modular production and group technology refer to Salvendy.

9.9 AUTOMATION AND ROBOTICS

Mass production has been assisted to a large extent by automation and robotics in the recent past. Automation refers generally to the bringing together of three basic building blocks: machine tools, material handling and controls. Often a considerable amount of time is spent to load, machine and unload work and to convey it between the single operation machines. This restriction has been partly relieved by the development of the multiple spindle machine. With this machine, a single motor driving several spindles through a gear train allows multiple operations to be performed by one machine. Machining time cycle does not change, but more machining operations can be performed within each cycle. And several machining operations can be performed on one machine by a single operator.

Automatic work piece indexing and transfer of work pieces from station to station has made it possible for one operator to control the work performed at several machining stations. Also the operator is able to load and unload at the load station while machining was going on.

Another trend with automation has been the use of industrial robots to perform some of the functions that were earlier done by manual operators.

An 'industrial robot', as defined by the Robot Institute of America, is a programmable, multi-function manipulator designed to move material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks. What separates an industrial robot from other types of automation is the fact that it can be reprogrammed for different applications; hence a robot falls under the heading of 'flexible automation', as opposed to 'hard' or dedicated automation.

Industrial robots comprise three basic components:

- 1 The manipulator (or arm), which is a series of mechanical linkages and joints capable of movement in various directions to perform the work task.

- 2 The controller, which actually directs the movements and operations performed by the manipulator. The controller may be an integral part of the manipulator or may be housed in a separate cabinet.
- 3 The power source, which provides energy to the actuators on the arm. The power source may be electrical, hydraulic, or pneumatic.

Major reasons for use of robots in industry are increased productivity, adaptability, safety, ease of training, return on investment and greater reliability. Robots are currently in operation in welding and assembly, drilling and routing, inspection, material handling, machine loading, die casting and a variety of other applications.

9.10 SUMMARY

In this unit we have presented the concept of mass production which essentially involves the assembly of identical (or inter-changeable) parts of components into the final product in stages at various work stations. The relative advantages and disadvantages of mass or flow production are discussed and conditions favouring the installation of such a system are identified.

How to design an assembly line starting from the work breakdown structure to the final grouping of tasks at work stations is also discussed using two commonly used procedures—the Kilbridge-Wester heuristic approach and the Helgeson-Birnie approach. Various problems with assembly lines including variable work element times, breakdowns at work stations and multi-product line are discussed.

The concepts of modular production and group technology are introduced to indicate how flexibility can be introduced in mass or flow manufacture. Finally, the role of automation and the use of industrial robots in mass production has been discussed.

9.11 KEY WORDS

Assembly line: A sequence of work stations where parts or components of a product are progressively worked on to produce the finished product.

Balance delay: The total idle time of all stations as a percentage of total available working time of all stations in an assembly line.

Cycle time: The time after which a finished product comes off the assembly line. It would equal the time of the bottleneck operation or the maximum station time.

Fabrication line: A production line made up of machining or other operations rather than assembly of components or parts.

Flow shop: A manufacturing system in which machines and other facilities are arranged on the basis of product flow (generally used for large production volumes and less product variety).

Group technology: A manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and manufacture.

Job shop: A manufacturing system in which similar machines and equipment are clubbed in departments and each job handled takes its own route. (Generally used for low production volumes with great product variety.)

Line balancing: The problem of assigning tasks to work stations in an assembly line in a way that the task times for all stations are equalised as far as possible.

Line efficiency: The ratio of the actual working time at all stations of an assembly line to the total allocated time at all stations.

Mass production: A manufacturing system based on interchangeable parts and the concept of the division of labour to produce generally large quantities of a product through successive operations/assemblies carried out at a sequence of work stations in an assembly line.

Modular production: The principle employed in modular production is to design, develop and produce the minimum number of parts or operations (called 'modules') that can be combined in the maximum number of ways to offer the greatest number of products or services.

Precedence diagram: A diagram showing the elemental tasks and the order in which they may be performed. This specifies the technological and other restrictions that must be respected while designing an assembly line.

Production system: A means by which inputs (like men, machines, materials, money, information and energy) are transformed into useful goods or services.

Project: A typical production system where production is infrequent (often, only once) characterised by a number of related jobs to be done with precedence restrictions.

Smoothness index: The square root of the sum of squares of idle time at all work stations in an assembly line. This is an index to indicate the relative smoothness of a given assembly line balance.

Station time: The sum of the element times of all tasks allotted to a work station in an assembly line.

Work element: The smallest portion of work identified during the work breakdown analysis of a job. It is uneconomical or technologically absurd to further subdivide the work elements, in designing an assembly line.

Work station: A place or stage in an assembly line where designated work (a combination of work elements) is performed on the part or components of the product.

9.12 SELF-ASSESSMENT EXERCISES

- 1 What are the key elements of mass manufacture?
- 2 Draw a precedence diagram for changing a car tyre. Discuss the way in which this job could be done with a flow shop configuration. Suggest a possible division of labour that would produce a reasonable line balance.
- 3 Design an assembly line for a cycle time of 10 minutes for the following 10 work elements

Elements	1	2	3	4	5	6	7	8	9	10
Immediate Predecessors	—	1	1	2,3	4	4	6	5	7,8	9
Duration in minutes	5	10	5	2	7	5	10	2	5	7

Use

- a) Kilbridge and Wester method
- b) Helgeson and Birnie method.

Calculate the line efficiency, balance delay and smoothness index in both cases.

- 4 Repeat problem 3 for a cycle time of 12 minutes.
- 5 Why do we use buffers between stations in assembly lines?

What would be the implications of

- a) too large a buffer?
- b) too small a buffer?

Suggest a method by which the optimal buffer quantities could be found out.

- 6 An assembly line is relatively inflexible. Explain how by using the notion of modular production or group technology, flexibility can be attained in a flow shop configuration.
- 7 Consider the following situation:

A toy manufacturer intends to make 10,000 pieces per year in the 2000 hours of regular time each year. He has identified 16 work elements with the following precedence restrictions and durations.

Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Immediate Predecessors	—	1	2,15	3	4	5,12	6,16	1	8	9	10,14	11	8	13	1	5
Standard times (hrs./pc.)	.14	.01	.13	.12	.01	.10	.07	.06	.17	.17	.20	.17	.03	.09	.20	.05

- Draw a precedence diagram for the assembly of toys
- Design an assembly line suitable for the toy manufacturer
- Computer the line efficiency, balance delay and smoothness index for your design in (b) above.

9.13 FURTHER READINGS

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