

# Assembly Systems and Line Balancing

\*Discrete products are assembled from components.

## The Assembly Process

*Definition:* assembly involves the joining together of two or more separate parts to form a new entity (assembly or subassembly).

\*The processes used to accomplish the assembly of the components can be divided into three major categories.

### 1. Mechanical Fastening – Mechanical action to hold components together.

Threaded fasteners - screws, bolts, nuts etc.

Rivets, crimping and other methods

Press fits

Snap fits – temporary interface of the two parts C-ring.

Sewing and stitching – for soft, thin material.

### 2. Joining Methods – welding, brazing and soldering

### 3. Adhesive Bonding – thermoplastic, thermosetting (chemical reaction)

## Assembly Systems

\*There are various methods used in industry to accomplish the assembly processes. Major methods can be classified:

### **1. Manual Single-Station Assembly**

\*Consist of a single workplace to accomplish the product or some major subassembly of the product.

\*Generally used on a product that is complex and produced in small quantities, one or more workers depending on the size of the product and the production rate.

\*Such as machine tools, industrial equipment, aircraft, ships and complex consumer products (appliances, car,...)

### **2. Manual Assembly Lines**

\*Consist of multiple workstations in which the assembly work is accomplished as the product (subassembly) is passed from station to station along the line.

\*At each workstation one or more human workers perform a portion of the total assembly work on the product, by adding one or more components to the existing subassembly.

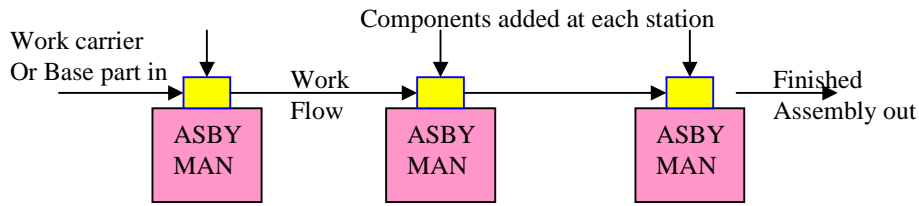
### **3. Automated Assembly System**

\*Use of automated methods at the workstations rather than human beings.

## I. Manual Assembly Lines

✳️ Are used in high-production situations where the work to be performed can be divided into small tasks and tasks assigned to the workstations on the line.

✳️ Key advantage of using manual assembly line is specialization of labor – By giving each worker a limited set of tasks to do repeatedly.



## Transfer of Work Between Workstations

\*There are two basic ways in which the work is moved on the line between operator workstations.

### 1. Non mechanical Lines

\*No belt or conveyor is used to move the parts. The parts are passed from station to station by hand.

#### **Problems:**

✘ Starving at stations – wait for parts from the preceding station.

✘ Blocking of station – wait for the next operator to finish the task before passing along the part.

#### **Results:**

✘ the flow of work is usually uneven

✘ cycle time vary

✘ buffer stocks of parts between workstations are often used to smooth out the production flow.

### 2. Moving Conveyer Lines

Use a moving conveyer (e.g. belt, convey, chain-in-the-floor)

#### **Problems:**

✘ Starving can occur as with none-mechanical lines

✘ Incomplete items are sometimes produced – unable to finish the current part.

To control the feed rate of the line:

$F_p$ : denote feed rate

$V_c$ : conveyer speed

$S_p$ : Spacing between parts on the moving conveyer

$$F_p = V_c / S_p$$

The time period (tolerance time)  $T_t$

$L_s$ : is determined largely by the operator's reach at the workstation

$$T_t = L_s / V_c$$

## II. The Line Balancing Problem

\*The line balancing problem is to arrange the individual processing and assembly tasks at the workstations so that the total time required at each workstation is approximately the same.

\*If the work elements can be grouped so that all the station times are exactly equal, we have perfect balance on the line and we can expect the production to flow smoothly.

\*In most practical situations it is very difficult to achieve perfect balance. When workstation times are unequal, the slowest station determines the overall production rate of the line.

### Terminology for Line Balancing

#### • *Minimum Rational Work Element*

\*Minimum rational work element is the smallest practical indivisible tasks into which the job can be divided. These work elements cannot be subdivided further

\*Example: drilling a hole, screw and nut etc.

\* $T_{ej}$ : where  $j$  is used to identify the element out of the  $n_e$  elements that make up the total work.

- *Total Work Content*

\*Total work,  $T_{wc}$ , content is the aggregate of all the work elements to be done on the line.

$$T_{wc} = \sum_{j=1}^{n_e} T_{ej}$$

- *Workstation Process Time*

\*Work is performed either manually or by some automatic device. The work performed at station consists of one or more of the individual work elements.

\* $T_{si}$ : indicate the process time at station  $i$  of an  $n$  stations line.

$$\sum_{i=1}^n T_{si} = \sum_{j=1}^{n_e} T_{ej}$$

- *Cycle Time*

\*Cycle time,  $T_c$ , is the ideal or theoretical cycle time of the flow line, which is the time interval between parts coming off the line.

\*When consider efficiency,  $E$ , the ideal cycle time must be reduce.

$$T_c \leq E / R_p$$

Where  $R_p$  is production rate.

\*At efficiencies less than 100% the ideal cycle time must be reduced (or ideal production rate must be increased).

\* The minimum possible value of  $T_c$  is established by the bottleneck station, the one with the largest value of  $T_s$ .

$$T_c \geq \max. T_{si}$$

$$T_c \geq T_{ej}$$

- *Precedence Constraints*

\*Technological sequencing requirements, the order in which the work elements can be accomplished is limited.

- *Precedence Diagram*

\*A graphical representation of the sequence of work elements as defined by the precedence constraints.

- *Balance Delay (Balancing Loss)*

\*Balance delay is a measure of the line inefficiency which results from idle time due to imperfect allocation of work among station.

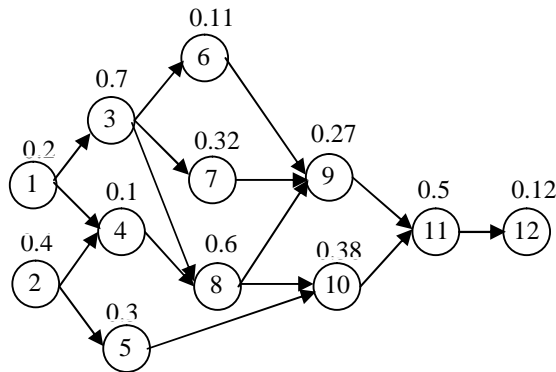
$$d = \frac{nT_c - T_{wc}}{nT_c}$$

**Example:** Work Elements (Small electrical appliance)

No.	Element Description	$T_{ej}$ (min.)	Must be Precedence by
1	Place frame on work holder and clamp	0.2	---
2	Assemble plug, grommet to power cord	0.4	---

3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1,2
5	Wire power cord to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to bracket	0.6	3,4
9	Align blade and attach to motor	0.27	6,7,8
10	Assemble switch to motor bracket	0.38	5,8
11	Attach cover, inspect, and test	0.5	9,10
12	Place in tote pan for packing	0.12	11

### Precedence Diagram



### III. Method of Line Balancing - (Manual)

\*None of the methods guarantee an optimal solution, but they are likely to result in good solutions which approach the true optimum.

#### 1. Largest-Candidate Rule (LCR)

##### Procedure:

Step 1. List all elements in descending order of  $T_e$  value, largest  $T_e$  at the top of the list.

Step 2. To assign elements to the first workstation, start at the top of the list and work done, selecting the first feasible element for placement at the station. A feasible element is one that satisfies the precedence requirements and does not cause the sum of the  $T_{ej}$  value at station to exceed the cycle time  $T_c$ .

Step 3. Repeat step 2.

##### Example for Largest-Candidate Rule (LCR)

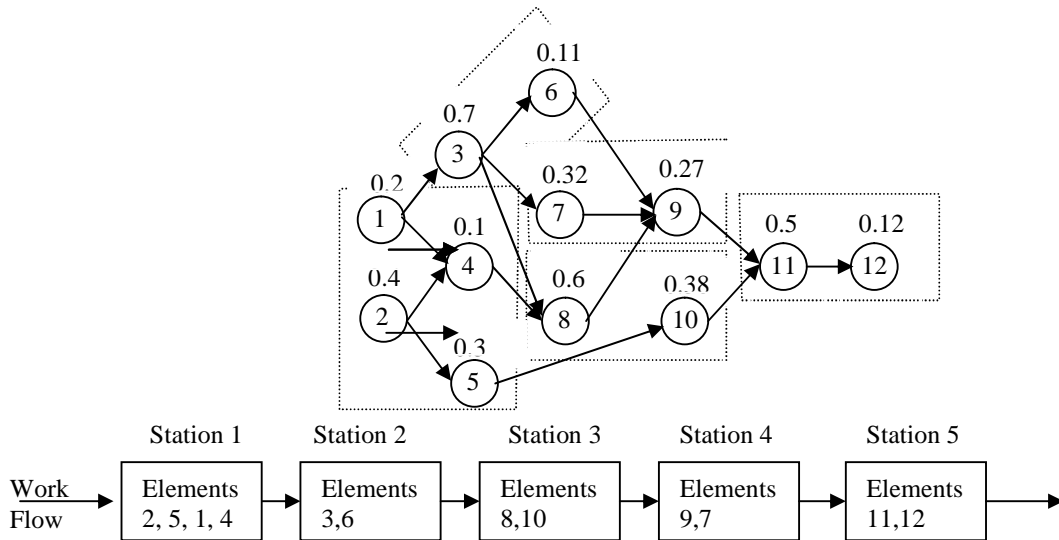
##### Step 1.

Work element	$T_e$	Immediate predecessor
3	0.7	1
8	0.6	3,4
11	0.5	9,10
2	0.4	---
10	0.38	5,8
7	0.32	3
5	0.3	2
9	0.27	6,7,8
1	0.2	---
12	0.12	11

6	0.11	3
4	0.1	1,2

**Step 2, 3.** If we assume  $T_c = 1.00$  min.

Station	Element	$T_e$	$\Sigma T_e$ at station
1	2	0.4	1.00
	5	0.3	
	1	0.2	
	4	0.1	
2	3	0.7	0.81
	6	0.11	
3	8	0.6	0.98
	10	0.38	
4	7	0.32	0.59
	9	0.27	
5	11	0.5	0.62
	12	0.11	



## 2. Kilbridge and Wester's Method (KWM)

\*It is a heuristic procedure which selects work elements for assignment to stations according to their position in the precedence diagram.

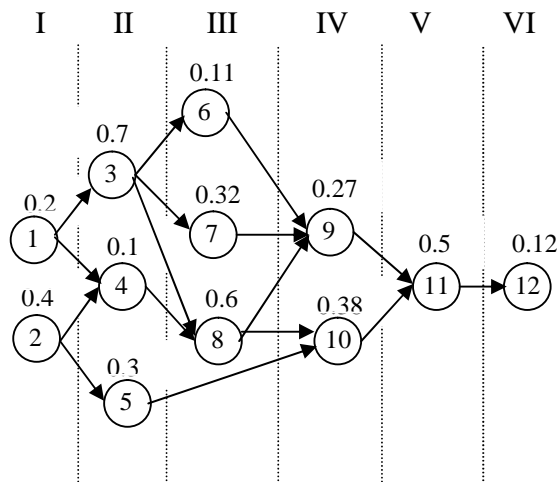
\*This overcomes one of the difficulties with the largest candidate rule (LCR), with which elements at the end of the precedence diagram might be the first candidates to be considered, simply because their values are large.

### Procedure:

- Step 1. Construct the precedence diagram so those nodes representing work elements of identical precedence are arranged vertically in columns.
- Step 2. List the elements in order of their columns, column I at the top of the list. If an element can be located in more than one column, list all columns by the element to show the transferability of the element.
- Step 3. To assign elements to workstations, start with the column I elements. Continue the assignment procedure in order of column number until the cycle time is reached ( $T_c$ ).

### Example for this method:

#### Step 1.



**Step 2.** Work elements arranged according to columns

Work element	Column	$T_e$	Sum of Column $T_e$
1	I	0.2	
2	I	0.4	0.6
3	II	0.7	
4	II	0.1	
5	II,III	0.3	1.1
6	III	0.11	
7	III	0.32	
8	III	0.6	1.03
9	IV	0.27	
10	IV	0.38	0.65
11	V	0.5	
12	V	0.12	0.62

**Step 3.** Work elements assigned to stations

Station	Element	$T_e$	$\Sigma T_e$ at station
1	1	0.2	
	2	0.4	
	4	0.1	
	5	0.3	1.00
2	3	0.7	
	6	0.11	0.81
	7	0.32	
3	8	0.6	0.92
4	9	0.27	
	10	0.38	0.65
5	11	0.5	
	12	0.11	0.62

\*Also, for stations that do have the same elements the sequence in which the elements are assigned is not necessary identical.

\*The balance delay is same as LCR  $d = 20\%$ .

### 3. Ranked Positional Weights Method (RPW)

\*Introduced by Helgeson and Birnie in 1961.

\*Combined the LCR and K-W methods.

\*The RPW takes account of both the  $T_e$  value of the element and its position in the precedence diagram. Then, the elements are assigned to workstations in the general order of their RPW values.

**Procedure:**

Step 1. Calculate the RPW for each element by summing the elements  $T_e$  together with the  $T_e$  values for all the elements that follow it in the arrow chain of the precedence diagram.

Step 2 List the elements in the order of their RPW, largest RPW at the top of the list. For convenience, include the  $T_e$  value and immediate predecessors for each element.

Step 3. Assign elements to stations according to RPW, avoiding precedence constraint and time cycle violations.

**Example for this method:**

**Step 1.** Sample calculation:

\*For element 1, the elements that follow it in the arrow chain are 3, 4, 6, 7, 8, 9, 10, 11, and 12.

\*The RPW for element 1 would be the sum of the  $T_e$ 's for all these elements, plus  $T_e$  for element 1.

**Step 2.**

Work element	RPW	$T_e$	immediate predecessors
1	3.3	0.2	-
3	3	0.7	1
2	2.67	0.4	-
4	1.97	0.1	1,2
8	1.87	0.6	3,4
5	1.3	0.3	2
7	1.21	0.32	3
6	1.00	0.11	3
10	1.00	0.38	5,8
9	0.89	0.27	6,7,8
11	0.62	0.5	9,10
12	0.12	0.12	11

**Step 3.** Work element assigned to stations

Station	Element	$T_e$	$\Sigma T_e$ at station
1	1	0.2	
	3	0.7	0.9
2	2	0.4	
	4	0.1	
	5	0.3	
	6	0.11	0.91
3	8	0.6	
	7	0.32	0.92
4	10	0.38	
	9	0.27	0.65
5	11	0.5	
	12	0.11	0.62

\*In the RPW line balance, the number of stations required is five, but the max. station process time is 0.92 minute, at number. According the line could be operated at a cycle time of  $T_c = 0.92$  rather than 1.0 minute.

**Benefit:**

1. Increase the production rate

$$R_c = 1 / 0.92 = 1.075 \text{ units/min.}$$

2. Balance delay

$$d = [5 (0.92) - 4] / [5 (0.92)] = 0.13 = 13\%$$

#### 4. Compare LCR, K-W, and RPW

\*The RPW solution represents a more efficient assignment of work elements to station than either of the two preceding solutions.

\*However, this result is accordingly by the acceptance of cycle time  $T_c = 1$  and make those methods different.

\*If the problem were reworked with  $T_c = 0.92$  minute, it might be possible to duplicate the efficiency.

#### 5. Other Ways to Improve the Line Balance

##### 1. Dividing work elements

\*A minimum rational work element was defined as the smallest practical indivisible task.

\*For example:

Drilling of a deep hole at one station was to cause a bottleneck situation should be separated into two steps.

\*Advantages- eliminates the bottleneck and increases the tool life.

##### 2. Changing work lead speeds at automatic stations

\*Through a process increasing the speed/feed combinations at the stations with long process time, and reducing the speed/feed combinations at stations with idle time.

##### 3. Method analysis

\*The study of human work activity may result in better workplace layout, redesigned tooling and fixturing or improved hand and body motions.

##### 4. Pre-assembly of components

\*Reduce the total amount of work done on the regular assembly line by another assembly cell or by purchasing.

a. Required process may be difficult to implement on the regular assembly line.

b. Variations in process times (adjustments or fitting)

##### 5. Inventory buffers between stations

##### 6. Parallel stations.

\*Disregard the stations must be arranged sequentially.

**\*Illustrate:**

a. Suppose that a five station line had station process times of 1 min at all but the fifth station is 2 minutes.

b. Then the production rate  $R_c = 30$  units/hr, if two station were arranged in parallel at the fifth station, the output could be increase  $R_c = 60$  units/hr.

**For example:**

Station	Element	$T_e$	$\sum T_e$ at station
	1	0.2	
1	2	0.4	
2	3	0.7	
	4	0.1	
	8	0.6	2.00
<u>3</u>	5	0.3	
	6	0.11	
	7	0.32	
	9	0.27	1.00
4	10	0.38	
	11	0.5	
	12	0.11	1.00

