Manual Assembly Lines

L-18

Contents

Factors Favoring the use of manual assembly lines include the following

a) Demand for the product is high or medium
b) The products made on the line are identical or similar
c) The total work required to assemble the product can be divided into small work elements
d) It is technologically impossible or economically infeasible to automate the assembly operations

Reasons why manual assembly lines are so productive compared with alternative methods

1) Specialization of labor
2) Interchangeable parts
3) Work principle
4) Line pacing

Products usually made on manual assembly lines:

Audio equipment	Lamps	Refrigerators
Automobiles	Luggage	Stoves
Cameras	Microwave ovens	Telephones
Cooking ranges	Personal computers and peripherals (printers, monitors, etc.)	Toasters
Dishwashers		Toaster ovens
Dryers (laundry)		Trucks, light and heavy
Electric motors	Power tools (drills, saws, etc.)	Video cassette players
Furniture	Pumps	Washing machines (laundry)

Fundamentals of Manual Assembly Lines

- It is a production line that consists of a sequence of workstations where assembly tasks are performed by human workers.
- Products are assembled as they move along the line
- At each station, a portion of the total work is performed on each unit
- The common practice is to launch base parts onto the beginning of the line at regular intervals. Each base part travels through successive stations and workers add components that progressively build the product

Diagram- manual assembly line

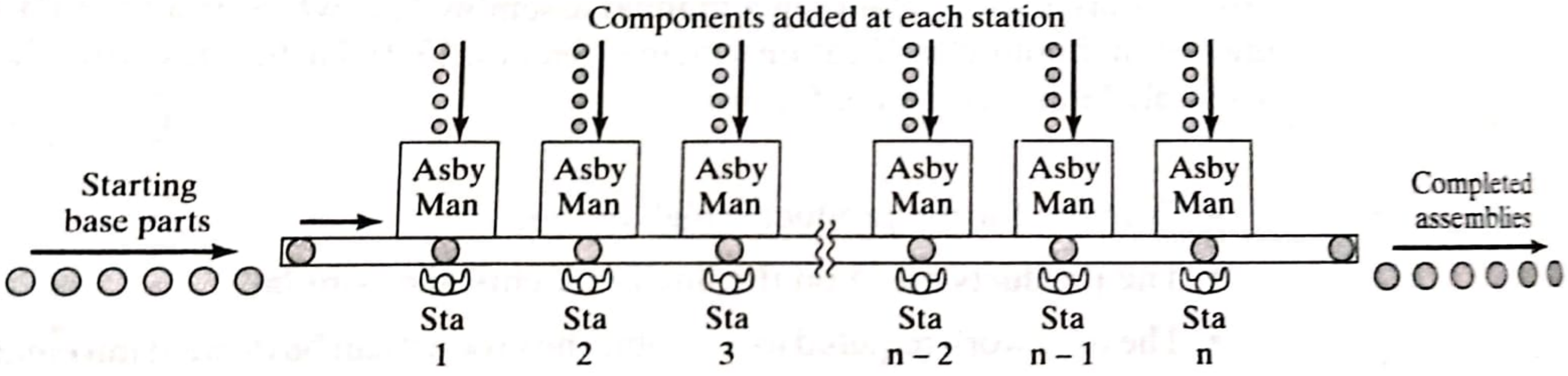


Figure 17.1 Configuration of a production line. Key: Asby = assembly, Man = manual, Sta = workstation, n = number of stations on the line.

a) Assembly Workstations

- A workstation on a manual assembly line is a designated location along the work flow path at which one or more work elements are performed by one or more workers

TABLE 17.2 Typical Assembly Operations Performed on a Manual Assembly Line

Application of adhesive	Riveting
Application of sealants	Shrink fitting applications
Arc welding	Snap fitting of two parts
Brazing	Soldering
Cotter pin applications	Spotwelding
Expansion fitting applications	Stapling
Insertion of components	Stitching
Press fitting	Threaded fastener applications

Source: See Groover [13] for definitions.

b) Work Transport Systems

- There are two basic ways to accomplish the movement of work units along a manual assembly line:

(1) Manually (2) by mechanized system

Mechanized transport systems used in production lines

(a) Continuous transport (b) Synchronous transport (c) Asynchronous transport

TABLE 17.3 Material Handling Equipment Used to Obtain the Three Types of Fixed Routing Work Transport Depicted in Figure 17.2

Work Transport System	*Material Handling Equipment (Text Reference)*
Continuous transport	Overhead trolley conveyor (Section 10.4) Belt conveyor (Section 10.4) Roller conveyor (Section 10.4) Drag chain conveyor (Section 10.4)
Synchronous transport	Walking beam transport equipment (Section 18.1.2) Rotary indexing mechanisms (Section 18.1.2)
Asynchronous transport	Power–and–free overhead conveyor (Section 10.4) Cart–on–track conveyor (Section 10.4) Powered roller conveyors (Section 10.4) Automated guided vehicle system (Section 10.2) Monorail systems (Article 10.3) Chain–driven carousel systems (Section 11.4.2)

Source: Text reference given in parentheses.

c) Line Pacing

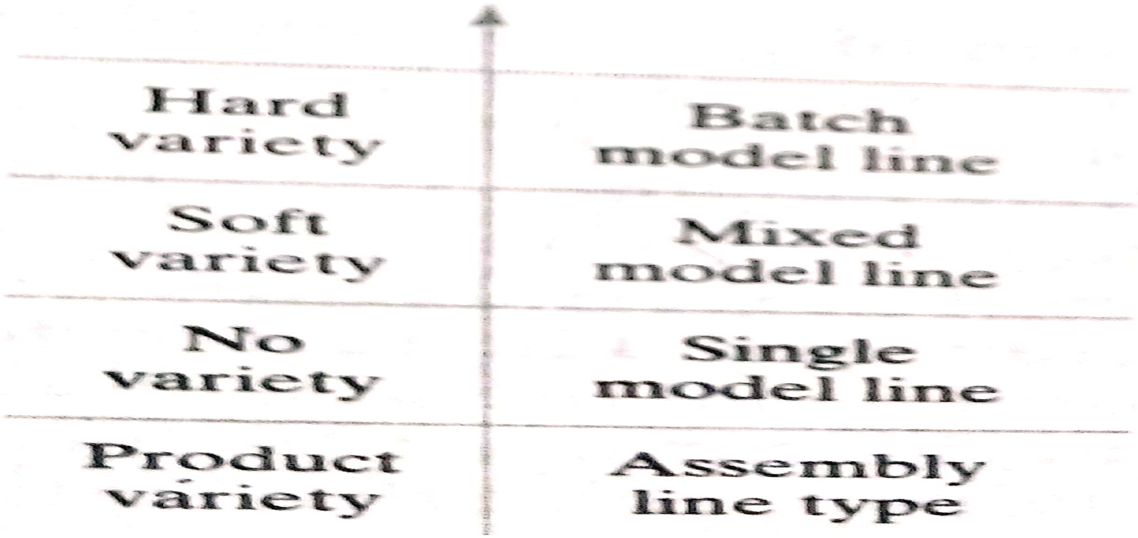
- A manual assembly line operates at a certain cycle time, which is established to achieve the required production rate of the line.
- On average, each worker must complete the assigned task at his/her station within this cycle time, or else the required production rate will not be achieved
- Manual assembly lines can be designed with three alternative levels of pacing

(i) Rigid pacing (ii) pacing with margin (iii) no pacing

d) Coping with Product Variety

- Because of the versatility of human workers, manual assembly lines can be designed to deal with differences in assembled products.
- Three types of assembly line can be distinguished as

(i) Single model (ii) batch model (iii) Mixed model



2) Alternative Assembly system

- Assembly line workers often complain about the monotony of the repetitive tasks they must perform and the unrelenting pace they must maintain when moving conveyor is used.
- Alternative assembly systems are available in which either the work is made less monotonous and repetitious by enlarging the scope of the tasks performed or the work is automated.
- The three types of alternative assembly systems are:

(i) Single-station manual assembly cells

(ii) Assembly cells based on worker teams

(iii) Automated assembly systems

3) Design for Assembly

- Design for assembly (DFA) has received much attention in recent years because assembly operations constitute a high labor cost for many manufacturing companies. The key to successful design for assembly can be simply stated

(i) Design the product with as few parts as possible

(ii) Design the remaining parts so they are easy to assemble

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Some important general principles of design for assembly, compiled from several sources. They apply to both manual and automated operations and their goal is to achieve the required design function by the simplest and lowest cost means:

(i) Use the fewest number of parts possible to reduce the amount of assembly required

(ii) Reduce the number of threaded fasteners required

(iii) Standardize fasteners

(iv) Reduce parts orientation difficulties

(v) Avoid parts that tangle

4) Analysis of Single Model Assembly Lines

Several factors that exist in the real assembly line. These Factors which tend to increase the number of workers above the theoretical minimum value are:

(i) Repositional losses: Some time will lost at each station for repositioning of the work unit or the worker. Thus, the time available per worker to perform assembly is less than T_c

(ii) The line balancing problem: It is virtually impossible to divide the work content time evenly among all workstations. Some stations are bound to have an amount of work that requires less time than T_c. This tends to increase the number of workers

(iii) Task time variability: There is inherent and unavoidable variability in the time required by a worker to perform a given assembly task. Extra time must be allowed for this variability

(iv) Quality problem: Defective components and other quality problems cause delays and rework that add to the workload.

Line Balancing problem

EXAMPLE 17.1 A Problem for Line Balancing

A small electrical appliance is to be produced on a single model assembly line. The work content of assembling the product has been reduced to the work elements listed in Table 17.4. The table also lists the standard times that have been established for each element as well as the precedence order in which they must be performed. The line is to be balanced for an annual demand of 100,000 unit/yr. The line will operate 50 wk/yr, 5 shifts/wk, and 7.5 hr/shift. Manning level will be one worker per station. Previous experience suggests that the uptime efficiency for the line will be 96%, and repositioning time lost per cycle will be 0.08 min. Determine: (a) total work content time T_{wc}, (b) required hourly production rate R_p to achieve the annual demand, (c) cycle time T_c, (d) theoretical minimum number of workers required on the line, and (e) service time T_s to which the line must be balanced.

TABLE 17.4 Work Elements for Example 17.1

No.	*Work Element Description*	T_{ek} *(min)*	*Must Be Preceded By*
1	Place frame in workholder 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 brackets	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

Solution: (a) The total work content time is the sum of the work element times in Table 17.4.

$$T_{wc} = 4.0 \text{ min}$$

(b) Given the annual demand, the hourly production rate is

$$R_p = \frac{100{,}000}{50(5)(7.5)} = 53.33 \text{ units/hr}$$

(c) The corresponding cycle time T_c with an uptime efficiency of 96% is

$$T_c = \frac{60(0.96)}{53.33} = 1.08 \text{ min}$$

(d) The theoretical minimum number of workers is given by Eq. (17.9):

$$w^* = \left(\text{Min Int} \geq \frac{4.0}{1.08} = 3.7\right) = 4 \text{ workers}$$

(e) The available service time against which the line must be balanced is

$$T_s = 1.08 - 0.08 = 1.00 \text{ min.}$$

5) Line balancing algorithms

The objective in line balancing is to distribute the total workload on the assembly line as evenly as possible among the workers. The objective can be expressed mathematically

$$\text{Minimize } (wT_s - T_{wc}) \text{ or Minimize } \sum_{i=1}^{w} (T_s - T_{si})$$

a) Largest candidate rule

17.5.1 Largest Candidate Rule

In this method, work elements are arranged in descending order according to their T_{ek} values, as in Table 17.5. Given this list, the algorithm consists of the following steps: (1) assign elements to the worker at the first workstation by starting at the top of the list and selecting the first element that satisfies precedence requirements and does not cause the total sum of T_{ek} at that station to exceed the allowable T_s; when an element is selected for assignment to the station, start back at the top of the list for subsequent assignments; (2) when no more elements can be assigned without exceeding T_s, then proceed to the next station; (3) repeat steps 1 and 2 for the other stations in turn until all elements have been assigned.

TABLE 17.5 Work Elements Arranged According to T_{ek} Value for the Largest Candidate Rule

Work Element	*T_{ek} (min)*	*Preceded By*
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

EXAMPLE 17.2 Largest Candidate Rule

Apply the largest candidate rule to Example Problem 17.1.

Solution: Work elements are arranged in descending order in Table 17.5, and the algorithm is carried out as presented in Table 17.6. Five workers and stations are required in the solution. Balance efficiency is computed as:

TABLE 17.6 Work Elements Assigned to Stations According to the Largest Candidate Rule

Station	*Work Element*	*T_{ek} (min)*	*Station Time (min)*
1	2	0.4	
	5	0.3	
	1	0.2	
	4	0.1	1.0
2	3	0.7	
	6	0.11	0.81
3	8	0.6	
	10	0.38	0.98
4	7	0.32	
	9	0.27	0.59
5	11	0.5	
	12	0.12	0.62

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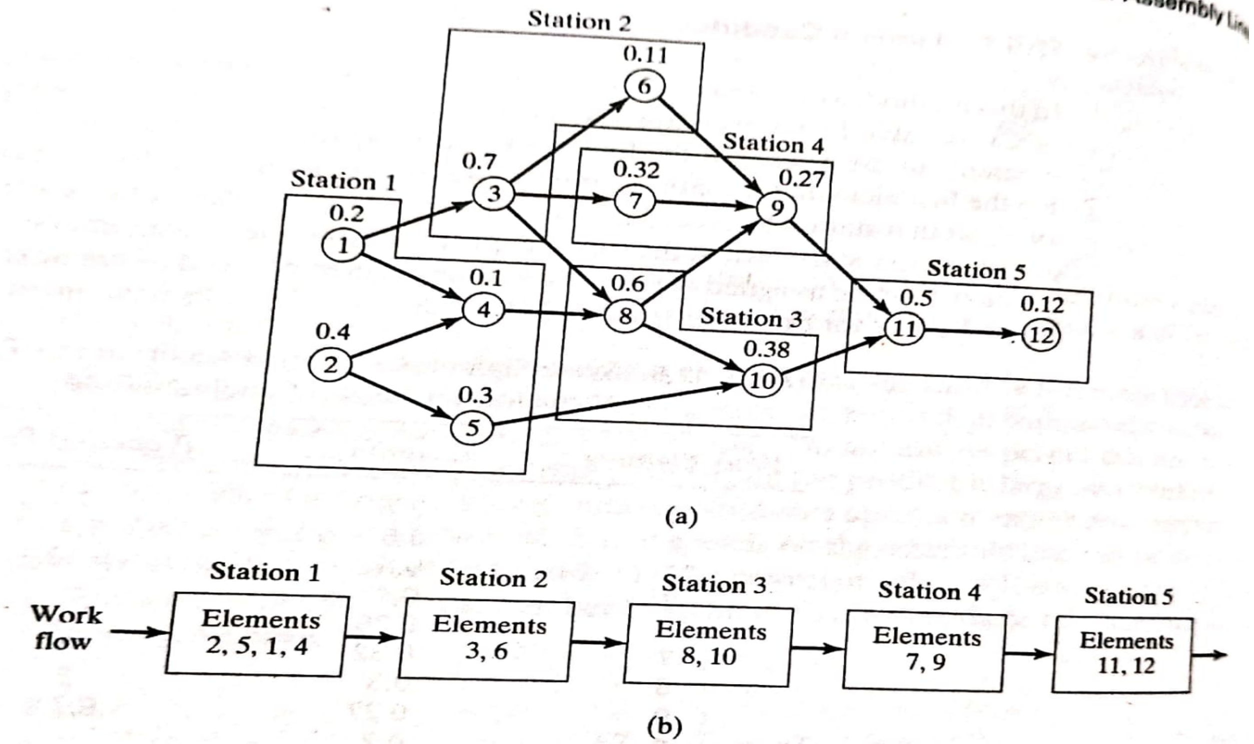

Figure 17.6 Solution for Example 17.2, which indicates: (a) assignment of elements according to the largest candidate rule and (b) physical sequence of stations with assigned work elements.

b) Kilbridge and Wester Method

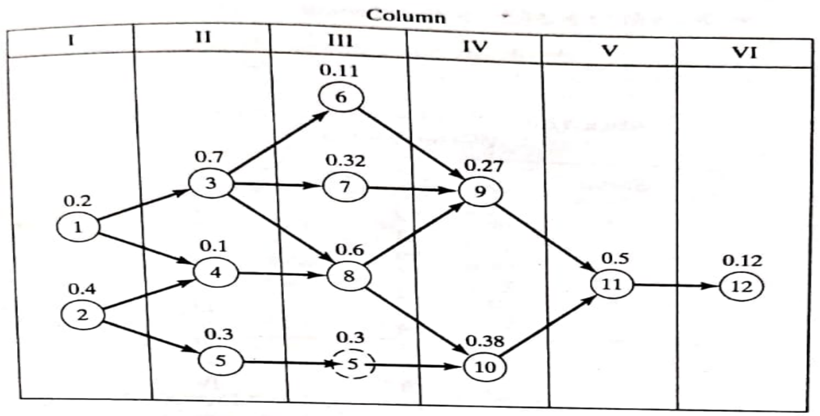

Figure 17.7 Work elements in example problem arranged into columns for the Kilbridge and Wester method.

TABLE 17.7 Work Elements Listed According to Columns from Figure 17.7 for the Kilbridge and Wester Method

Work Element	*Column*	T_{ek} *(min)*	*Preceded By*
2	I	0.4	–
1	I	0.2	–
3	II	0.7	1
5	II, III	0.3	2
4	II	0.1	1,2
8	III	0.6	3,4
7	III	0.32	3
6	III	0.11	3
10	IV	0.38	5,8
9	IV	0.27	6,7,8
11	V	0.5	9,10
12	VI	0.12	11

we have done in the case of element 5. In our list, we have added the feature that elements in a given column are presented in the order of their T_{ek} value; that is, we have applied the largest candidate rule within each column. This is helpful when assigning elements to stations, because it ensures that the larger elements are selected first, thus increasing our chances of making the sum of T_{ek} in each station closer to the allowable T_c limit. Once the list is established, the same three-step procedure is used as before.

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EXAMPLE 17.3 Kilbridge and Wester Method

Apply the Kilbridge and Wester method to Example Problem 17.1.

TABLE 17.8 Work Elements Assigned to Stations According to the Kilbridge and Wester Method

Station	*Work Element*	*Column*	T_{ek} *(min)*	*Station Time (min)*
1	2	I	0.4	
	1	I	0.2	
	5	II	0.3	
	4	II	0.1	1.0
2	3	II	0.7	
	6	III	0.11	0.81
3	8	III	0.6	
	7	III	0.32	0.92
4	10	IV	0.38	
	9	IV	0.27	0.65
5	11	V	0.5	
	12	VI	0.12	0.62

Solution: Work elements are arranged in order of columns in Table 17.7. The Kilbridge and Wester solution is presented in Table 17.8. Five workers are again required, and the balance efficiency is once more $E_b = 0.80$. Note that although the balance efficiency is the same as in the largest candidate rule, the allocation of work elements to stations is different.

C) Ranked Positional Weights Method

17.5.3 Ranked Positional Weights Method

The ranked positional weights method was introduced by Helgeson and Birnie [14]. In this method, a ranked positional weight value (call it RPW for short) is computed for each element. The RPW takes into account both the T_{ek} value and its position in the precedence diagram. Specifically, RPW_k is calculated by summing T_{ek} and all other times for elements that follow T_{ek} in the arrow chain of the precedence diagram. Elements are compiled into a list according to their RPW value, and the algorithm proceeds using the same three steps as before.

EXAMPLE 17.4 Ranked Positional Weights Method

Apply the ranked positional weights method to Example Problem 17.1.

Solution: The RPW must be calculated for each element. To illustrate,

$$RPW_{11} = 0.5 + 0.12 = 0.62$$

$$RPW_8 = 0.6 + 0.27 + 0.38 + 0.5 + 0.12 = 1.87$$

Work elements are listed according to RPW value in *Table 17.9*. Assignment of elements to stations proceeds with the solution presented in *Table 17.10*. Note that the largest T_s value is 0.92 min. This can be exploited by operating the line

Contd.

TABLE 17.9 List of Elements Ranked According to Their Ranked Positional Weights (RPW)

Work Element	*RPW*	T_{ek} *(min)*	*Preceded By*
1	3.30	0.2	–
3	3.00	0.7	1
2	2.67	0.4	–
4	1.97	0.1	1,2
8	1.87	0.6	3,4
5	1.30	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

TABLE 17.10 Work Elements Assigned to Stations According to the Ranked Positional Weights (RPW) Method

Station	*Work Element*	T_{ek} *(min)*	*Station Time (min)*
1	1	0.2	
	3	0.7	0.90
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	0.12	0.62

at this faster rate, with the result that line balance efficiency is improved and production rate is increased.

$$E_b = \frac{4.0}{5(.92)} = 0.87$$

The cycle time is $T_c = T_s + T_r = 0.92 + 0.08 = 1.00$; therefore,

$$R_c = \frac{60}{1.0} = 60 \text{ cycles/hr, and from Eq. (17.6), } R_p = 60 \times 0.96 = 57.6 \text{ units/hr}$$

This is a better solution than the previous line balancing methods provided. It turns out that the performance of a given line balancing algorithm depends on the problem to be solved. Some line balancing methods work better on some problems, while other methods work better on other problems.

d) Computerized Techniques

Rapidly executed computer programs, these algorithms are still heuristic and do not guarantee an optimum solutions. Attempts have been made to exploit the high speed of the digital computer by developing algorithms that either

(i) Perform a more exhaustive search of the set of solutions to a given problems

(ii) Utilize some mathematical optimization technique to solve it.

6) Mixed Model Assembly Lines

a) Determining workers on the line
b) Mixed model line balancing
c) Model launching in mixed model lines

7) Other considerations in assembly line design

Factors some of which may improve line performance beyond what the balancing algorithms provide. Following are considerations.

(i) Methods analysis
(ii) Subdividing work elements
(iii) Sharing work elements between two adjacent stations
(iv) Utility workers
(v) Changing workhead speeds at mechanized stations
(vi) Preassembly of components
(vii) Storage buffers between stations
(viii) Zoning and other constraints
(ix) Parallel workstations