APSCIM 4e

IE 469 Manufacturing Systems

Automated Assembly Systems

APSCIM 4e

Outlines

1. Fundamentals of Automated Assembly Systems

2. Analysis of Automated Assembly Systems

Automated Assembly - Defined

- The use of mechanized and automated devices to perform the various assembly tasks in an assembly line or cell.

- Fixed automation usually
  - Most automated assembly systems are designed to perform a fixed sequence of assembly steps on a specific product that is produced in very large quantities

Automated Assembly - Application Characteristics

- Where is automated assembly appropriate:
  - High product demand
  - Stable product design
  - The assembly consists of no more than a limited number of components
  - The product is designed for automated assembly

APSCIM 4e

Typical Products

Alarm clocks
Ball bearings
Ball point pens
Cigarette lighters
Door mechanisms
Gear boxes
Light bulbs
Locks
Mechanical pencils
PCB assemblies
Small electric motors
Wrist watches

APSCIM 4e

Assembly Processes in Automated Assembly

Adhesive bonding
Insertion of components
Placement of components
Riveting
Screw fastening
Snap fitting
Soldering
Spot welding
Stapling
Stitching

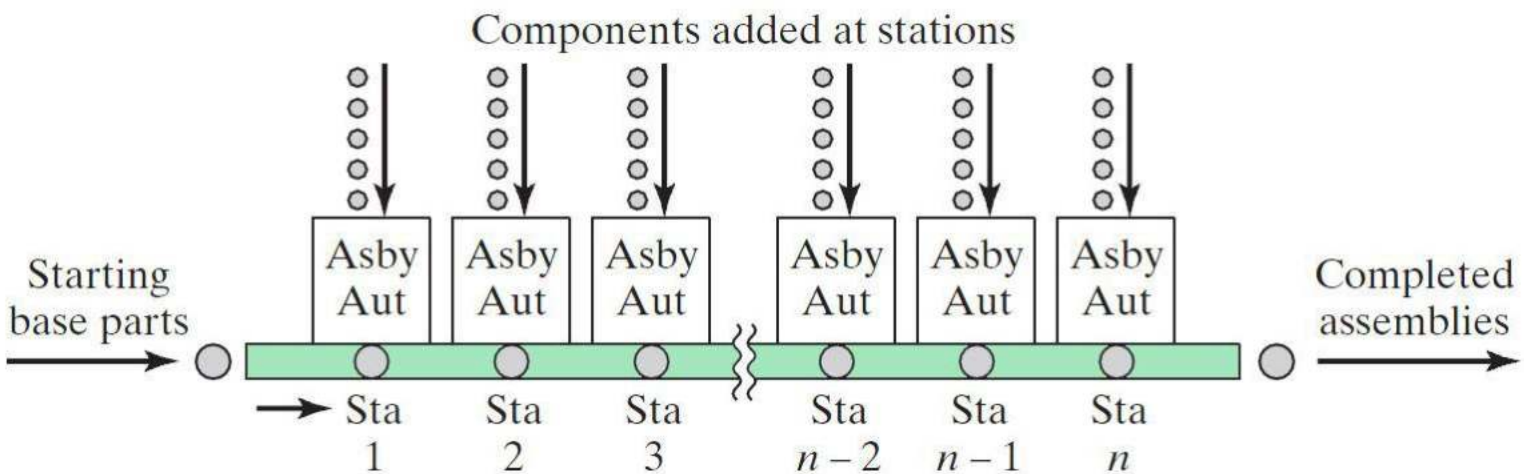
System Configurations

1. In-line assembly machine
2. Dial indexing machine
3. Carousel assembly system
4. Single-station assembly cell

In-Line Assembly Machine

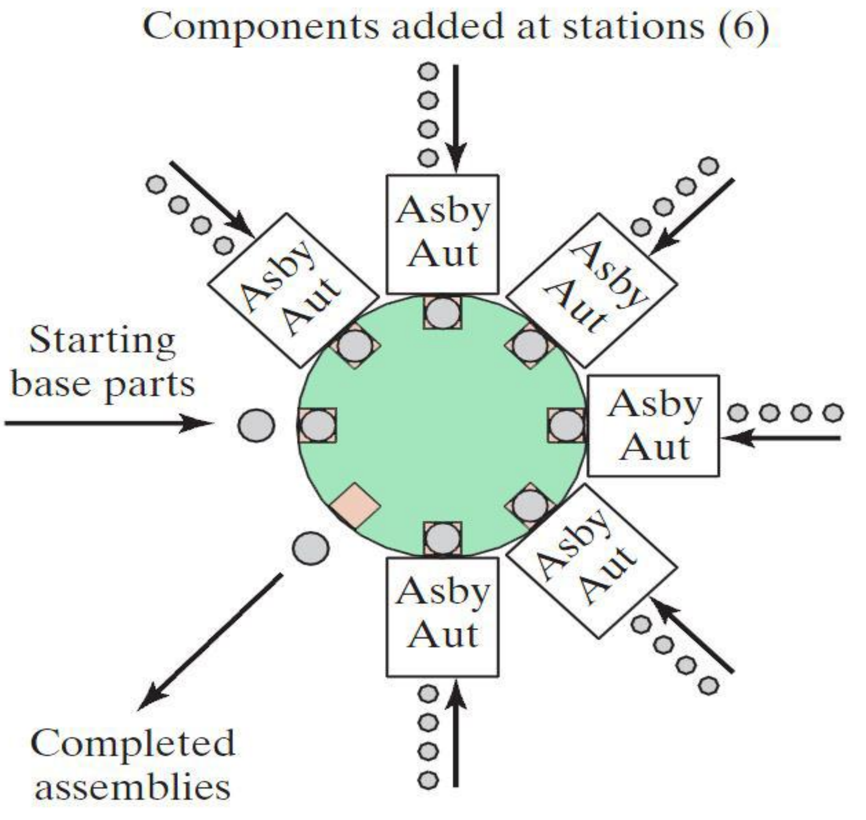
- A series of automatic workstations located along and in-line transfer system

  - Either synchronous or asynchronous work transfer used



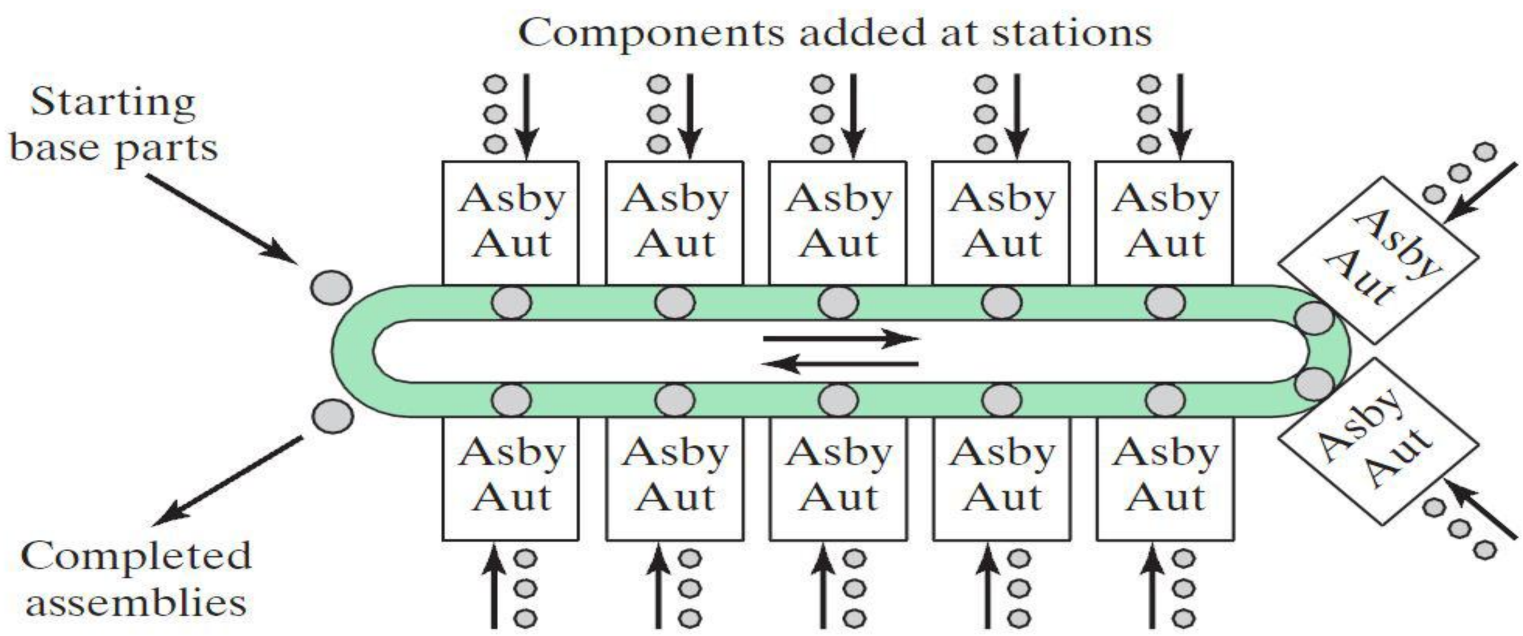
Dial Indexing Machine

- Base parts are loaded onto fixtures or nests attached to a circular dial table, and components are added at workstations located around the periphery of the dial as it indexes from station to station.



Carousel Assembly System

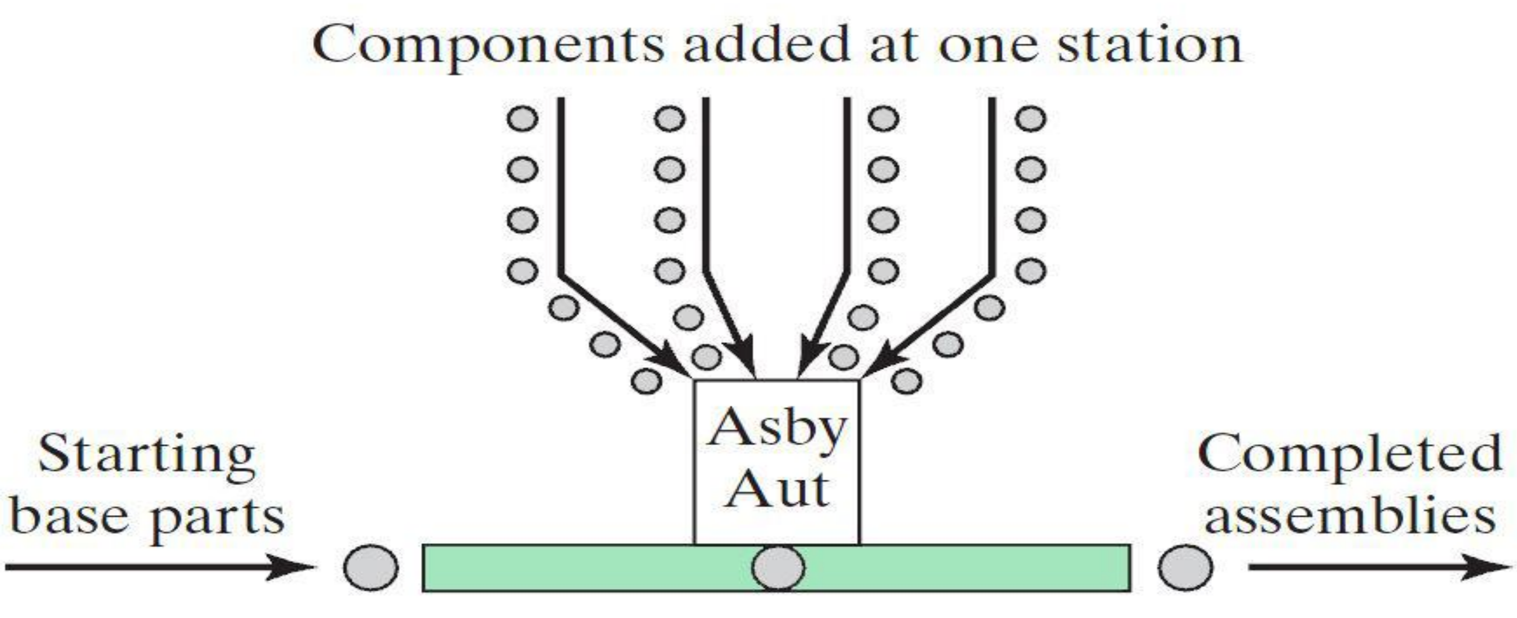
- A hybrid between circular work flow of dial indexing machine and straight work flow of in-line system



Single-Station Assembly Cell

- Assembly operations are performed on a base part at a single location

  - A robot is sometimes used as the assembly machine



Multi-Station vs. Single-Station

- Multi-station assembly machine or line
  - Faster cycle rate
  - High production quantities
  - More operations possible
  - More components per assembly
- Single-station assembly cell
  - Suited to robotic assembly
  - Intended for lower production quantities

APSCIM 4e

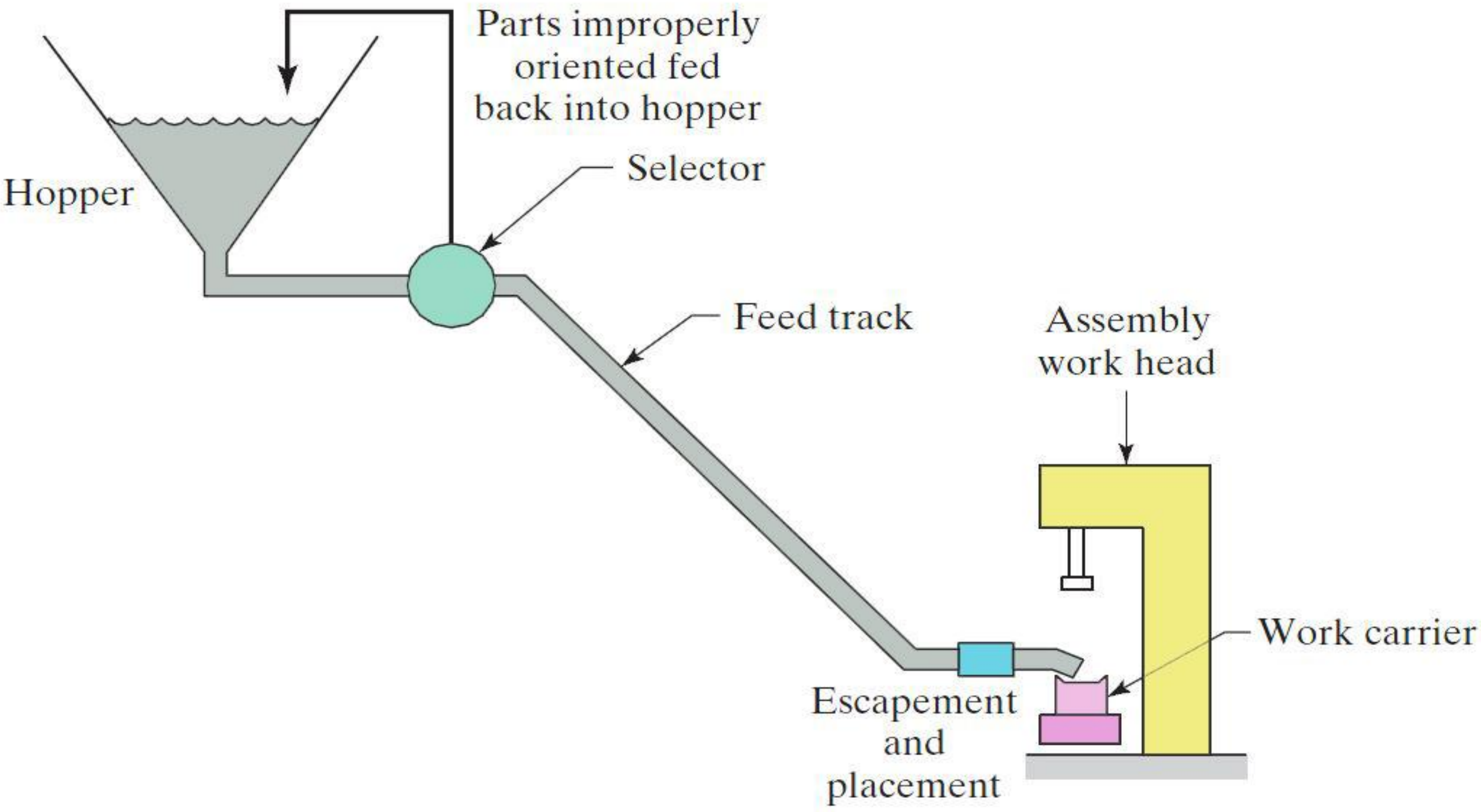
Parts Delivery at Workstations

- Typical parts delivery system at a workstation consists of the following hardware components:

1. Hopper - container for parts
2. Parts feeder - removes parts from hopper
3. Selector and/or orientor - to assure part is in proper orientation for assembly at workhead
4. Feed track - moves parts to assembly workhead
5. Escapement and placement device - removes parts from feed track and places them at station

APSCIM 4e

Parts Delivery System at Station

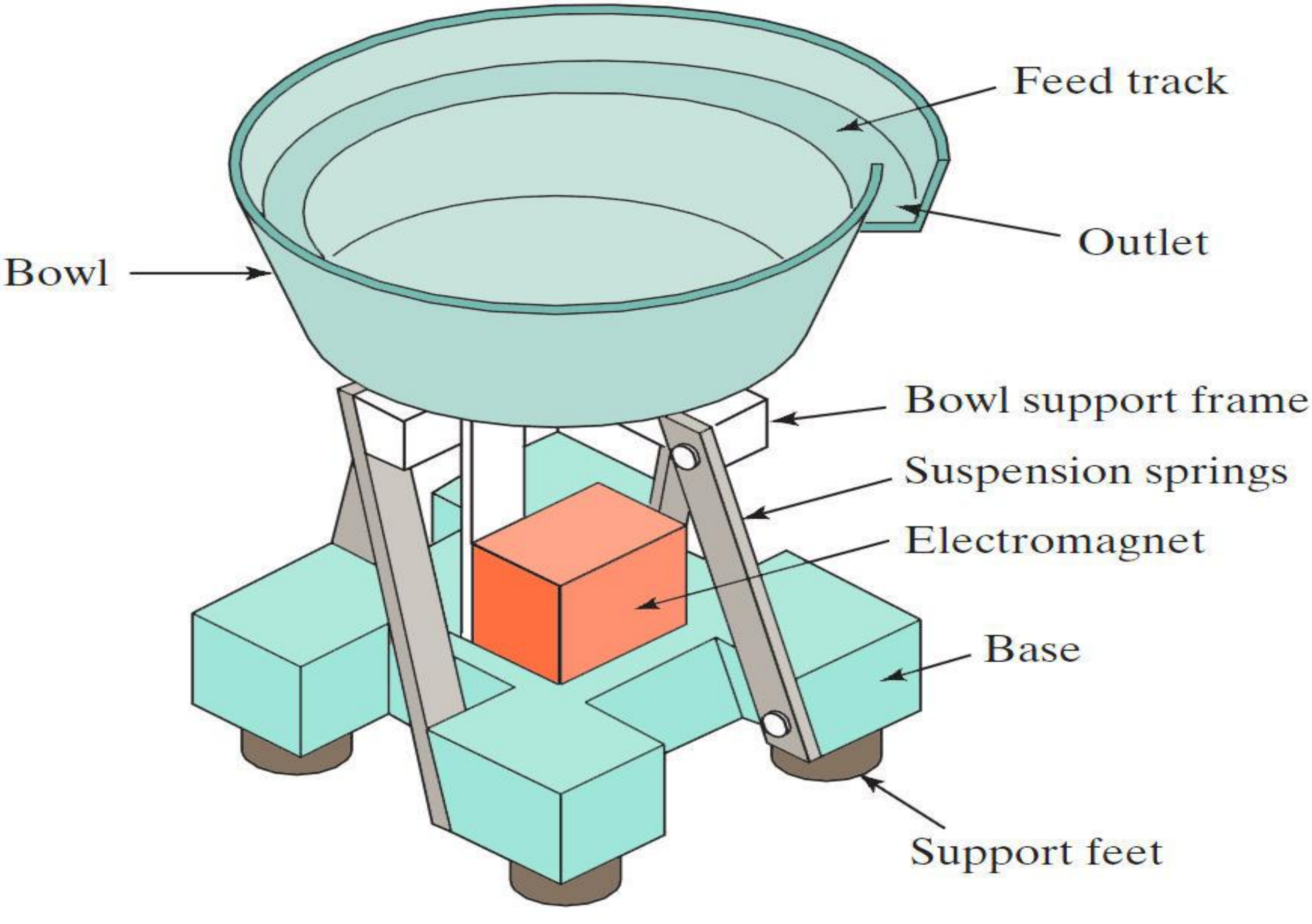


Vibratory Bowl Feeder

- Most versatile of hopper feeders for small parts.
- Consists of bowl and helical track.
  - Parts are poured into bowl
  - Helical track moves part from bottom of bowl to outlet
- Vibration applied by electromagnetic base.
  - Oscillation of bowl is constrained so that parts climb upward along helical track

APSCIM 4e

Vibratory Bowl Feeder



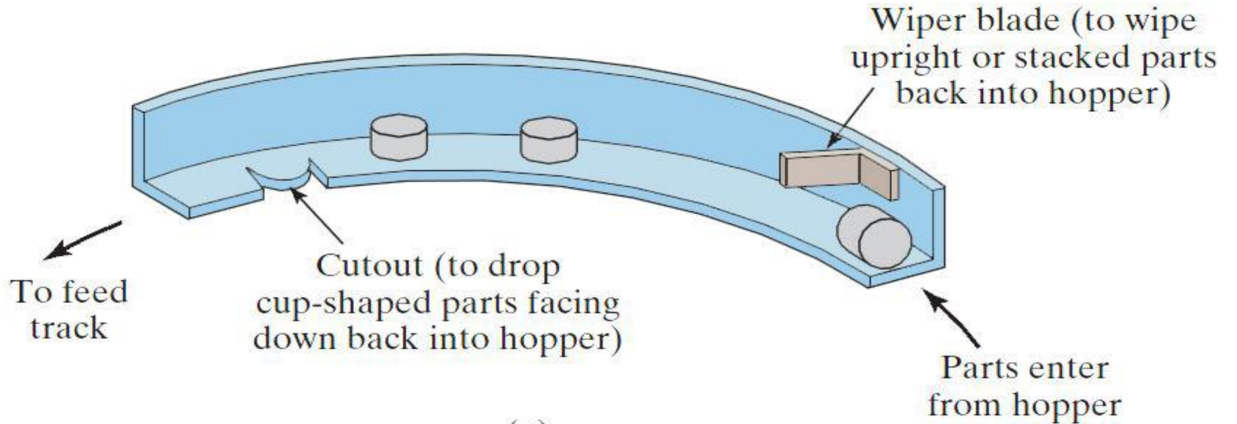
APSCIM 4e

Selector and/or Orientor

- Purpose - to establish the proper orientation of the components for the assembly workhead
- Selector
  - Acts as a filter
  - Only parts in proper orientation are allowed to pass through to feed track
- Orientor
  - Allows properly oriented parts to pass
  - Reorients parts that are not properly oriented

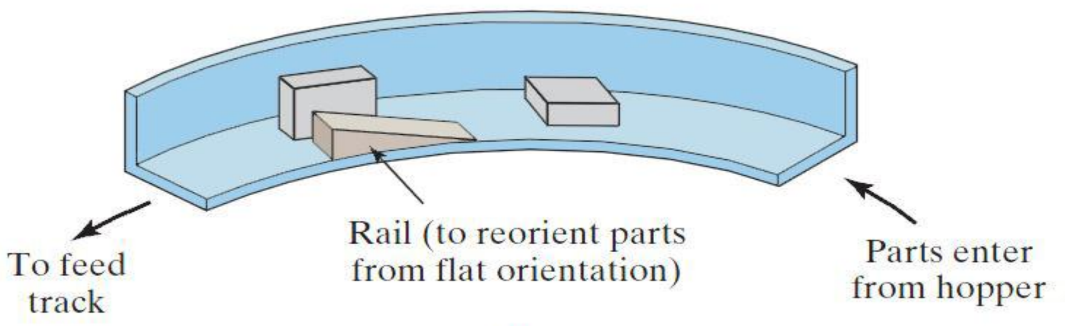
Parts Selection and Orientation

(a) Selector



(a)

(b) Orientor



(b)

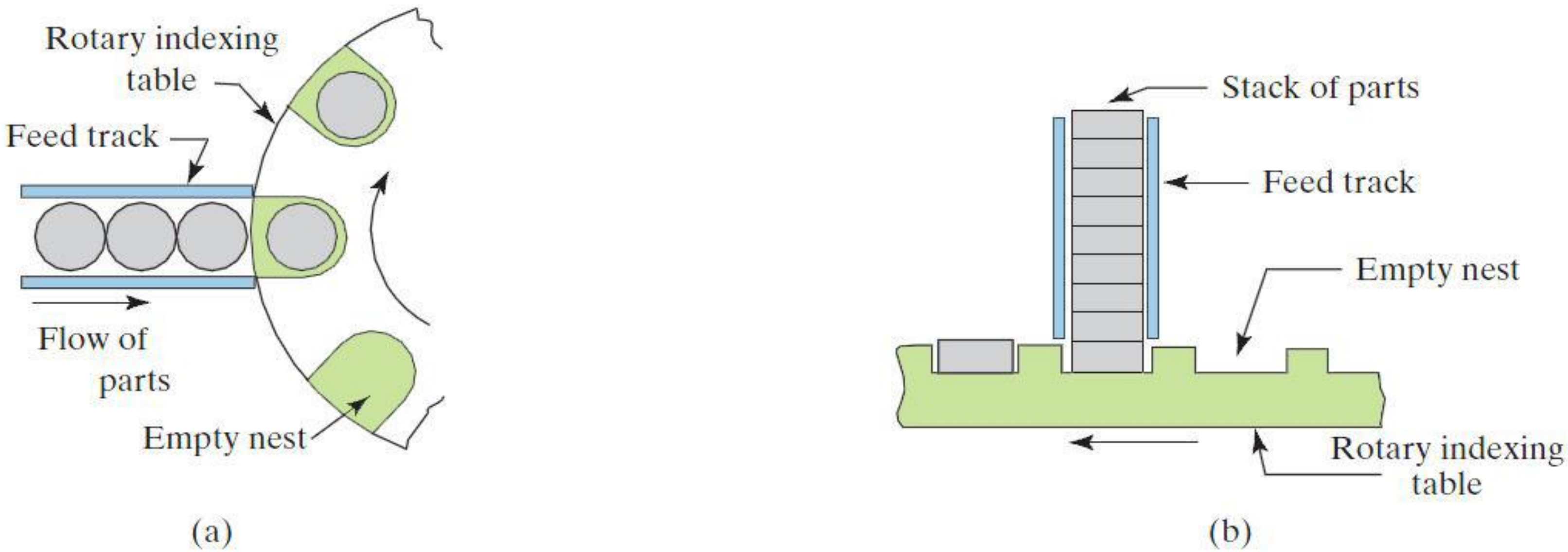
Feed Track

- Moves parts from hopper to assembly workhead
- Categories:
  1. Gravity - hopper and feeder are located at higher elevation than workhead
  2. Powered - uses air or vibration to move parts toward workhead

Escapement and Placement Devices

- Escapement device
  - Removes parts from feed track at time intervals that are consistent with the cycle time of the assembly workhead
- Placement device
  - Physically places the parts in the correct location at the assembly workstation
- Escapement and placement devices are sometimes the same device, sometimes different devices

Escapement and Placement Devices



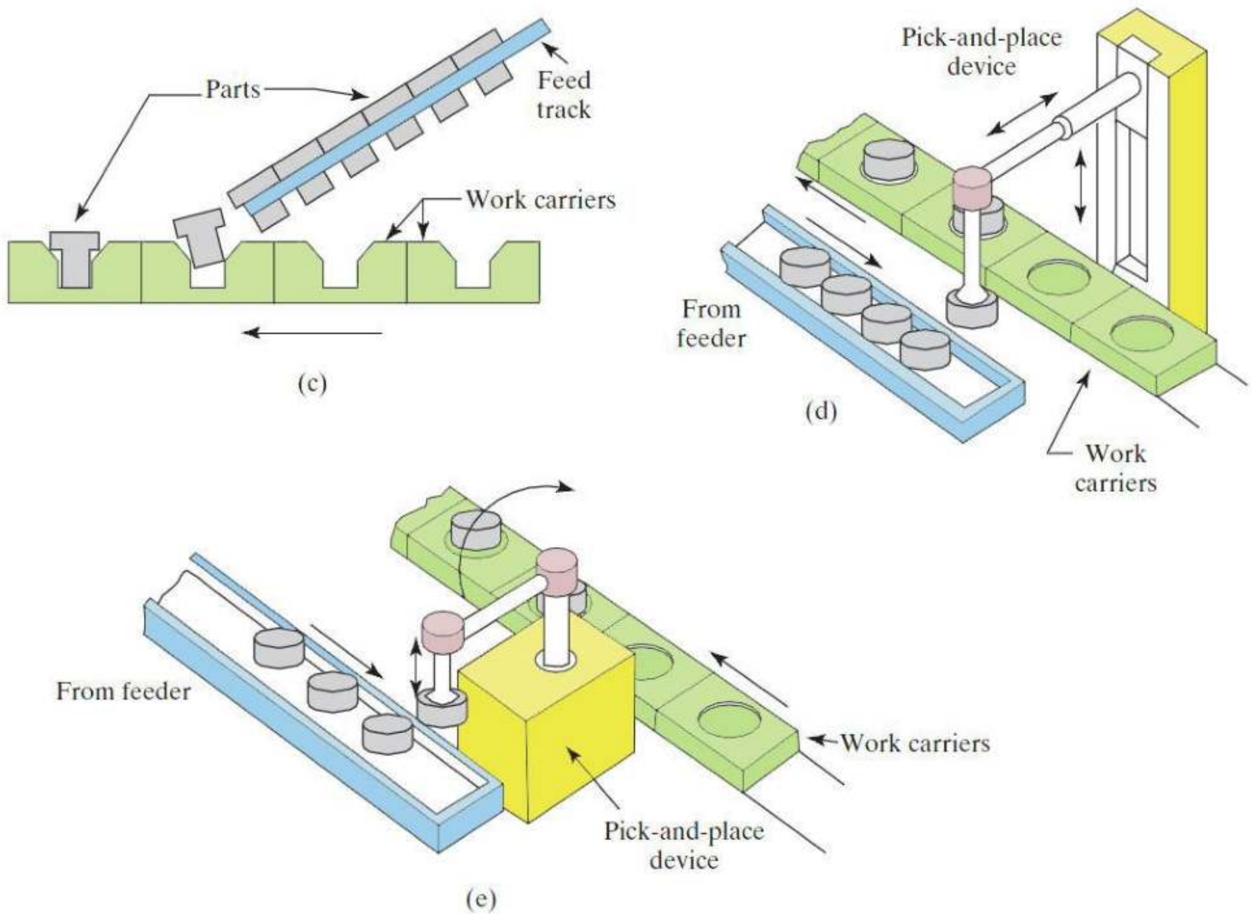
(a) Horizontal and (b) vertical devices for placement of parts onto dial-indexing table

APSCIM 4e

Escapement and Placement Devices

(c) Escapement of rivet-shaped parts actuated by work carriers

(d) and (e) two types of pick-and-place mechanisms

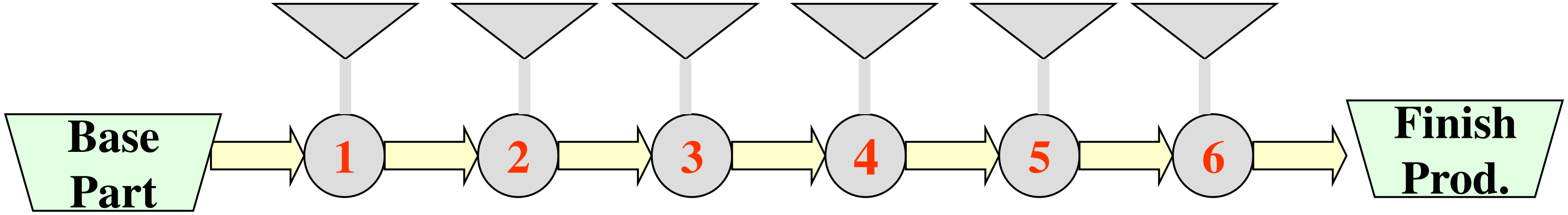


APSCIM 4e

Quantitative Analysis of Assembly Systems

1. Multi-station assembly machines
2. Single-station assembly cells
3. Partial automation

Multi-station assembly machines



When a component is fed, three events may occur at a particular work-station (i):

1. **The component is defective and cause a station jam.**
2. **The component is defective and does not cause a station jam.**
3. **The component is not defective.**

Assume:

q_i **= Probability of the component is defective**

m_i **= Probability that a defective component cause jam**

APSCIM 4e

Multi-station assembly machines

For the first event:

The probability that the defective part cause a jam $p_i = m_i q_i$

For the second event:

The probability that the defective part does not cause a jam

$$\nu_i = (1 - m_i) q_i$$

For the third event:

The probability that the part is not defective $\vartheta_i = 1 - q_i$

Thus, the sum of the three probabilities:

$$\rho_i + \upsilon_i + \vartheta_i = m_i q_i + (1 - m_i) q_i + (1 - q_i) = 1$$

For n stations:

$$\prod_{i=1}^{n} [m_i q_i + (1 - m_i) q_i + (1 - q_i)] = 1$$

For equal probability, $[mq + (1 - m) q + (1 - q)]^n = 1$

APSCIM 4e

Multi-station assembly machines

For n stations; The proportion of acceptable product coming off the line

$$P_{ap} = \prod_{i=1}^{n}\left[\left(1-q_i\right)+m_i q_i\right]$$

For equal probability, $P_{ap} = \left[\left(1-q\right)+mq\right]^n$

The assembly proportion that contain at least one defect

$$P_{qp} = 1-\prod_{i=1}^{n}\left[\left(1-q_i\right)+m_i q_i\right]$$

For equal probability, $P_{qp} = 1-\left[\left(1-q\right)+mq\right]^n$

The frequency of downtime occurance per cycle

$$F = \sum_{i=1}^{n}\rho_i = \sum_{i=1}^{n} m_i q_i$$

For equal probability, $F = nmq$

APSCIM 4e

Multi-station assembly machines

$$\text{The Average production time per assembly}$$

$$T_P = T_C + \sum_{i=1}^{n} m_i q_i T_d$$

$$\text{For equal probability,} \qquad T_P = T_C + nmqT_d$$

$$\text{The avarage production rate,} \qquad R_P = 1/T_P$$

$$R_{ap} = \frac{\prod_{i=1}^{n}\left[\left(1-q_i\right)+m_i q_i\right]}{T_P} = \frac{P_{qp}}{T_P}$$

$$\text{For equal probability,} \qquad R_{ap}(\text{Production rate for acceptable products}) = \frac{\left[\left(1-q\right)+mq\right]^n}{T_P}$$

$$\text{The Efficiency,} \qquad E = T_C/T_P$$

$$\text{The Deficiency,} \qquad D = T_D/T_P$$

$$\text{The Cost,} \qquad C_{PC} = \frac{C_m + C_L T_P + C_t}{P_{ap}}$$

Example 1

A ten-station in-line assembly machine has an ideal cycle time = 6 sec. The base part is automatically loaded prior to the first station, and components are added at each of the stations. The fraction defect rate at each of the ten stations is $q = 0.01$, and the probability that a defect will jam is $m = 0.5$. When a jam occurs, the average downtime is 2 min. Cost to operate the assembly machine is $42/hr. Other costs are ignored. Determine:

(a) Average production rate of all assemblies,
(b) Yield of good assemblies,
(c) Average production rate of good product,
(d) Uptime efficiency of the assembly machine, and
(e) Cost per unit.

Example 1

(a) $T_c = 6$ sec $= 0.1$ min. The average production cycle time is

$$T_p = 0.1 + (10)(.5)(.01)(2.0) = 0.2 \text{ min}$$

The production rate is therefore

$$R_p = \frac{60}{0.2} = 300 \text{ total assemblies / hr}$$

(b) The yield is given by Eq. (17.7):

$$P_{ap} = \{1 - .01 + 0.5(0.01)\}^{10} = 0.9511$$

(c) Average actual production rate of good assemblies is determined by Eq. (17.15):

$$R_{ap} = 300(0.9511) = 285.3 \text{ good asbys/hr}$$

(d) The efficiency of the assembly machine is

$$E = 0.1/0.2 = 0.50 = 50\%$$

(e) Cost to operate the assembly machine $C_o = \$42/\text{hr} = \$0.70/\text{min}$

$$C_{pc} = (\$0.70/\text{min})(0.2 \text{ min/pc})/0.9511 = \$0.147/\text{pc}$$

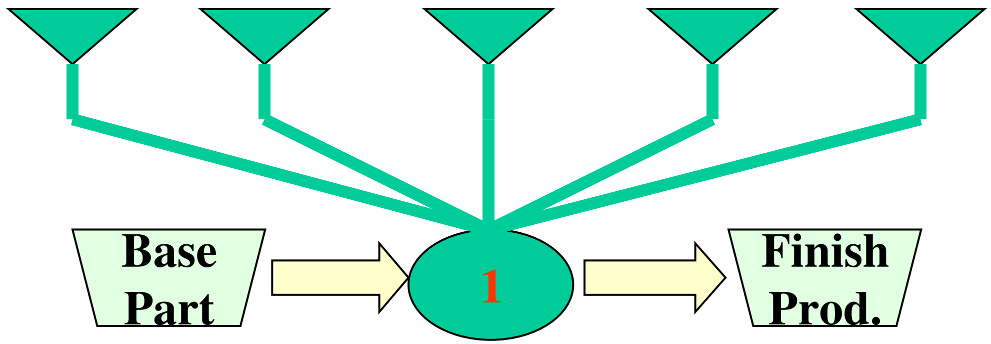
Example 2

10-station in-line assembly machine has an ideal cycle time =6 sec. The base part is automatically loaded prior to first station, and components are added at each stations. For jamming rates (m=0, 0.5, 1.0) and defect rates (q=0 ,0.01, 0.02), find: a) Production Rate of line---b) Yield of good assemblies---c) Production Rate of good assemblies---d) Uptime Efficiency---e) Cost per unit

q	m	T_p= (T_C+ nmqT_d) , Min	R_p=1/ T_p assbly/hr	Yield P_{ap} = $(1-q+mq)^n$	R_{ap}= R_p* P_{ap}	E=T_C /T_p %	Cost, C_{pc} = C_o * T_p / P_{ap} ,$/ass
0	0	0.1	600	1	600	100	0.07
0.01	0	0.1	600	0.9044	542.6	100	0.0774
0.02	0	0.1	600	0.8171	490.2	100	0.0857
0	0.5	0.1	600	1	600	100	0.07
0.01	0.5	0.2	300	0.9511	285.3	50	0.1472
0.02	0.5	0.3	200	0.9044	180.9	33.3	0.2322
0	1.0	0.1	600	1	600	100	0.07
0.01	1.0	0.3	200	1	200	33.3	0.21
0.02	1.0	0.5	120	1	120	20	0.35

APSCIM 4e

Single Station Analysis



The cycle time per assembly

$$T_c = T_h + \sum_{i=1}^{n} T_{ei}$$

where;

T_h = *Handling time*

T_{ei} = *Element time*

The Average production time per assembly

$$T_p = T_c + \sum_{i=1}^{n} m_i q_i T_d$$

For equal probability, $T_p = T_c + nmqT_d$

APSCIM 4e

Example 3

A single-station assembly machine performs five work elements to assemble four components to a base part. The elements are listed in the table below, together with the fraction defect rate (q) and probability of a station jam (m) for each of the components added (NA means not applicable).

Element	Operation	Time	q	m	p
1	Add gear	4	0.02	1.0	
2	Add spacer	3	0.01	0.6	
3	Add gear	4	0.015	0.8	
4	Add gear and mesh	7	0.02	1.0	
5	Fasten	5	0	NA	0.012

Time to load the base part is 3 sec and time to unload the completed assembly is 4 sec, giving a total load/unload time of $T_h = 7$ sec. When a jam occurs, it takes an average of 1.5 minutes to clear the jam and restart the machine. Determine

(a) production rate of all product, (b) yield of good product, (c) production rate of good product, and (d) uptime efficiency of the assembly machine.

Example 3

(a) The ideal cycle time of the assembly machine is

$$T_c = 7 + (4 + 3 + 4 + 7 + 5) = 30 \text{ sec} = 0.5 \text{ min}$$

Frequency of downtime occurrences is

$$F = 0.02(1.0) + 0.01(0.6) + 0.015(0.8) + 0.02(1.0) + 0.012 = 0.07$$

Adding the average downtime due to jams,

$$T_p = 0.5 + 0.07(1.5) = 0.5 + 0.105 = 0.605 \text{ min}$$

Production rate is therefore

$$R_p = 60/0.605 = 99.2 \text{ total assemblies/hr}$$

(b) Yield of good product is the following, from Eq. (17.5):

$$P_{ap} = \{1 - 0.02 + 1.0(0.02)\}\{1 - 0.01 + 0.6(0.01)\}$$
$$\{1 - 0.015 + 0.8(0.015)\}\{1 - 0.02 + 1.0(0.02)\}$$
$$= (1.0)(0.996)(0.997)(1.0) = 0.993$$

(c) Production rate of only good assemblies is

$$R_{ap} = 99.2(0.993) = 98.5 \text{ good assemblies/hr}$$

(d) Uptime efficiency is

$$E = 0.5/0.605 = 0.8264 = 82.64\%$$

Partial Automation

$$T_p = T_c + \sum_{i \in n_a} p_i T_d$$

P_i = the probability of breakdowns per cycle

$$p_i = m_i q_i$$

If all p_i, m_i, and q_i are equal, respectively to p, m, and q, then:

$$T_p = T_c + n_a p T_d$$

Partial Automation

- Given that:

  n_a = the number of automated stations

  n_w = the number of stations operated by workers

$$n = n_a + n_w$$

C_{asi} = Cost to operate automatic workstation i, $/min

C_{wi} = Cost to operate manual workstation i, $/min

C_{at} = Cost to operate the automatic transfer mechanism

- Then the total cost to operate the line is

$$C_o = C_{at} + \sum_{i \in n_a} C_{asi} + \sum_{i \in n_w} C_{wi}$$

where C_o = cost of operating the partially automated production system, $/min. For all $C_{asi} = C_{as}$, and all $C_{wi} = C_w$, then

$$C_o = C_{at} + n_a C_{as} + n_w C_w$$

$$C_{pc} = \frac{C_m + C_o T_p + C_t}{P_{ap}}$$

Example 4

The company is considering replacing one of the current manual workstations with an automatic workhead on a 10-station production line. The current line has six automatic stations and four manual stations. Current cycle time is 30 sec. The limiting process time is at the manual station that is proposed for replacement. Implementing the proposal would allow the cycle time to be reduced to 24 sec. The new station would cost \$0.20/min. Other cost data: C_w = \$0.15/min, C_{as} = \$0.10/min, and C_{at} = \$0.12/min. Breakdowns occur at each automated station with a probability $p = 0.01$. The new automated station is expected to have the same frequency of breakdowns. Average downtime per occurrence $T_d = 3.0$ min, which will be unaffected by the new station. Material costs and tooling costs will be neglected in the analysis. It is desired to compare the current line with the proposed change on the basis of production rate and cost per piece. Assume a yield of 100% good product.

Example 4

For the current line, $T_c = 30 \text{ sec} = 0.50 \text{ min}$

$$T_p = 0.50 + 6(0.01)(3.0) = 0.68 \text{ min}$$

$$R_p = 1/0.68 = 1.47 \text{ pc/min} = 88.2 \text{ pc/hr}$$

$$C_o = 0.12 + 4(0.15) + 6(0.10) = \$1.32/\text{min}$$

$$C_{pc} = 1.32(0.68) = \$0.898/\text{pc}$$

For the proposed line, $T_c = 24 \text{ sec} = 0.4 \text{ min}$

$$T_p = 0.40 + 7(0.01)(3.0) = 0.61 \text{ min}$$

$$R_p = 1/0.61 = 1.64 \text{ pc/min} = 98.4 \text{ pc/hr}$$

$$C_o = 0.12 + 3(0.15) + 6(0.10) + 1(0.20) = \$1.37/\text{min}$$

$$C_{pc} = 1.37(0.61) = \$0.836/\text{pc}$$

Example 5

Considering the current line in previous Example, suppose that the ideal cycle time for the automated stations on the current line T_c = 18 sec. Under the method of operation assumed in the previous example, both manual and automated stations are out action when a breakdown occurs at an automated station. Suppose that storage buffers could be provided for every operator to insulate them from breakdowns at automated stations. What effect would this have on production rate and cost per piece?

Example 5

Given $T_c = 18$ sec $= 0.3$ min, the average actual production time on the automated stations is computed as follows:

$$T_p = 0.30 + 6(0.01)(3.0) = 0.48 \text{ min}$$

Since this is less than the longest manual time of 0.50, the manual operations could work independently of the automated stations if storage buffers of sufficient capacity were placed before and after each manual station. Thus, the limiting cycle time on the line would be $T_c = 30$ sec $= 0.50$ min, and the corresponding production rate would be

$$R_p = R_c = 1/0.50 = 2.0 \text{ pc/min} = 120.0 \text{ pc/hr}$$

Using the line operating cost from Example 17.5, $C_o = \$1.32$/min, we have a piece cost of

$$C_{pc} = 1.32(0.50) = \$0.66/\text{pc}$$

What the Equations Tell Us

- The parts delivery system at each station must deliver components to the assembly operation at a net rate that is greater than or equal to the cycle rate of the assembly workhead
  - Otherwise, assembly system performance is limited by the parts delivery system rather than the assembly process technology

- Component quality has an important effect on system performance - poor quality means
  - Jams at stations that stop the entire assembly system
  - Assembly of defective components in the product

APSCIM 4e

What the Equations Tell Us

- As the number of stations increases, uptime efficiency and production rate are adversely affected due to parts quality and station reliability effects.

- The cycle time of a multi-station assembly system is determined by its slowest station.

- By comparison with a multi-station assembly system, a single-station assembly cell with the same number of assembly tasks has a lower production rate but a higher uptime efficiency.

What the Equations Tell Us

- Multi-station assembly systems are appropriate for high production applications and long production runs.
- By comparison, single-station assembly cells have a longer cycle time and are more appropriate for mid-range quantities.
- Storage buffers should be used on partially automated production lines to isolate the manual stations from breakdowns at the automated stations.
- An automated station should be substituted for a manual station only if it has the effect of reducing cycle time sufficiently to offset negative effects of lower reliability.

Questions?