Assembly Technology

Lecture 3: Automated Assembly

Outline

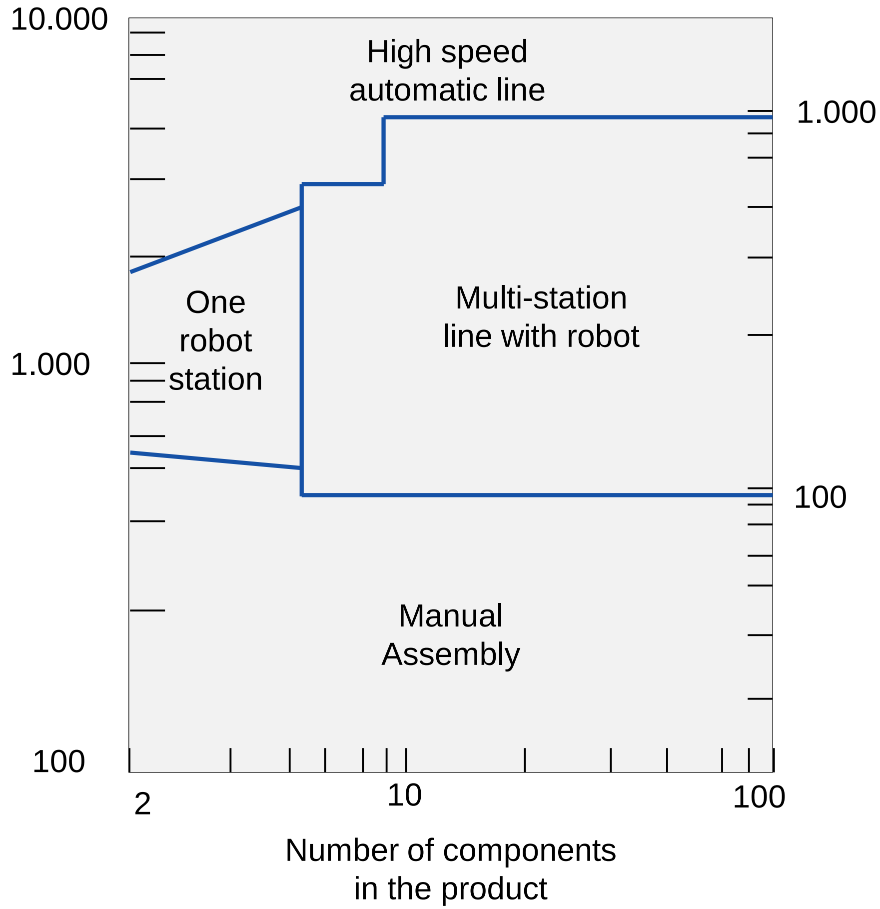
- Automatic assembly line
- Part 1 High speed assembly line
- Part 2 Important concept related to high speed and other form of assembly automation

Automated assembly lines

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

The vast majority of automated assembly systems are designed to perform a fixed sequence of assembly steps on a specific product (High Speed Automation) whereas more flexible installation, featuring for example robots can be characterized on some extent as the other generic automated production line.

Assembly approaches



Batch size (thousand)

Multi-station
line with robot

Yearly volume on two
shifts (thousand)

This graph is only indicative: you must always evaluate case by case

Part 1

High speed automatic assembly lines

Intended Learning Outcomes

- Describe automated assembly systems, and their associated system configurations
- List the hardware components used for parts delivery at workstations
- Outline typical automated assembly processes
- Describe the functioning of the high level sensor and the low level sensor in parts delivery at workstations
- Specify why automated assembly is sometimes considered a “game of chance”
- List performance metrics associated with multi-station assembly machines
- State why partial automation may be used
- Analyze and solve typical problem connected with different kinds of high speed automated lines

High speed automation

Automated assembly is generally considered appropriate if it meets the following conditions:

- High product demand—for products made in millions of units, or close to this range
- Stable product design—product design changes means changes in workstation tooling which can be expensive
- A limited number of components in the assembly—a maximum of a dozen parts
- Product designed for automated assembly

High speed assembly automation vs. Other automation commonly found on the shop-floor

Although automated assembly systems are considered expensive to create and implement, the capital investment required is not as great as for automated transfer lines, because work units produced on automated assembly systems are usually smaller, which means that the large mechanical forces and power requirements used for transfer line operations are not necessary. Automated assembly systems tend to be physically smaller than transfer lines, which usually reduces the cost of the system.

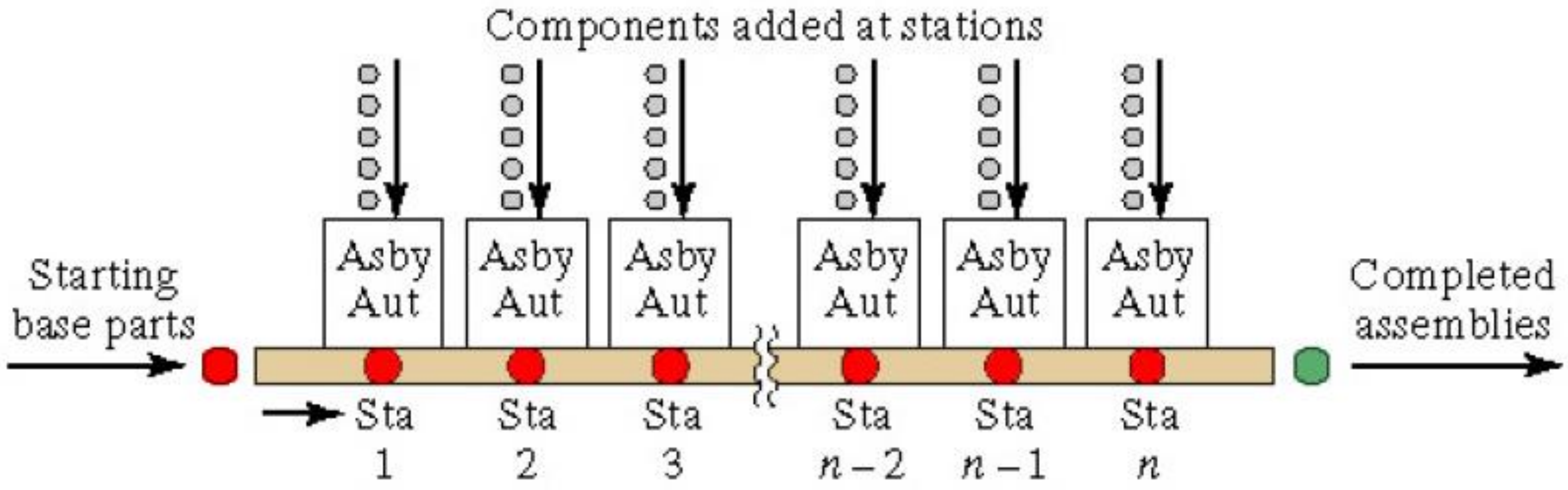
System configuration

The most common configurations for high speed assembly systems are the following:

- In-line
- Dial-type
- Carousel assembly system
- Single station assembly

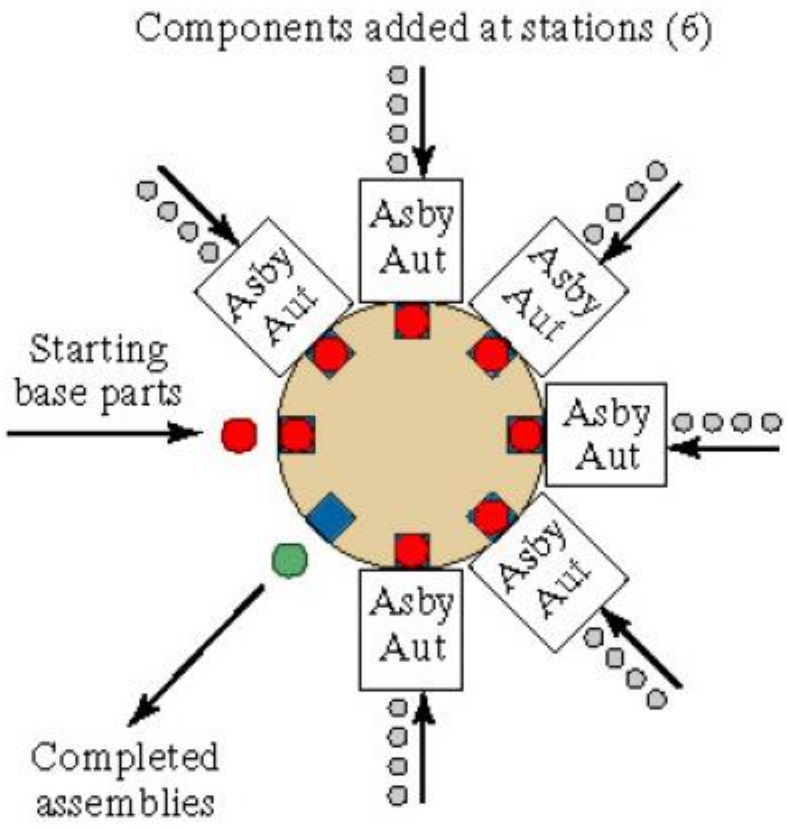
In-line configuration

A series of automatic workstations located along an in-line transfer system—the assembly version of the machining transfer line. Synchronous and asynchronous transfer systems may be used to transport parts from workstation to workstation



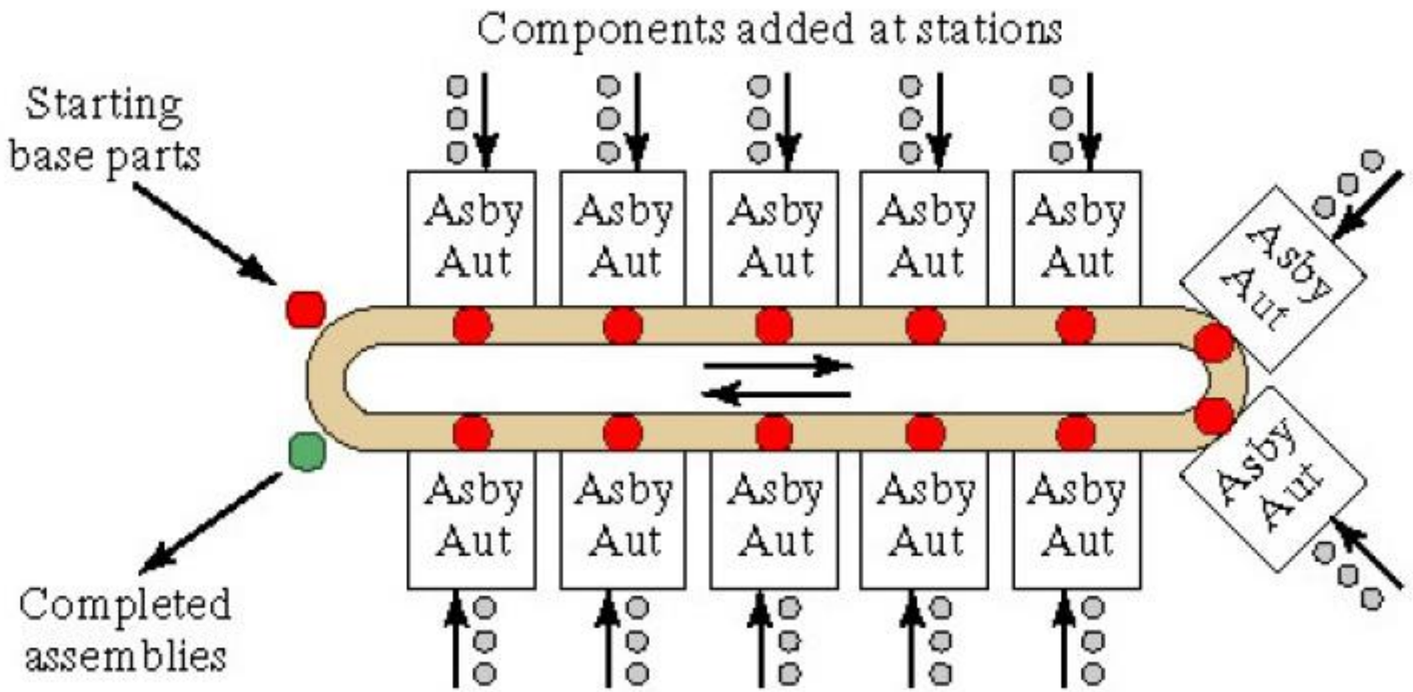
Dial-type configuration

Base parts loaded onto fixtures or nests around the periphery of the circular dial, and—as the dial table turns—components are assembled sequentially onto the base part. Synchronous transfer system in operation, as all nests move at the same time, sometimes through continuous motion, but more often intermittently.



Carousel configuration

Represents a hybrid between the circular work flow of the dial-type assembly machine, and the straight work flow of the in-line system. Carousels can be operated with continuous, synchronous, or asynchronous transfer mechanisms.



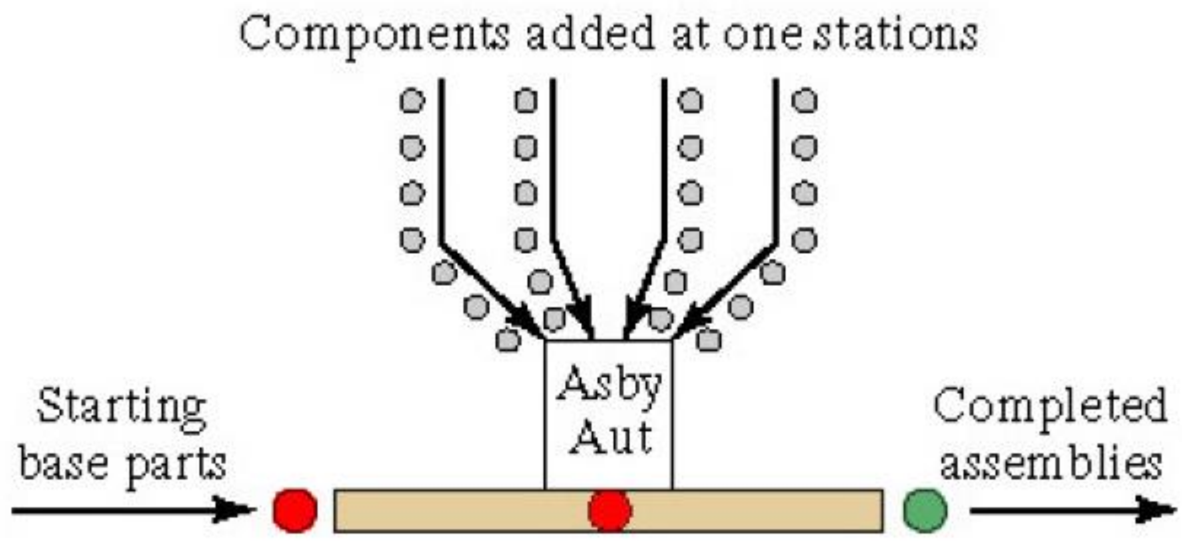
Part delivery at workstation

Parts delivery at workstations is, in general, dependent on the following hardware components:

- the hopper;
- the parts feeder;
- selector and/or orientor devices;
- the feed track;
- escapement and placement devices.

Single station configuration

Consists of one workstation where components are assembled, successively, onto a base part that has entered the system. Once all the components have been assembled onto the base part, the base part leaves the system. Inherently slower than the other three system configurations, as only one base part is processed at a time.



The hopper

A container into which components are loaded at the workstation, and which passes components to the parts feeder.

The parts feeder

A mechanism used for removing components from the hopper, and passing them to the feed track; the parts feeder is often connected to the hopper to form one unit

Selector and/or orientor devices

Devices found on the feedtrack that establish the proper orientation of the components for the assembly workhead: a selector is a filter device that only-correctly oriented parts to pass; while an orientor re-orients parts that are not properly oriented initially on the feed track

The feed track

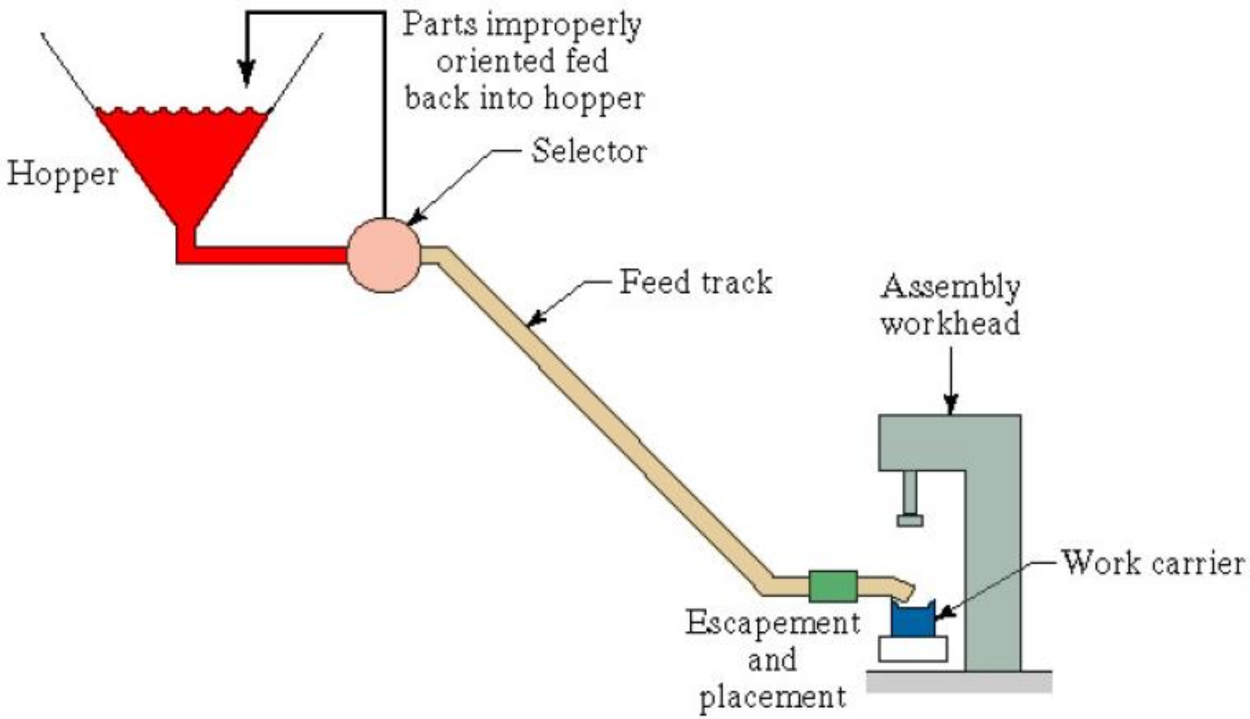
The pathway along which the components pass from the hopper and parts feeder to the assembly workhead, whilst maintaining proper orientation of the parts via selectors/orientors along the way; it generally operates by gravity, though powered feed tracks (operated by vibratory action or air pressure) may also be encountered

Escapement and placement devices.

Devices used to remove components from the feedtrack (escapement), and to place them at the workstation for the assembly operation (placement); there are a number of different device designs to accomplish this

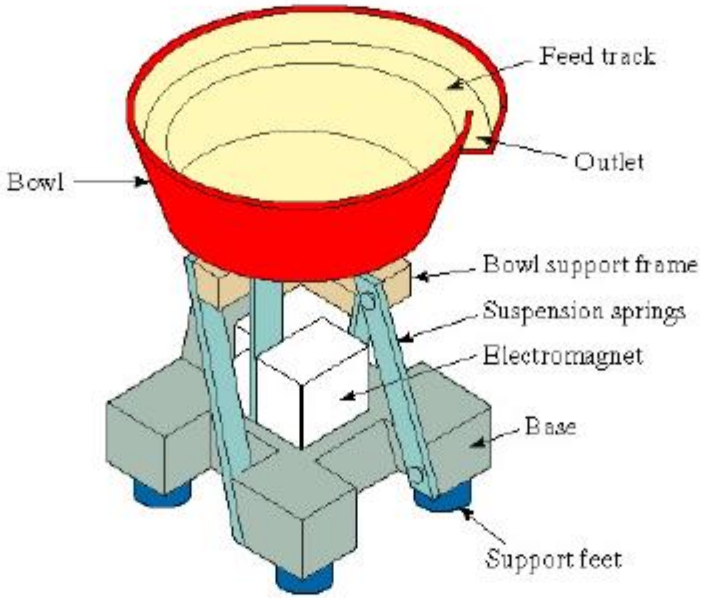
Part delivery at workstation

General arrangement of the hardware



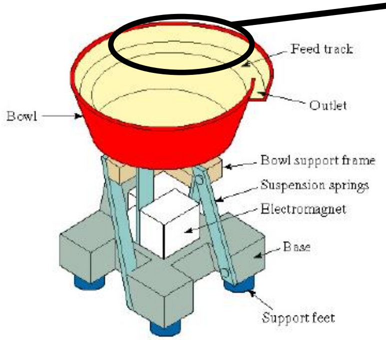
Part delivery at workstation

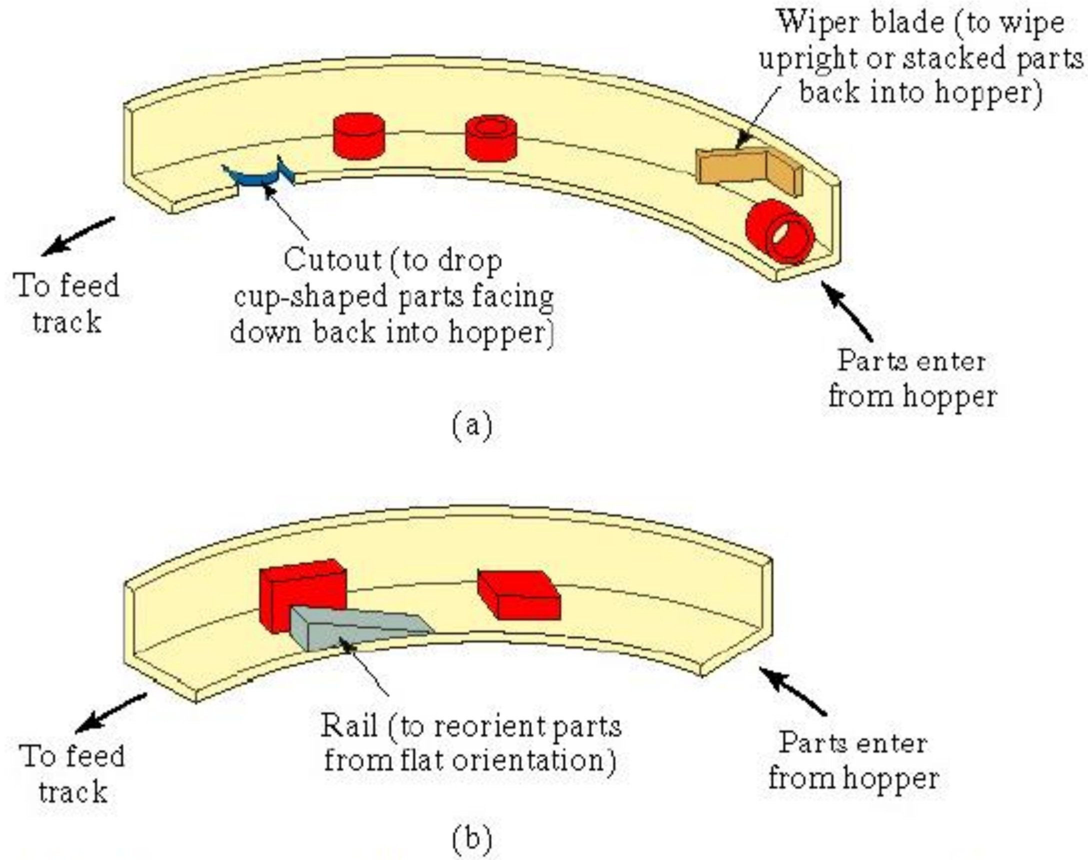
Typical system including hopper and part feeder with related feed track and selector orientor devices



Part delivery at workstation

Typical system including hopper and part feeder with related feed track and selector orientor devices





(a) Selector and (b) orientor devices used upon the feedtrack

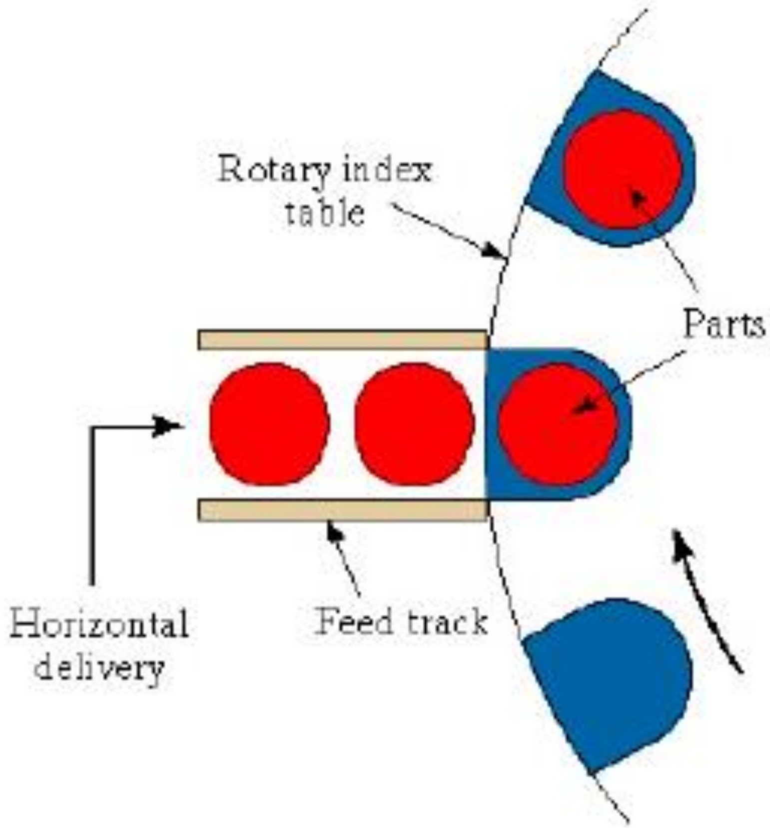
Part delivery at workstation

Escapement and placement devices include:

- Horizontal placement device
- Vertical placement device
- Escapement device
- Pick-and-place mechanism

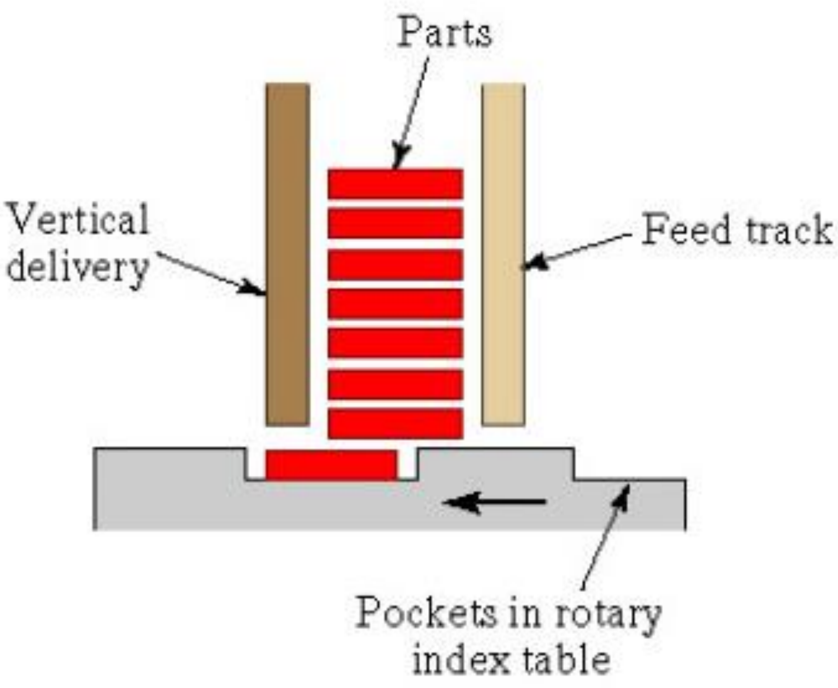
Horizontal placement device

Device used on dial-type assembly machines: parts move via horizontal delivery into vacant nests on the dial, as they appear, from the feed track; meanwhile the circular motion of the dial table means that the nests are revolved away from the feed track, permitting the next component in the feed track to move into the next vacant nest, and so forth.



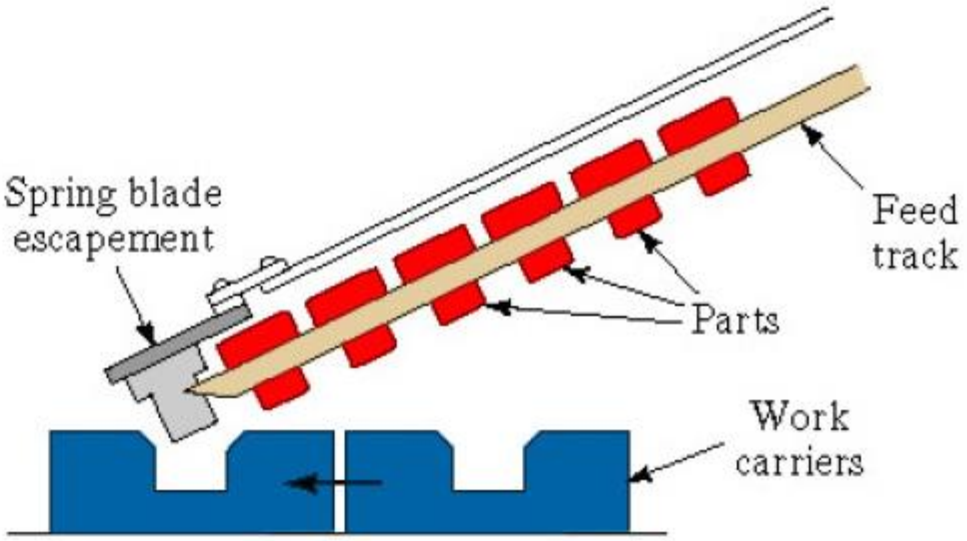
Vertical placement device

Device used on dial-type assembly machines: here, the parts feeder is arranged vertically above the dial table, so that when the table turns, to reveal an empty nest, the component can fall by gravity from the feed track into the empty nest. Successive parts fall by gravity to take up their position at the mouth of the feed track in turn.



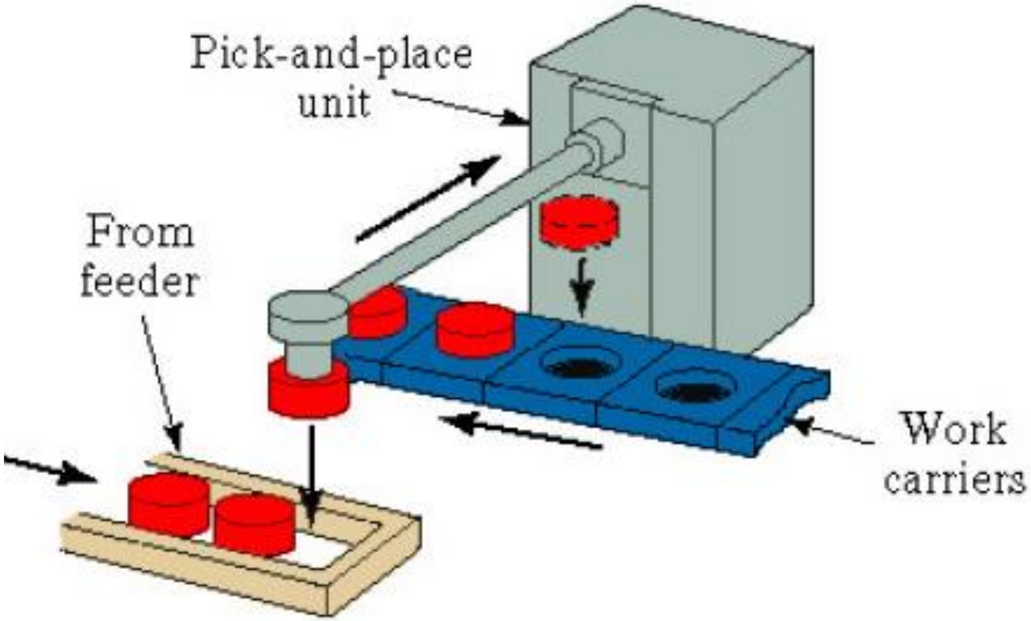
Escapement device

This device is actuated by the top of the carrier contacting the lower surface of the rivet-shaped part, causing its upper surface to press against the spring blade, which releases the part so that it falls into the work carrier nest. The work carriers are moved horizontally to cause the release of the part, and—after the first part has escaped—the work carrier and released part move off, to be replaced by the next work carrier, and so forth.



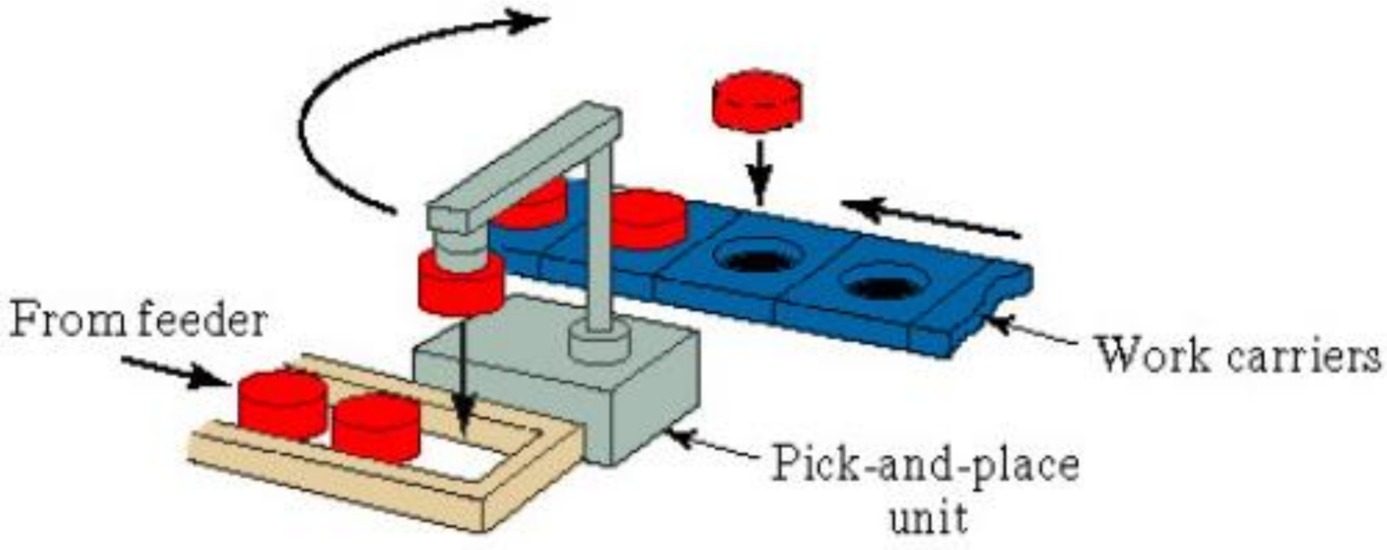
Pick-and-place mechanism (1)

This mechanism uses a pick-and-place unit with a horizontal arm that may be extended and retracted as necessary, so that parts may be removed from the feed track, and placed into work carriers.



Pick-and-place mechanism (2)

This mechanism uses a pick-and-place unit with a revolving arm, so that parts may be removed from the feed track, and placed into work carriers.



Example of automatic high speed assembly system

Video:

- Brush feeder single (0:21)
- Brush feeder (0:07)
- Laser welding and bulk feeder (1:40)
- Vibratory feeder (0:32)
- Vision system feeder (2:03)

Quantitative analysis of high speed automated lines

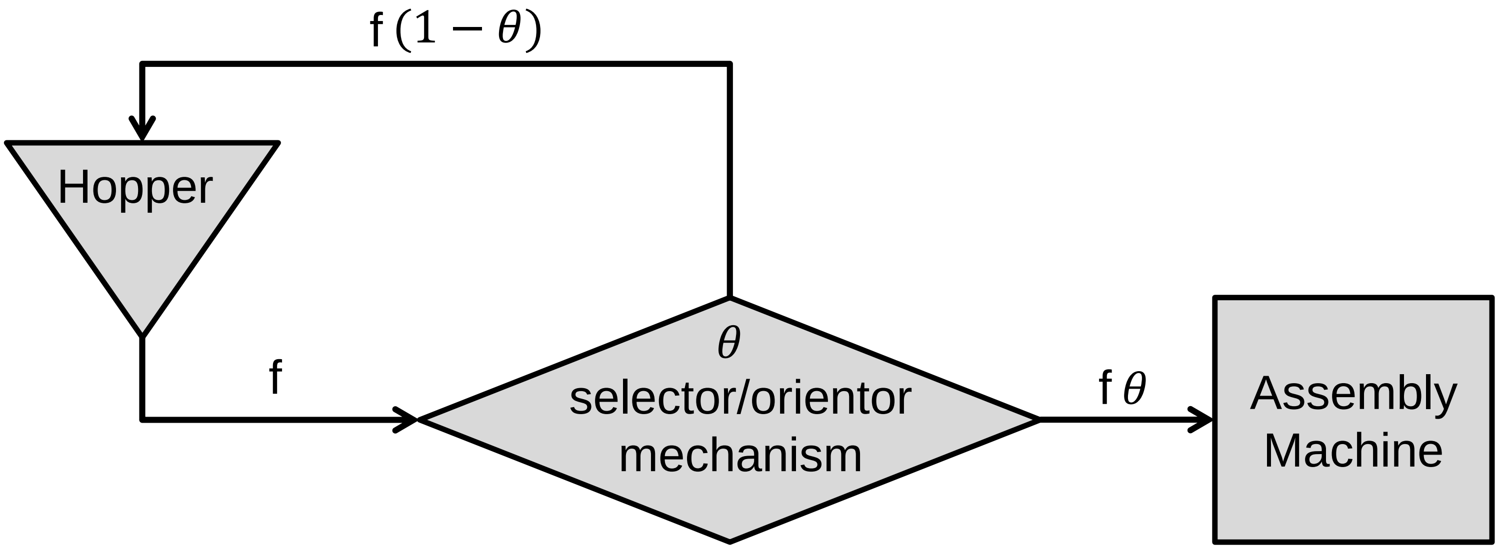
We will examine four cases:

- Parts delivery system at workstations
- Multi-station automated assembly systems
- Single-station automated assembly systems
- Partial automation

Parts delivery system at workstations

Given:

- f = Rate at which the parts are removed from the hopper and presented to the selector/orientor mechanism
- θ = proportion of the parts that pass the selector/orientor



Parts delivery system at workstations

The delivery rate $f\theta$ must keep up with the cycle rate of the assembly machine otherwise the machine will be starving

Given R_c = cycle rate of the assembly machine if we discover that $f\theta$ is greater than R_c, then we must limit the flow of components into the system, or it will become overloaded.

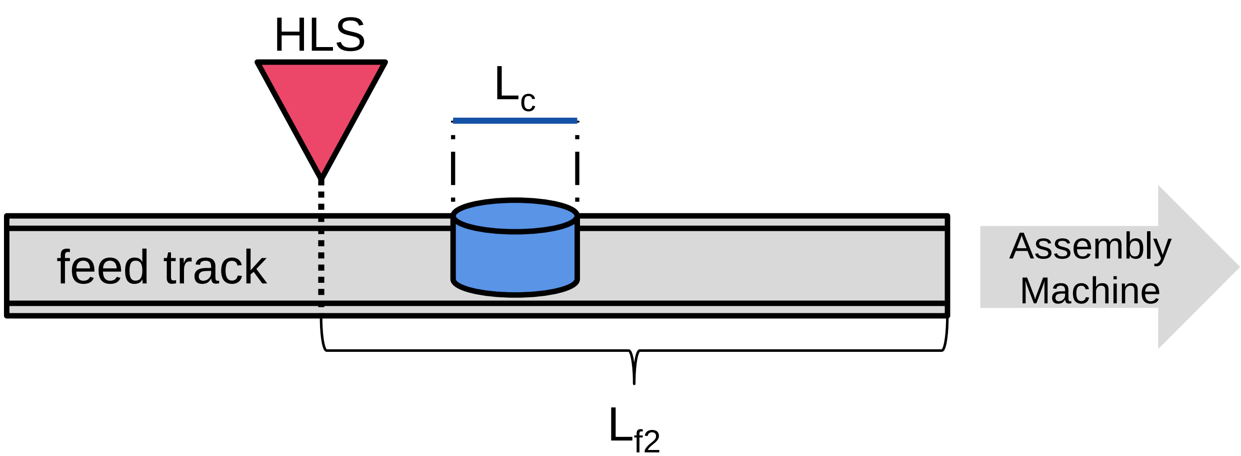
Two sensors are used:

- the high level sensor (HLS), for stopping the feeding mechanism when the feed track is at full capacity
- the low level sensor (LLS) which is used to switch the feeding mechanism back on after it has been turned-off, and after the risk of workstation overloading has been avoided

Parts delivery system at workstations

The high level sensor (HLS), is placed on the feed track at a certain location to achieve this; it turns off the feeding mechanism when the feed track is full. The location of the HLS defines the active length of the feed track (L_{f2}). Assume the length of a component in the feed track is L_c, then the number of parts held in the feed track or capacity of the feeding track (n_{f2}) is given by:

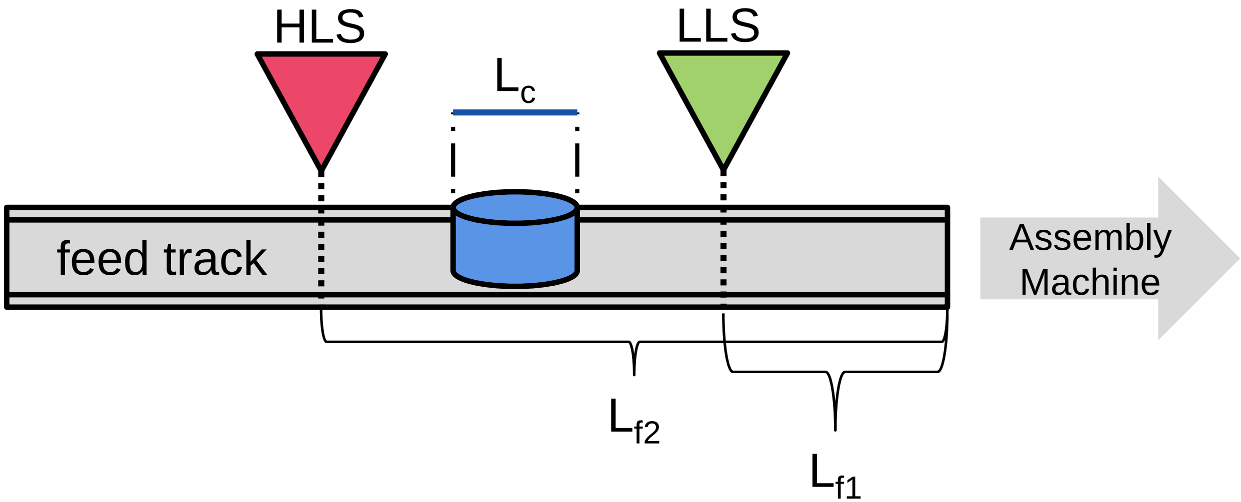
$$n_{f2} = \frac{L_{f2}}{L_c}$$



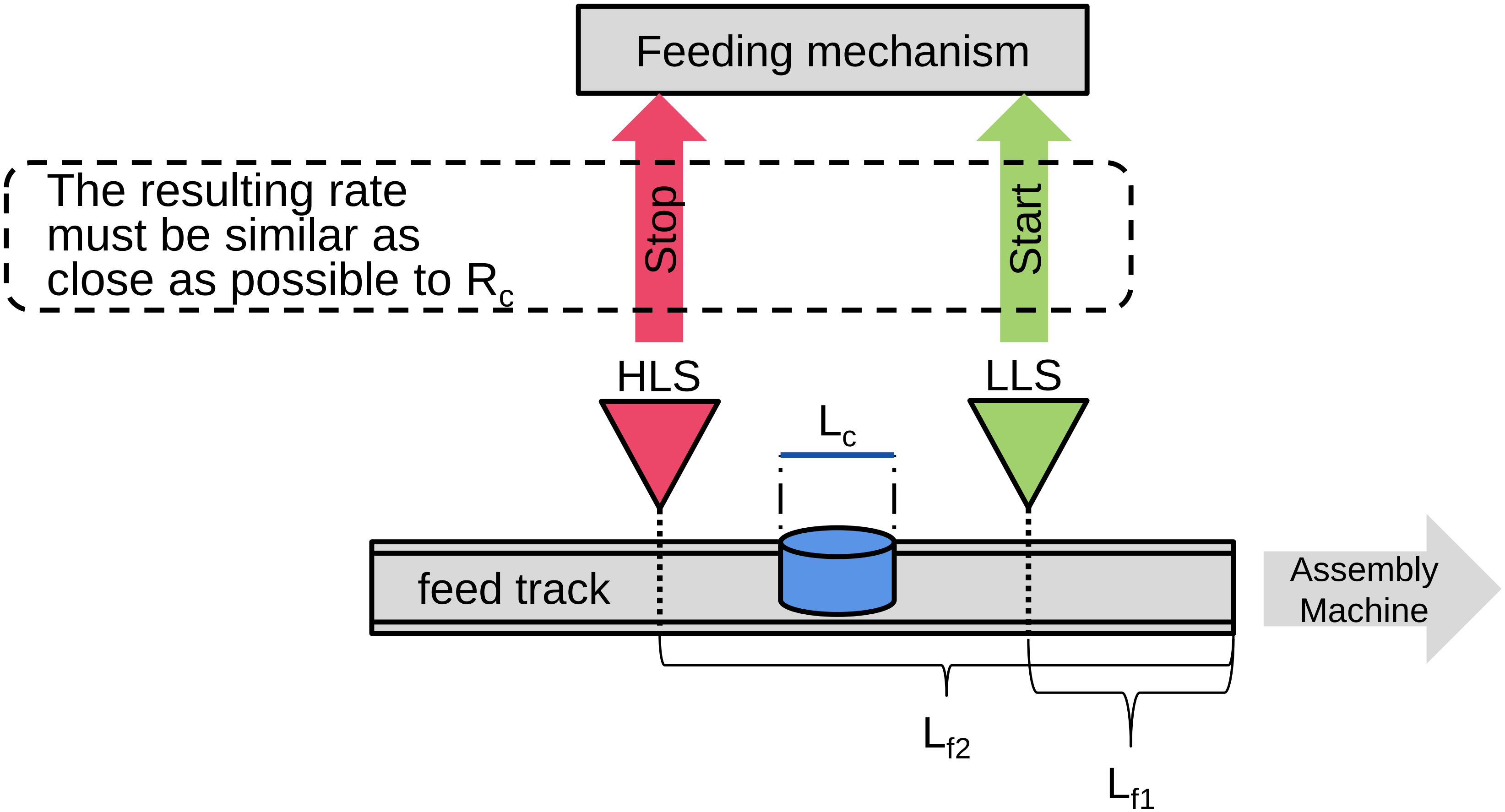
Parts delivery system at workstations

The low level sensor (LLS) is placed some distance from the HLS, is now added to the feed track to re-start the feeding mechanism after it has been stopped. If the location of the LLS is defined as L_{f1}, then the number of parts held in the feed track to the LLS (n_{f1}) is given by:

$$n_{f1} = \frac{L_{f1}}{L_c}$$



Overview of the mechanism



Example: parts delivery system at workstations

A feeder-selector device at one of the stations of an automated assembly machine has a feed rate of 25 parts per minute and provides a throughput of one part in four. The ideal cycle time of the assembly machine is 10 sec. The low level sensor on the feed track is set at 10 parts, and the high level sensor is set at 20 parts.

a) How long will it take for the supply of parts to be depleted from the high level sensor to the low level sensor once the feeder-selector device is turned off?

b) How long will it take for the parts to be resupplied from the low level sensor to the high level sensor, on average, after the feeder-selector device is turned on?

c) What proportion of the time that the assembly machine is operating will the feeder-selector device be turned on? Turned off?

Solution

a) How long will it take for the supply of parts to be depleted from the high level sensor to the low level sensor once the feeder-selector device is turned off?

Time to deplete from n_{f2} to n_{f1}

Rate of depletion = cycle rate R_c = 60/10 = 6 parts/min

Time to deplete = (20 - 10)/6 = 10/6 = 1.667 min

Solution

b) How long will it take for the parts to be resupplied from the low level sensor to the high level sensor, on average, after the feeder-selector device is turned on?

Time to resupply from n_{f1} to n_{f2}

Given the data

- $f = 25$
- $\theta = 0.25$

Rate of resupply = $f\theta$ - R_c = 25(0.25) - 6 = 0.25 parts/min

Time to resupply = (20 - 10)/0.25 = 10/0.25 = 40 min

Solution

c) What proportion of the time that the assembly machine is operating will the feeder-selector device be turned on? Turned off?

Total cycle of depletion and resupply = 41.667 min (sum of the previous times calculated)

Proportion of time feeder-selector is on = 40/41.667 = 0.96

Proportion of time feeder-selector is off = 1.667/41.667 = 0.04

Exercise in class

A feeder-selector device at one of the stations of an automated assembly machine has a feed rate of 50 parts per minute and provides a throughput of one part in four. The ideal cycle time of the assembly machine is 5 sec. The low level sensor on the feed track is set at 15 parts, and the high level sensor is set at 25 parts.

a) How long will it take for the supply of parts to be depleted from the high level sensor to the low level sensor once the feeder-selector device is turned off?

b) How long will it take for the parts to be resupplied from the low level sensor to the high level sensor, on average, after the feeder-selector device is turned on?

c) What proportion of the time that the assembly machine is operating will the feeder-selector device be turned on? Turned off?

Multi-station automated assembly systems

Here we analyse the operation of an automated assembly system with several workstations that use a synchronous transfer system. The following assumptions are made::

- Assembly operations at the stations have constant element times, although the times are not necessarily equal across all stations
- Synchronous parts transfer is used
- There is no internal storage

Multi-station automated assembly systems

- Defective parts occur in manufacturing with a certain fraction defect rate q, where ($0 \leq q \leq 1.0$). In the operation of an assembly workstation, q is the probability that the component to be added to the assembly during the current cycle is defective.
- A defective component might or might not cause a workstation to jam; thus we let m be the probability that a defect causes the workstation to jam, causing a consequential stoppage of the line.
- Since the values of q and m may be different for different workstations in the system, we subscript these terms as q_i and m_i, where $i = 1, 2, 3, \ldots, n$, and where n is the number of workstations in the system.

Multi-station automated assembly systems

In relation with this description we can have three events:

- The defective component causes a station jam,(where p_i is the probability of this event occurring):

$$p_i = m_i q_i$$

- The defective component does not cause a station jam:

$$p_i = (1 - m_i) q_i$$

- The component is not defective:

$$p_i = 1 - q_i$$

Multi-station automated assembly systems

These three possible events sum to unity for any workstation:

$$m_i q_i + (1 - m_i) q_i + (1 - q_i) = 1$$

In the special case where *mi* is the same as *m*, and *qi* is the same as *q*, then this equation can be simplified to:

$$mq + (1 - m)q + (1 - q) = 1$$

The complete distribution of possible outcomes that can occur on an n-station assembly machine, and given the special case where mi is the same as m, and qi is the same as q, then:

$$[mq + (1 - m)q + (1 - q)]^n = 1$$

Keypoint

We must consider the assembly machine and the delivery of parts to its multiple stations as a game of chance, where potentially defective components may or may not cause individual workstations to jam.

Performance metrics: multi-station automated assembly systems

The proportion of acceptable product coming off the line (P_{ap}):

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

In the special case, where m_i is the same as m, and q_i is the same as q, then this equation can be simplified to:

$$P_{ap} = \left(1 - q + mq\right)^n$$

The proportion of assemblies containing at least one defective component (P_{qp}):

$$P_{qp} = 1 - P_{ap}$$

Performance metrics: multi-station automated assembly systems

The frequency of downtime occurrences per cycle (F):

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

In the special case, where m_i is the same as m, and q_i is the same as q, then this equation can be simplified to:

$$F = nmq$$

Performance metrics: multi-station automated assembly systems

The average actual production time per assembly (T_p) is:

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

where T_d is the average downtime per occurrence. In the special case, where m_i is the same as m, and q_i is the same as q, then this equation can be simplified to:

$$T_p = T_c + nmqT_d$$

The average actual production time (R_p):

$$R_p = \frac{1}{T_p}$$

Performance metrics: multi-station automated assembly systems

But this equation has to be corrected for the existence of defective components that may be added at different stations in the system; thus we determine the average actual production rate of acceptable product (R_{ap}):

$$R_{ap} = P_{ap} R_p = \frac{P_{ap}}{T_p} = \frac{\prod_{i=1}^{n} \left(1 - q_i + m_i q_i\right)}{T_p}$$

In the special case, where m_i is the same as m, and q_i is the same as q, then this equation can be simplified to:

$$R_{ap} = P_{ap} R_p = \frac{P_{ap}}{T_p} = \frac{\left(1 - q + mq\right)^n}{T_p}$$

Performance metrics: multi-station automated assembly systems

Line efficiency (E):

$$E = \frac{R_p}{R_c} = \frac{T_c}{T_p}$$

The proportion downtime (D):

$$D = 1 - E$$

The cost per assembled product (C_{pc}):

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

where C_m is the cost of materials; C_o is the operating cost of the assembly system; and C_t is the cost of disposable tooling.

Excercise: multi-station automated assembly systems

An eight-station assembly machine has an ideal cycle time of 6 sec. The fraction defect rate at each of the 8 stations is $q = 0.015$ and a defect always jams the affected station. When a breakdown occurs, it takes 1 minute, on average, for the system to be put back into operation.

Determine the production rate for the assembly machine (R_p), the yield of good product (P_{ap} final assemblies containing no defective components), and proportion uptime of the system (E).

Solution

In order to calculate R_p it is necessary to know the actual production time T_p

$$T_p = T_c + nmqT_d$$

6 sec = 0.1 min

T_p = 0.1 + 8(1.0)(0.015)(1.0) = 0.22 min/asby.

Given: $R_p = \frac{1}{T_p}$

R_p = 60/0.22 = **272.7 asbys/hr**

Solution

If defects always jam the affected station, then *m* = 1.0

Given: $$P_{ap} = (1 - q + mq)^n$$

P_{ap} = (1 - 0.015 + 1x0.015)^8 = **1.0** = yield

Given: $$E = \frac{R_p}{R_c} = \frac{T_c}{T_p}$$

E = 0.1/0.22 = 0.4545 = **45.45%**

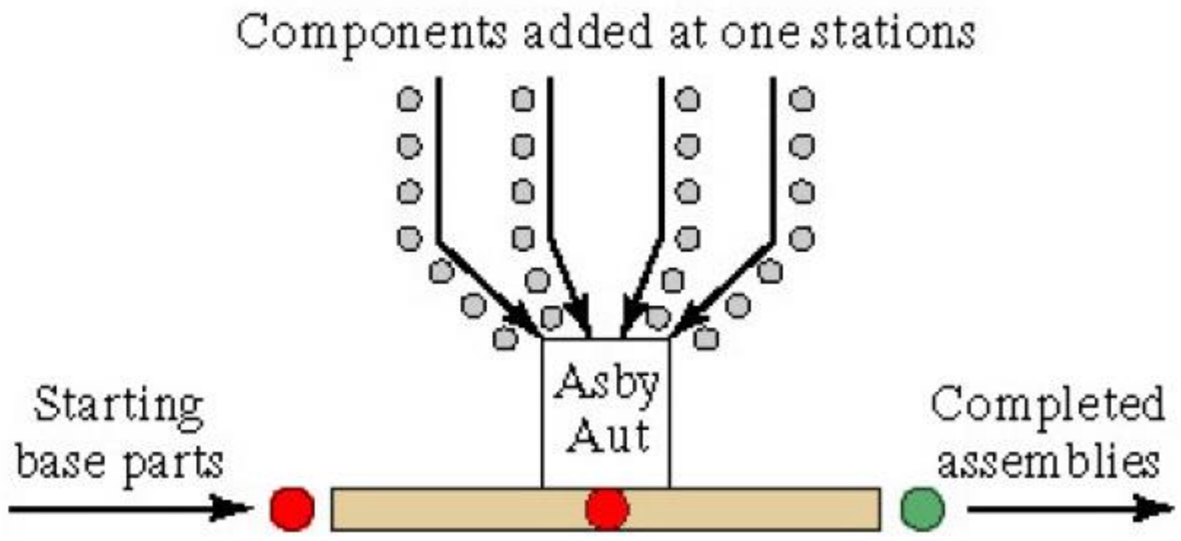
Exercise in class

An eight-station assembly machine has an ideal cycle time of 18 sec. The fraction defect rate at each of the 8 stations is q = 0.03 and a defect always jams the affected station. When a breakdown occurs, it takes 2 minute, on average, for the system to be put back into operation.

Determine the production rate for the assembly machine (Rp), the yield of good product (Pap final assemblies containing no defective components), and proportion uptime of the system (E)

Single-station automated assembly systems

The single-station assembly machine consists of one workstation where several components are assembled onto a base unit.



Single-station automated assembly systems

Main assumption for the analysis: a single workhead, with several components feeding into the station to be assembled to the base part

Let n_e be the number of distinct assembly elements that are performed on the machine. Each element has an element time T_{ej}, where j = 1, 2, 3, …, n_e. The ideal cycle time for the single-station machine is the sum of individual element times of the assembly operations to be performed on the machine, plus the handling time (T_h) to load the base part into position and unload the completed assembly. This can be expressed as:

$$T_c = T_h + \sum_{j=1}^{n_e} T_{ej}$$

Single-station automated assembly systems

Each component type has a certain fraction defect rate q_j, and there is a certain probability that a defective component will jam the workstation m_j. When a jam occurs, the machine will stop, and it will take an average time (T_d) to clear the jam and restart the system. The inclusion of downtime resulting from jams in the machine cycle time gives:

$$T_p = T_c + \sum_{j=1}^{n_e} q_j m_j T_d$$

In the special case, where m_i is the same as m, and q_i is the same as q, then this equation can be simplified to:

$$T_p = T_c + nmqT_d$$

Single-station automated assembly systems

The proportion of assemblies that contain no defective components can be calculated using the same equation as specified for multi-station assembly machines:

$$P_{ap} = \prod_{i=1}^{n} (1 - q_i + m_i q_i) \quad \text{or*} \quad P_{ap} = (1 - q + mq)^n$$

Uptime efficiency (E) is computed as:

$$E = \frac{T_c}{T_p}$$

*In the special case, where m_i is the same as m, and q_i is the same as q

Single-station automated assembly systems

Keypoint

In the single-station assembly machine only one workstation is used to assemble multiples of components. We must, therefore, determine the ideal cycle time of the workstation by summing the individual element times of the assembly operations to be performed on the machine, plus adding in additional times as necessary.

Example: single-station automated assembly systems

A single station robotic assembly system performs a series of five assembly elements, each of which adds a different component to a base part. Each element takes 4.5 sec. In addition, the handling time needed to move the base part into and out of position is 4 sec. For identification, the components, as well as the elements that assemble them, are numbered 1, 2, 3, 4, and 5. The fraction defect rate is 0.005 for all components, and the probability of a jam by a defective component is 0.7. Average downtime per occurrence = 2.5 min.

Determine:

A. production rate,
B. yield of good product in the output,
C. uptime efficiency,

Example: Single-station automated assembly systems

Solution A production rate

$T_p = T_c + nmqT_d$

T_c =loading of base object + n_e*(process time)

$T_c = 4 + 5(4.5) = 26.5$ sec = 0.44167 min

$T_p = 0.44167 + 5(0.7)(0.005)(2.5) = 0.48542$ min

$R_p = 1/0.48542 = 2.06$ asbys/min = **123.6 asbys/hr**

Example: Single-station automated assembly systems

Solution B yield of good product in the output

P_{ap} = (1 - 0.005 + 0.7(0.005))5 = (0.9985)5 = **0.9925**

Example: Single-station automated assembly systems

Solution C uptime efficiency

E = 0.44167/0.48542 = 0.90986 = **91.0%**

Exercise: Single-station automated assembly systems

A single station robotic assembly system performs a series of five assembly elements, each of which adds a different component to a base part. Each element takes 6.5 sec. In addition, the handling time needed to move the base part into and out of position is 2 sec. For identification, the components, as well as the elements that assemble them, are numbered 1, 2, 3, 4, and 5. The fraction defect rate is 0.007 for all components, and the probability of a jam by a defective component is 0.8. Average downtime per occurrence = 3.5 min.

Determine:

A. production rate,
B. yield of good product in the output,
C. uptime efficiency,

Partial automation

The cases for partial automation—that is, the combination of automated and manual workstations—are two:

- Automation may be introduced gradually on an existing manual line
- Certain manual operations are too difficult or too costly to automate

We will discuss this when talking of DFAA

Partial automation

Assumptions for the analysis:

- Workstations perform either processing or assembly operations
- Processing and assembly times at automated stations are constant, though not necessarily equal at all stations
- The system uses synchronous transfer of parts between stations
- The system does not use internal buffer storage
- Station breakdowns occur only at automated stations

We will detail on this later on

Partial automation

The ideal cycle time (T_c) is determined by the slowest station on the line, which is usually a manual station, in which case T_c may display a considerable degree of variability reflecting the randomness of the human operator. Here we assume an average value for T_c over time.

Partial automation

Station breakdowns occur only at automated stations. Let n_a be the number of automated stations in the system, and T_d the average downtime per occurrence. For automated stations performing processing operations, let p_i be the probability (or frequency) of breakdowns per cycle; whilst for automated stations that perform assembly operations, let q_i and m_i equal, respectively, the defect rate and probability that the defect will cause station i to stop. For assembly station is valid the relation $p_i=m_iq_i$ .Thus, the average actual production time (T_p) is given by:

$$T_p = T_c + \sum_{i \in n_a} p_i T_d \quad \text{or*} \quad T_p = T_c + n_a p T_d \quad **$$

*In the special case, where m_i is the same as m, and q_i is the same as q
**p = mq for those stations that perform assembly consisting of the addition of a part

Partial automation

Let n_w be the number of stations in system operated by manual workers; therefore the total number of workstations in the system (n) is:

$$n = n_a + n_w$$

The total cost to operate the line (C_o) is:

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

Where:

- C_{at} is the cost to operate the automatic transfer mechanism
- C_{asi} is the cost to operate the automatic workstation i
- C_{wi} is the cost to operate manual workstation i

Partial automation

Assuming that the costs in the same kind of station are costant thus $C_{asi} = C_{as}$ and $C_{wi} = C_w$ it is possible to simplify the previous to:

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

The total cost per unit produced (C_{pc}) is:

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

where C_m is the cost of materials and C_t is the cost of disposable tooling.

Partial automation

Keypoint

For partial automation we must divide our analysis into a consideration of the times, costs and benefits of automated workstations, and the times, costs and benefits of manual workstations, before combining the two to achieve the final result.

Example: partial automation

A partially automated production line has a mixture of three mechanized and three manual workstations. There are a total of six stations, and the ideal cycle time of 1.0 min, which includes a transfer time of 6 sec. Data on the six stations are listed in the following table.

	Station	Type	Process time	p_i
	1	Manual	36 sec	0
	2	Automatic	15 sec	0.01
	3	Automatic	20 sec	0.02
	4	Automatic	25 sec	0.01
Bottleneck	5	Manual	54 sec	0
	6	Manual	33 sec	0

Example: partial automation

Cost of the transfer mechanism C_{at} = \$0.10/min, cost to run each automated station C_{as} = \$0.12/min, and labor cost to operate each manual station C_w = \$0.17/min.

It has been proposed to substitute an automated station in place of station 5. The cost of this station is estimated at C_{as5} = \$0.25/min and its breakdown rate $p_5 = 0.02$, but its process time would be only 30 sec, thus reducing the overall cycle time of the line from 1.0 min to 36 sec.

Average downtime per breakdown of the current line, as well as for the proposed configuration, is 3.5 min.

Example: partial automation

Assume the line operates without storage buffers, so when an automated station stops, the whole line stops, including the manual stations. Also, in computing costs, neglect material and tooling costs.

Determine the following for the current line and the proposed line:

(a) production rate

(b) proportion uptime

(c) cost per unit.

Example: partial automation

Solution current line

(a) T_c = 1.0 min, F = 0.01 + 0.02 + 0.01 = 0.04

T_p = 1.0 + 0.04(3.5) = 1.0 + 0.14 = 1.14 min/unit, R_p = 1/1.14 = 0.877 units/min = **52.6 units/hr**

(b)

E = 1.0/1.14 = 0.877 = **87.7%**

(c)

C_o = 0.10 + 3(0.12) + 3(0.17) = \$0.97/min. C_{pc} = (0.97)(1.14) = **\$1.106/unit**.

Example: partial automation

Solution proposed line

(a) T_c = 36 sec = 0.6 min F = 0.01 + 0.02 + 0.01 + 0.02 = 0.06

T_p = 0.6 + 0.06(3.5) = 0.6 + 0.21 = 0.81 min/unit, R_p = 1/0.81 = 1.235 units/min = **74.1 units/hr**

(b) E = 0.6/0.81 = 0.7407 = **74.1%**

(c)

C_o = 0.10 + 3(0.12) + 0.25 + 2(0.17) = $1.05/min C_{pc} = (1.05)(0.81) = **$0.851/unit**.

Lesson learned (1)

1. The parts delivery system must deliver components at a net rate, otherwise the assembly system performance is limited by the parts delivery system rather than the assembly process technology
2. The quality of components added in an automated assembly system has a significant effect on system performance. Poor quality components can result in jams at stations, or the assembly of defective components onto base units, which renders the entire assembled product defective
3. As the number of workstations increases in an automated assembly system, uptime efficiency and production rate tend to decrease due to parts quality and station reliability effects

Lesson learned (2)

4. The cycle time of a multi-station assembly system is determined by the slowest station in the system
5. Compared with a multi-station assembly machine, a single-station assembly system with the same number of assembly tasks has a lower production rate but a higher uptime efficiency
6. Multi-station assembly systems are appropriate for high production applications and long production runs; single-station assembly systems have longer cycle times, and are more suited to mid-range quantities of product
7. Storage buffers should be used on partially automated production lines to isolate the manual stations from breakdowns of the automated stations
8. An automated station should be substituted for a manual station only if it reduces cycle time sufficiently to offset any negative effectives of lower reliability

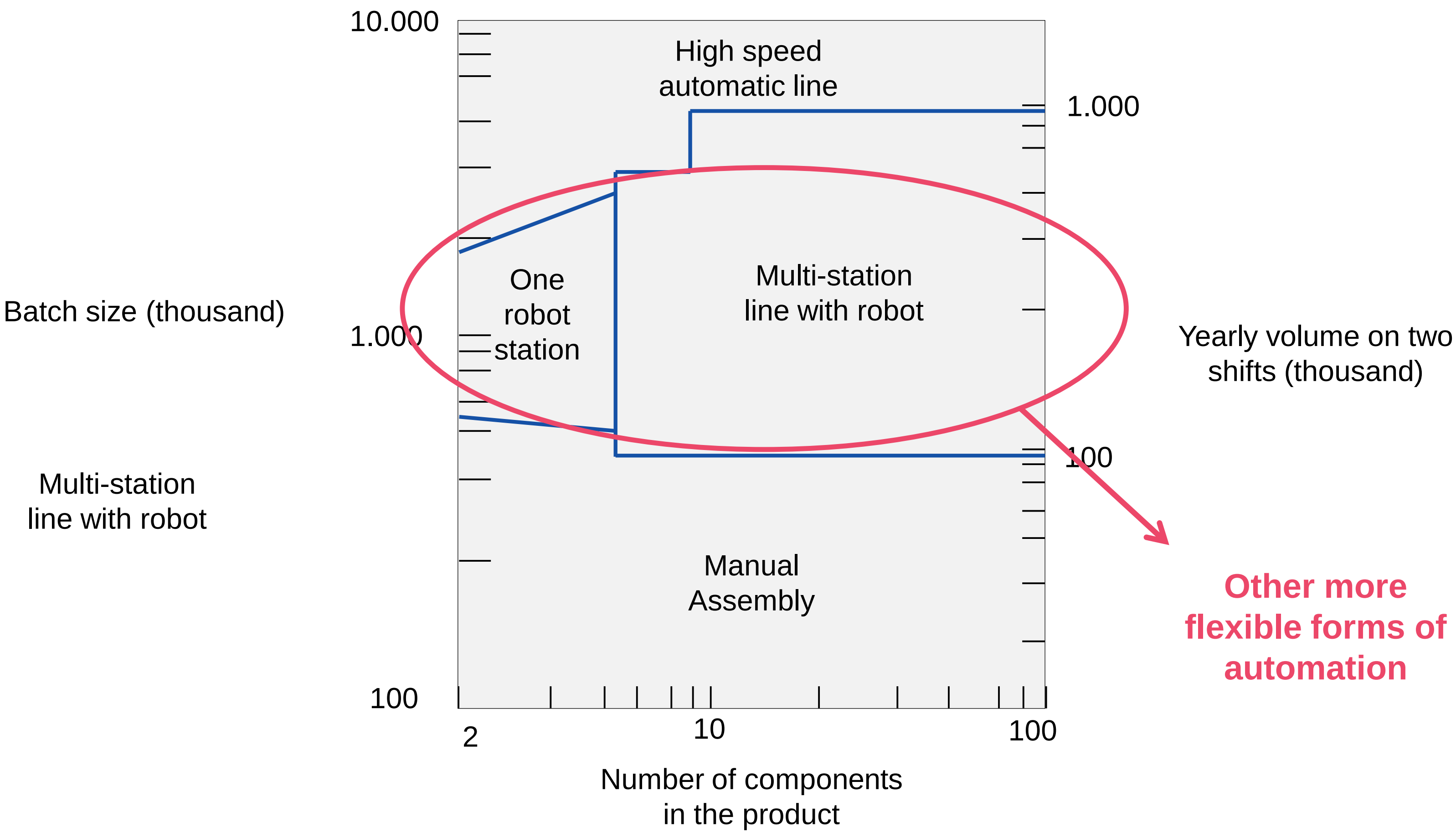
Questions for the formative assessment

1. What are automated assembly systems? What system configurations can automated assembly systems take?
2. List the hardware components used for parts delivery at workstations.
3. What would generally be seen as typical automated assembly processes?
4. How do the high level sensor and the low level sensor in parts delivery at workstations function?
5. Why is automated assembly sometimes considered a “game of chance”?
6. List performance metrics associated with multi-station assembly machines.
7. For what reasons would partial automation be used?

Part 2

Important concept related to high speed and other form of assembly automation

Assembly approaches



Automated production line

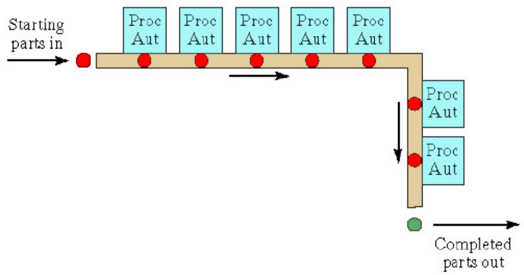
From now on we will extend the domain of automated assembly to the whole automated production. The characterization of automated assembly systems that do not fall in the cathegory of high speed assembly automation can be effectively done within this extended domain

Intended Learning Outcome

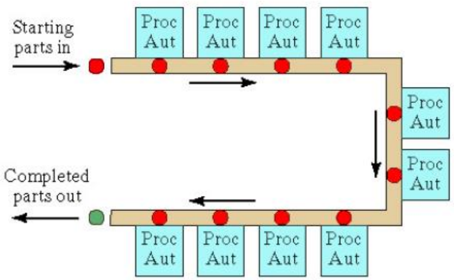
- Discuss the use of synchronous and asynchronous transport systems and buffers and their integration
- Describe and characterize the salient aspects of flexible automation

Other possible layout

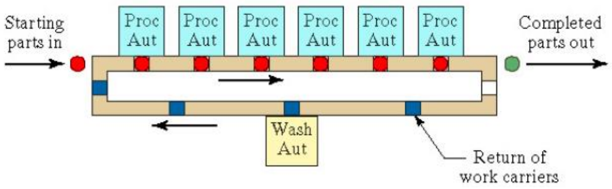
L-shaped layout



U-shaped layout



Rectangular layout



Consists of two or more straight-line transfer sections, where the segments are usually perpendicular to each other. Layout designs include:

- L-shaped layout,
- U-shaped layout,
- Rectangular layout.

Reasons for favoring segmented in-line over in-line configurations include:

- floor space considerations;
- reorientation of workparts to present different surfaces in different line segments;
- the swift return of work holding fixtures (in the rectangular arrangement).

Workpart transfer

The function of the workpart transfer system is to move parts between stations on the production line, a function performed by means of transfer mechanisms that are either:

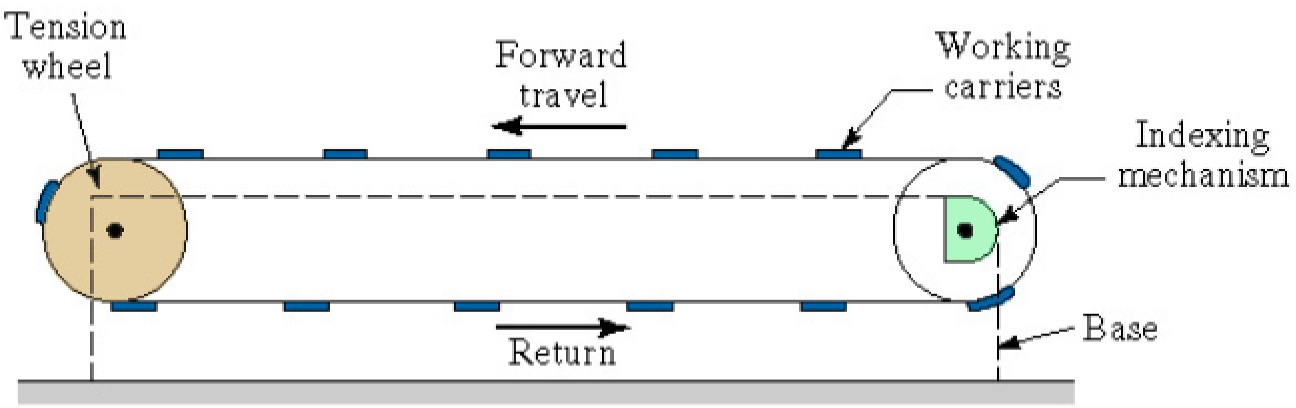
- synchronous
- asynchronous.

Synchronous transfer is the traditional method of moving parts within a production system, but asynchronous transfer has the following advantages:

- Greater flexibility
- Fewer pallet fixtures needed
- Easy to rearrange or expand the production system

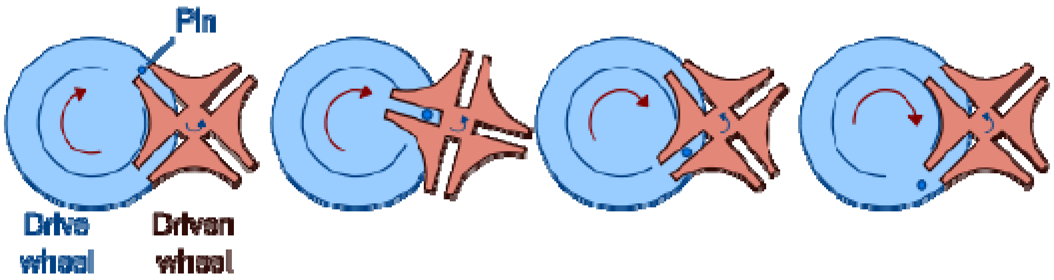
Linear Transfer system

Types of linear transfer systems used for workpart transfer include powered roller conveyors, belt conveyors, chain driven conveyors, and cart-on-track conveyors. Work carriers attached to the conveyor ensure that workparts are transferred in a synchronous fashion from one workstation to the next, while the ‘over-and-under’ design of the conveyor belt ensures a continuous supply of empty carriers for reloading.

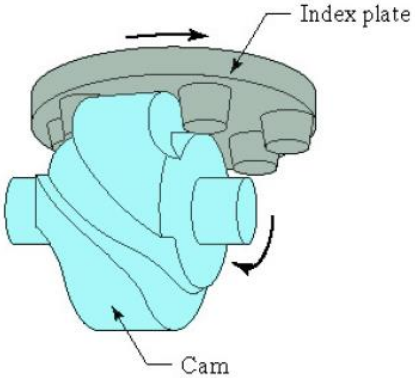


Rotary Indexing Mechanisms

Several mechanisms can be used to generate the type of rotary power required by rotary indexing machines. Two of these are the Geneva mechanism



and the cam drive.

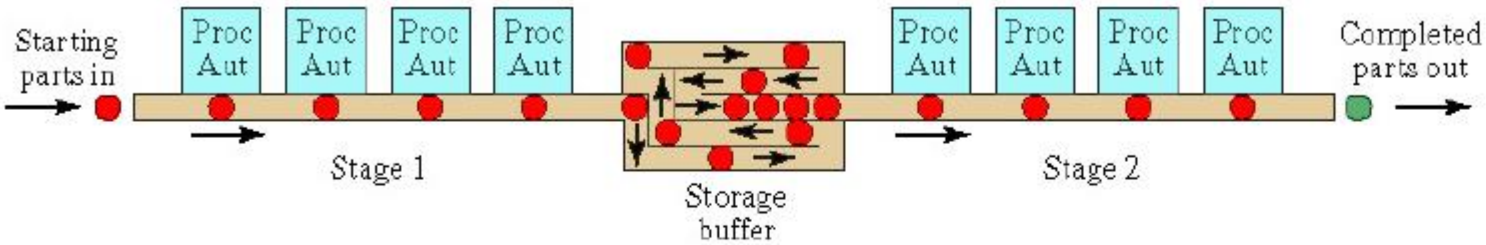


Storage buffers

Automated production lines may also contain storage buffers, which act as temporary storage for parts that are traversing the line, before being released from the buffer so that they may proceed to downstream workstations. Storage buffers are either manually operated or automated. In automated versions, a mechanism is used to accept parts from upstream workstations, a place is designated as storage for the incoming parts, and a mechanism subsequently releases the parts, as required, to supply downstream workstations

Storage buffers

Storage capacity—the number of parts a particular storage buffer may hold—is an important metric for determining storage effectiveness; as well as the location and arrangement of storage buffers—which may be located between every pair of adjacent workstations, or between lines stages containing multiple workstations (see fig below).



Storage buffers advantages in automated production lines

- They reduce the impact of station breakdowns—storage buffers can supply lines that are continuing to operate, whilst other lines are down for repair.
- They provide a bank of parts to supply the line—parts may be collected into a storage unit and automatically fed to a downstream manufacturing system, thus permitting untended operation of the system between refills.
- They provide a place to put the output of the line.
- They allow for curing time or other process delay—curing may be required for some operations (e.g. paint to dry, or adhesives to bond); the storage buffer can provide sufficient time for this to occur before supplying parts to the downstream station.
- They smooth cycle time variations—cycle time variations may occur on the line, so that by means of storage buffers downtimes or time delays may be avoided or offset to the benefit of the overall cycle time.

Control of production lines

Three basic control functions can be distinguished in the operation of an automatic transfer machine:

- Sequence control
- Safety monitoring
- Quality control

Control of production lines

Sequence control:

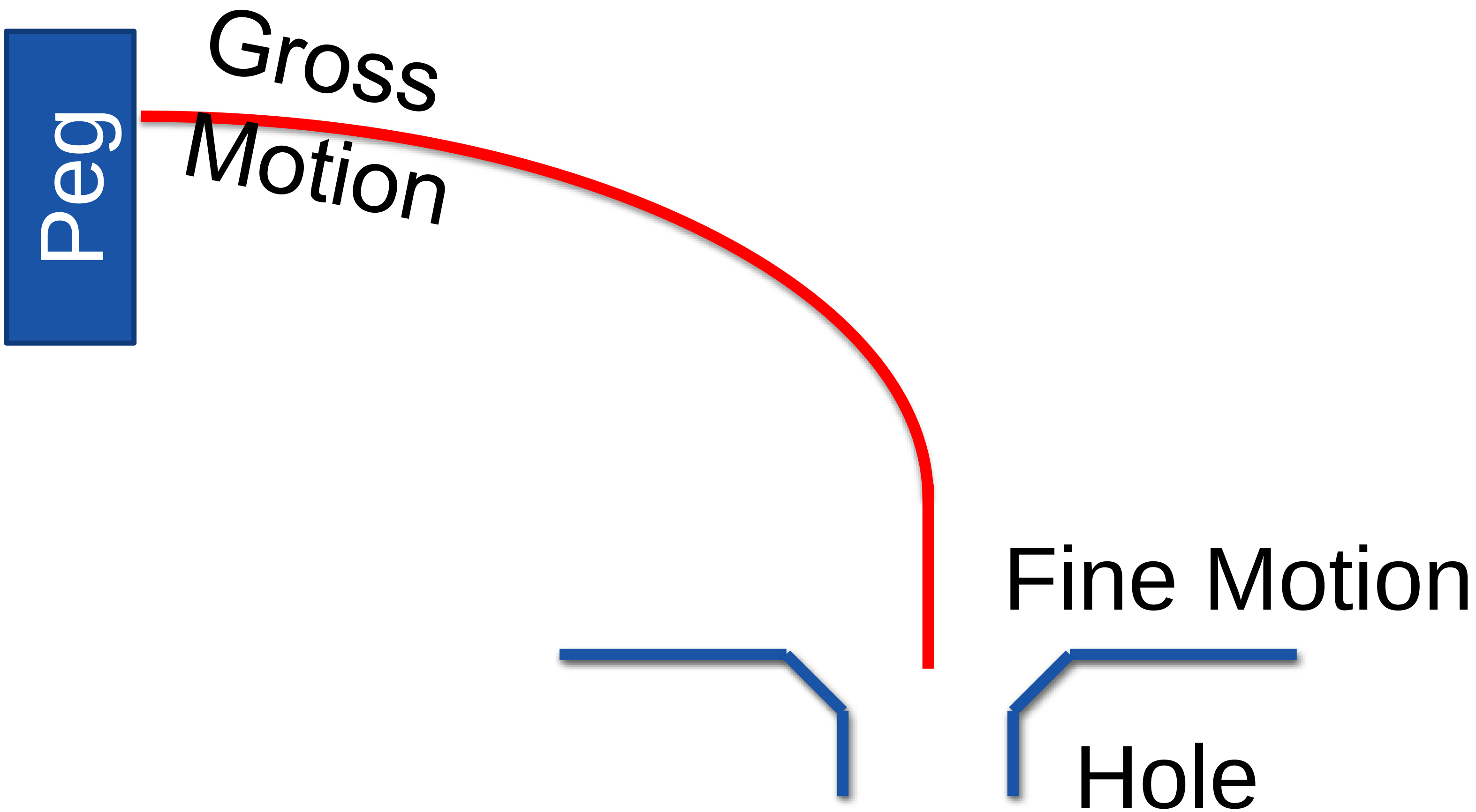
This co-ordinates the set of actions of the transfer system and associated workstations, so that the various activities of the production line are carried out with split-second timing and accuracy. In automated production lines sequence control includes both logic control and sequencing

The Assembly Motions

An Assembly process is a series of two basic kinds of motions:

- Gross Motions
- Fine Motions

The Assembly Motions



Gross Motions

- Fast and with no needs of high accuracy
- Used mostly for trasport purposes
- Large if compared with the size of the part
- Usually without “control” on the trajectory
- No contact during gross motions (collisions)

Fine Motions

- High Accuracy needed
- Usually slower than gross motion
- Small if compared with the size of the part
- Made by a series of “controlled” contacts

Errors

Gross Motion

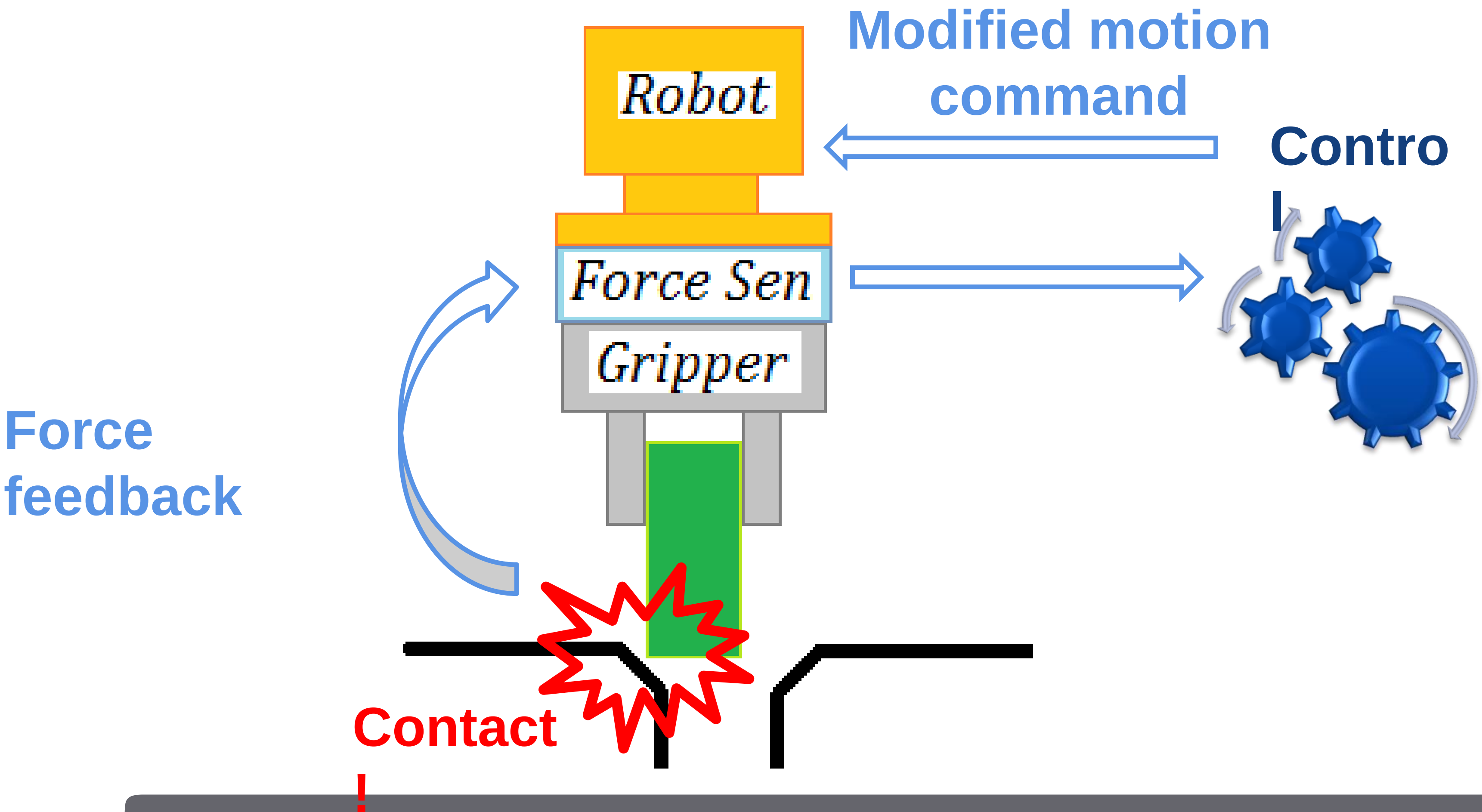
- They can be seen, but not felt until it is too late
- Can be avoided with preplanning (simulation of the process is a cheap and effective tool!)

Fine Motion:

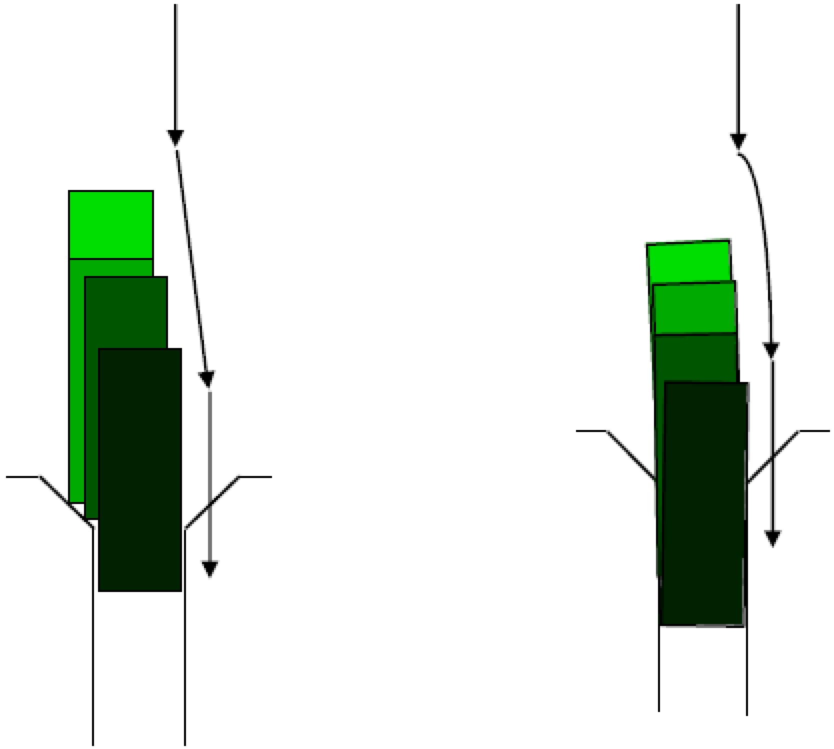
- They can't be seen but they can be felt and corrected according with the related signals
- Preplanning is not rewarded
- Unavoidable for a reasonnable cost

Therefore a closed loop control approach is suitable!

Closed Loop Control



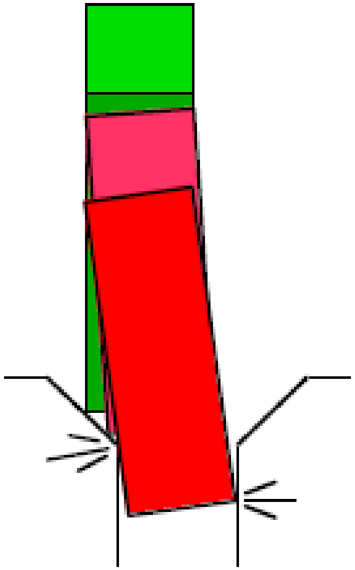
Lateral and Angular errors



Lateral error requires lateral motion to correct it

Angular error requires angular motion to correct it

Lateral Errors→Angular errors!!



"Lateral errors can become angular errors with unforseable results"

Control of production lines

Safety monitoring:

This ensures that the production line does not operate in an unsafe manner, prioritizing human safety first, and equipment safety second. Safety monitoring is accomplished by sensors integrated with the production line, which complete a safety feedback loop and avoid hazardous operation. Safety devices used include interlocks on equipment that activate during maintenance, and tool monitoring systems to avoid excessive tool wear during production.

Control of production lines

Quality control

Here certain quality attributes of the workparts are monitored, so that defective work units may be detected and rejected by the production line. Inspection devices for quality control are sometimes integrated into individual workstations; at other times, separate inspection stations are included in the line for the sole purpose of checking the desired quality characteristic

Analysis of transfer lines

Three areas are considered for analysis:

Line balancing—where the total processing work accomplished on the automated line must be divided as evenly as possible among the workstations. Work tasks are easier to divided into balanced segments in manual assembly lines, where operator flexibility may be relied on; however, technological considerations complicates the issue for the automated production line.

Process technology—this refers to the body of knowledge about the theory and principles of the particular manufacturing processes used on the production line. Many of the problems encountered, for example in machining, can be solved by direct application of good machining principles.

System reliability—that is, determining the overall reliability of the system put in place. In a highly complex and integrated system, the failure of any one component can stop the entire system. We examine scenarios of transfer lines with no internal parts storage, and scenarios of transfer lines with internal storage buffers.

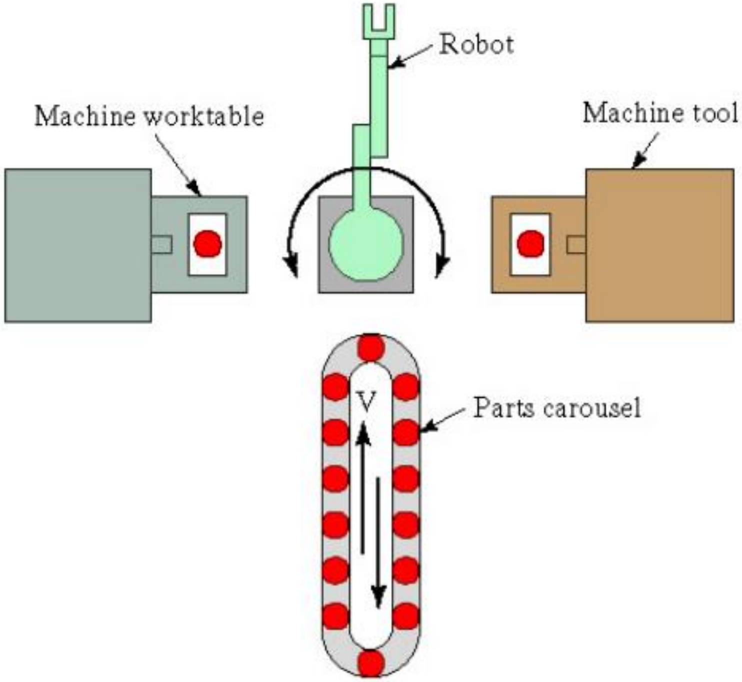
Flexible Automation*

To qualify as being flexible, a manufacturing system should satisfy the following criteria ("yes" answer for each question):

1. Can it process different part styles in a non-batch mode?
2. Can it accept changes in production schedule?
3. Can it respond gracefully to equipment malfunctions and breakdowns?
4. Can it accommodate introduction of new part designs?

* Flexible workstation includes assembly station!

Flexible Automation: test



Automated manufacturing cell with two machine tools and robot. Is it a flexible cell?

Flexible Automation: test

Example: while repairs are being made on the broken machine, can its work be temporarily reassigned to the other machine?

1. Part variety test: Can it machine different part configurations in a mix rather than in batches?
2. Schedule change test: Can production schedule and part mix be changed?
3. Error recovery test: Can it operate if one machine breaks down?
4. New part test: As new part designs are developed, can NC part programs be written off-line and then downloaded to the system for execution?

Flexible Automation

Kinds of operations:

- Processing vs. assembly
- Type of processing
  - If machining, rotational vs. non-rotational

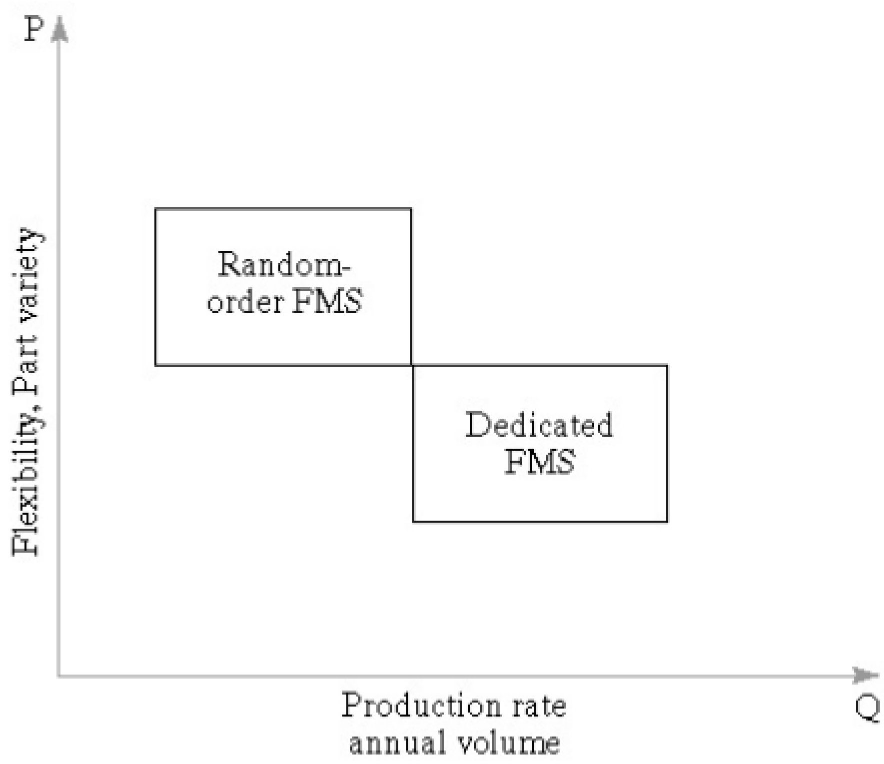
Number of machines (workstations):

- 1. Single machine cell (n = 1)
- 2. Flexible manufacturing cell (n = 2 or 3)
- 3. Flexible manufacturing system (n = 4 or more) **FMS**

FMS type: level of flexibility

1. Dedicated FMS □
   - Designed to produce a limited variety of part styles □
   - The complete universe of parts to be made on the system is known in advance □
   - Part family likely based on product commonality rather than geometric similarity
2. Random-order FMS □
   - Appropriate for large part families □
   - New part designs and engineering changes will be introduced □
   - Production schedule is subject to daily changes

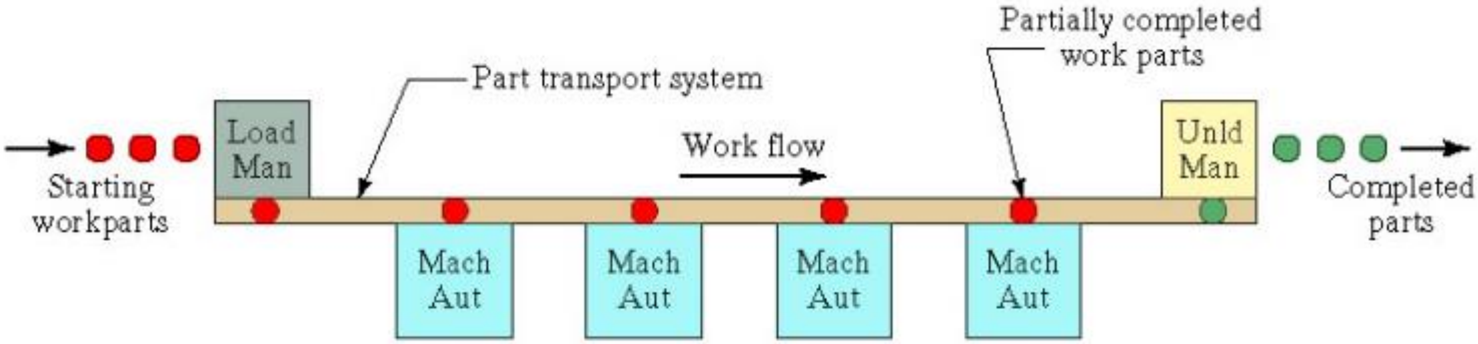
FMS type: level of flexibility



FMS Layout

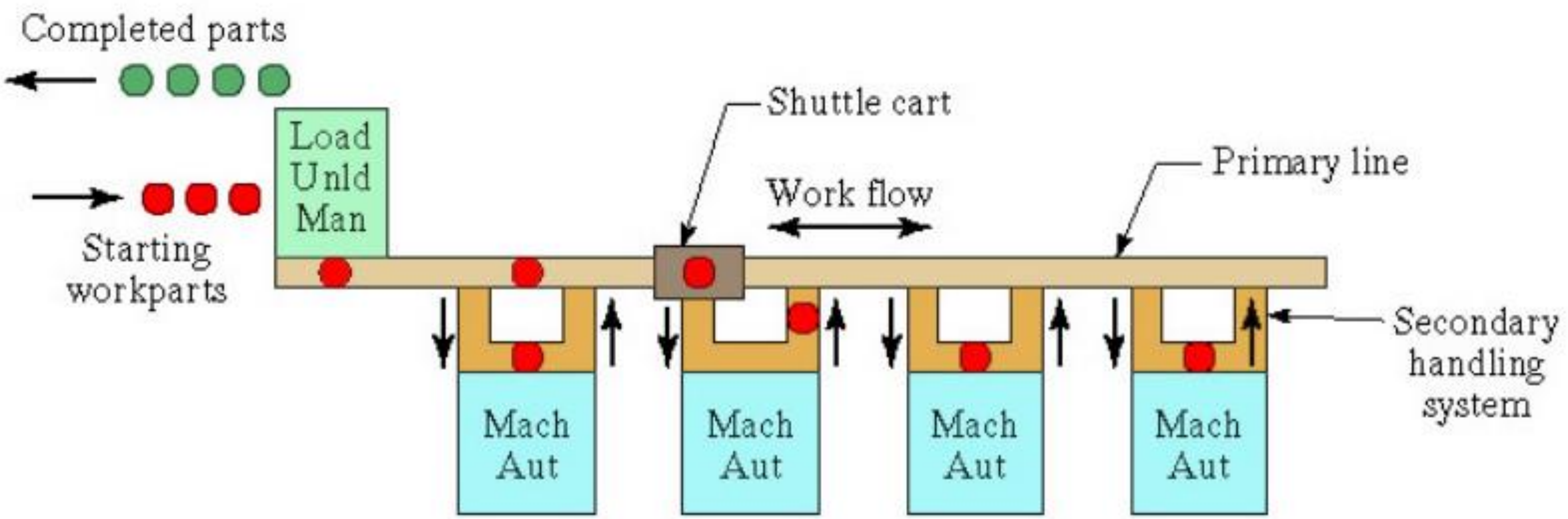
- The layout of the FMS is established by the material handling system:
- Five basic types of FMS layouts
  1. In-line
  2. Loop
  3. Ladder
  4. Open field
  5. Robot-centered cell

FMS In-Line Layout



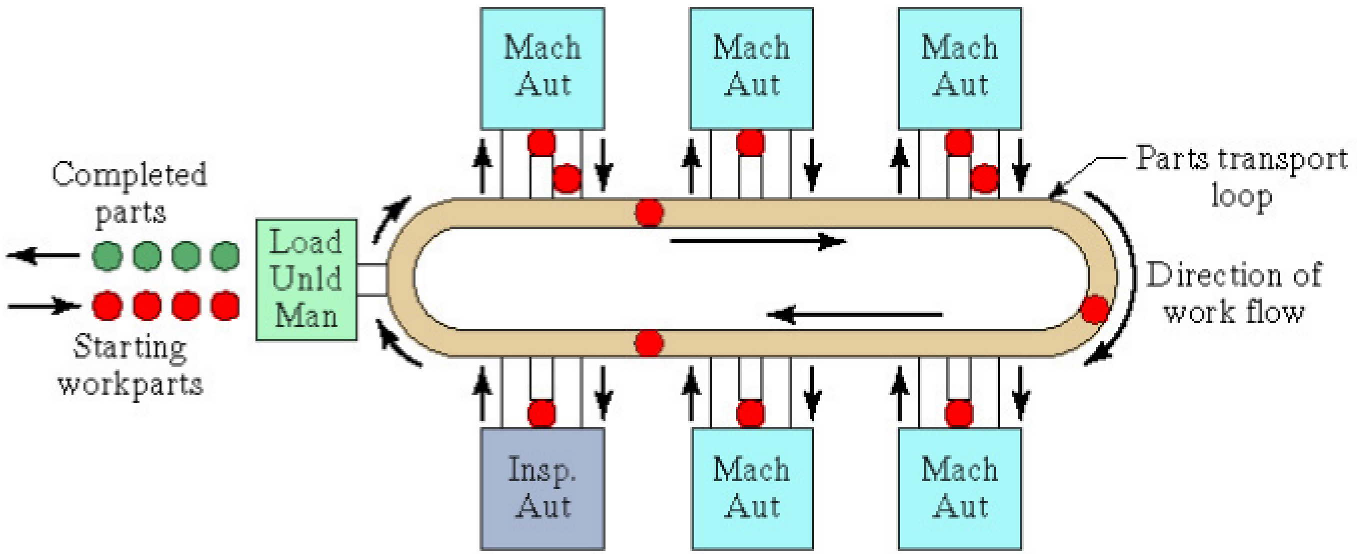
- Straight line flow, well-defined processing sequence similar for all work units □
- Work flow is from left to right through the same workstations □
- No secondary handling system

FMS In-Line Layout



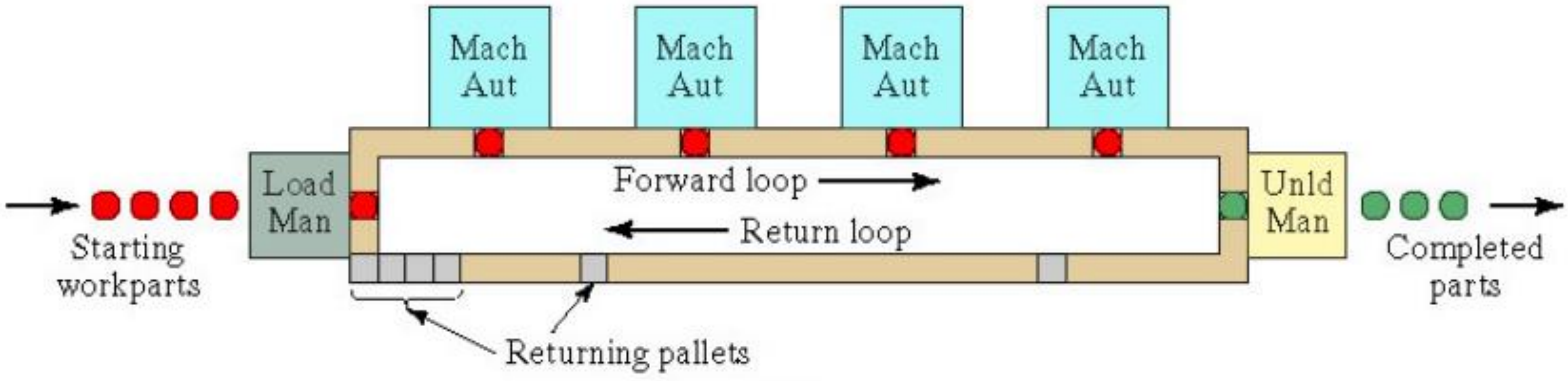
Linear transfer system with secondary parts handling system at each workstation to facilitate flow in two directions

FMS Loop Layout



- One direction flow, but variations in processing sequence possible for different part types
- Secondary handling system at each workstation

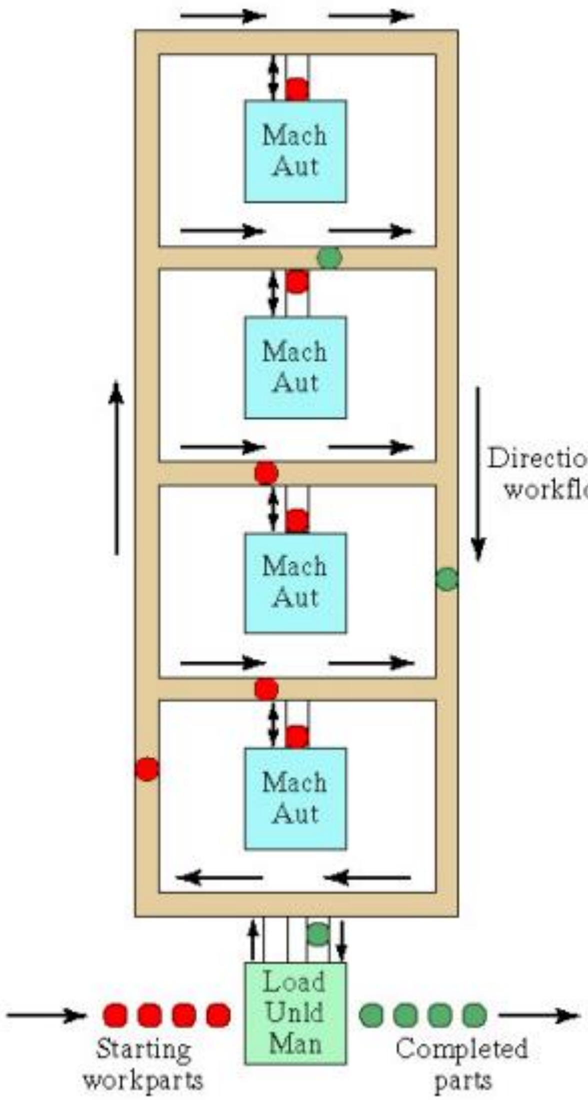
FMS Rectangular Layout



Rectangular layout allows recirculation of pallets back to the first station in the sequence after unloading at the final station

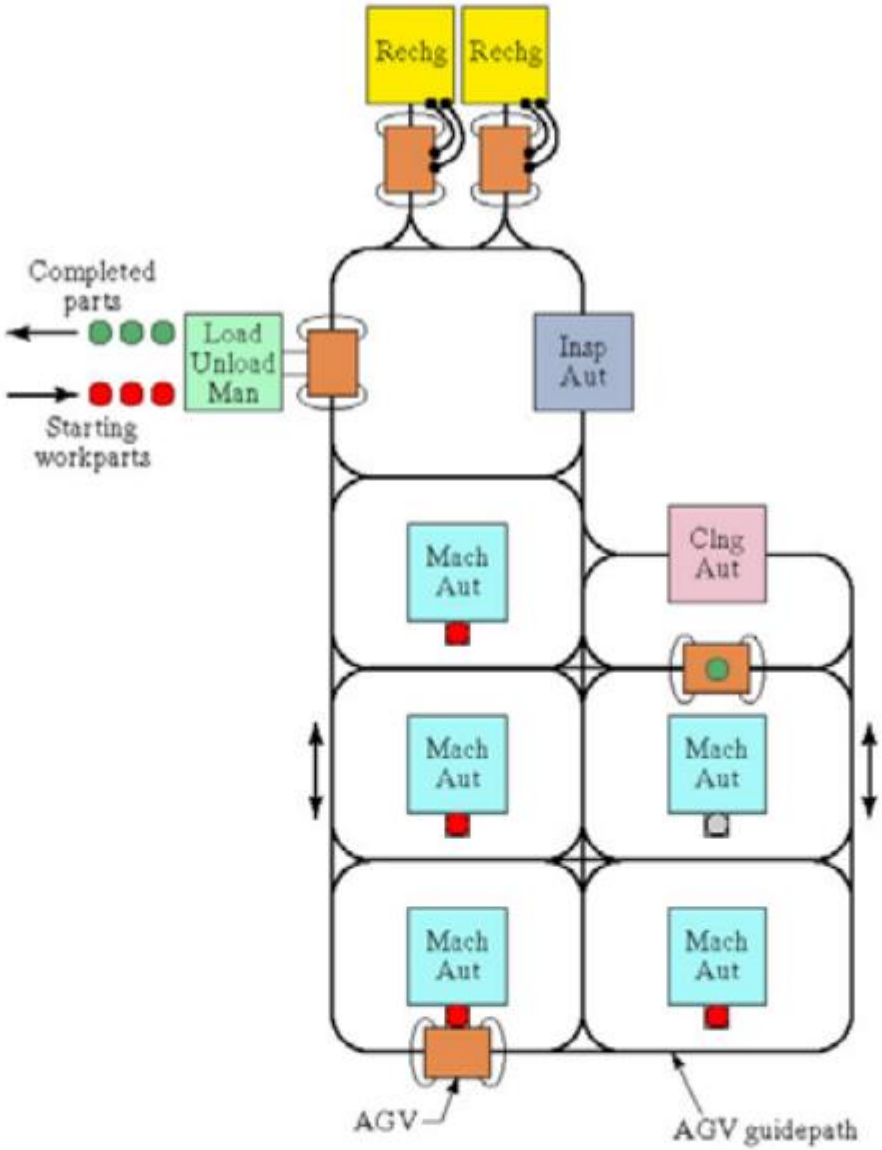
FMS Ladder Layout

- Loop with rungs to allow greater variation in processing sequence



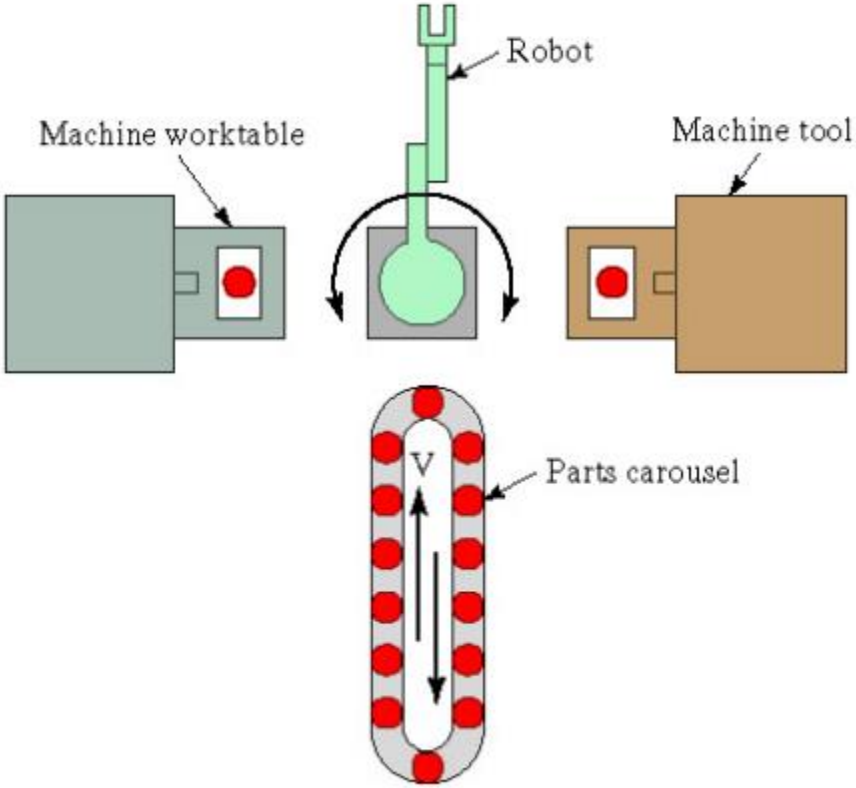
FMS Open Field Layout

Multiple loops and ladders, suitable for large part families



FMS Robot-Centered Cell Layout

Suited to the handling of rotational parts and turning operations



FMS computer functions

1. Workstation control: individual stations require controls, usually computerized
2. Distribution of control instructions to workstations: central intelligence required to coordinate processing at individual stations
3. Production control: product mix, machine scheduling, and other planning functions
4. Traffic control: management of the primary handling system to move parts between workstations
5. Shuttle control: coordination of secondary handling system with primary handling system
6. Workpiece monitoring: monitoring the status of each part in the system

FMS computer functions

7. Tool control. Tool location: keeping track of each tool in the system. Tool life monitoring: monitoring usage of each cutting tool and determining when to replace worn tools
8. Performance monitoring and reporting: availability, utilization, production piece counts, etc.
9. Diagnostics: diagnose malfunction causes and recommend repairs

FMS human labour

- Loading and unloading parts from the system
- Changing and setting cutting tools
- Maintenance and repair of equipment
- NC part programming
- Programming and operating the computer system
- Overall management of the system

FMS Benefits

1. Increased machine utilization □
- Reasons: □
  - 24 hour operation likely to justify investment □
  - Automatic tool changing □
  - Automatic pallet changing at stations □
  - Queues of parts at stations to maximize utilization □
  - Dynamic scheduling of production to account for changes in demand □
2. Fewer machines required
3. Reduction in factory floor space required

FMS Benefits

4. Greater responsiveness to change □
5. Reduced inventory requirements: different parts produced continuously rather than in batches □
6. Lower manufacturing lead times □
7. Reduced labor requirements □
8. Higher productivity □
9. Opportunity for unattended production: machines run overnight ("lights out operation")

Video

- Complete Custom Built Line Automation (6:57)
- Car Assembly Line (2:51)
- Automatic car coating (1:10)
- How its made Ballpoint Pens (5:00)
- Industrial conveyor overview (1:16)

Other video

- Modular Conveyors (6:25)

Question for the formative assessment

8. Which are the possible reasons for favoring segmented in-line over in-line configurations?
9. Which are the advantages of asynchronous transfer system compared to synchronous ones?
10. Which are the advantages of storage buffers in automated production lines?
11. Which criteria should a manufacturing system satisfy to be qualified as flexible?