

## Automated Assembly Systems

Assembly involves the joining together of two or more separate parts to form new entity which may be assembly or subassembly.

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

Automated assembly system performs a sequence of automated operations to combine multiple components in to a single entity which can be a final product or sub assembly.

Automated assembly technology should be considered when the following condition exists.

- ✓ 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.

Automated assembly system involves less investment compared to transfer lines because

1. Work part produced are smaller in size compared to transfer lines.
2. Assembly operations do not have the large mechanical forces and power requirement
3. Size is very less compared to transfer lines.

## DESIGNS FOR AUTOMATED ASSEMBLY

Recommendations and principles that can be applied in product design to facilitate automated assembly

- ☞ **Reduce the amount of assembly required:** This principle can be realized during design by combining functions within the same part that were previously accomplished by separate components in the product. The use of plastic molded parts to substitute for sheet metal parts is an example of this principle. A more complex geometry molded into a plastic part might replace several metal parts.

Although the plastic part may seem to be more costly, the savings-in assembly time probably justify the substitution in many cases.

- ☞ ***Use modular design:*** In automated assembly, increasing the number of separate assembly steps that are done by a single automated system will result in an increase in the downtime of the system. To reduce this effect, Riley suggests that the design of the product be modular, with perhaps each module requiring a maximum of 12 or 13 parts to be assembled on a single assembly system. Also, the subassembly should be designed around a base part to which other components are added.
- ☞ ***Reduce the number of fasteners required:*** Instead of using separate screws and nuts, and similar fasteners, design the fastening mechanism into the component design using snap fits and similar features. Also, design the product modules so that several components are fastened simultaneously rather than each component fastened separately.
- ☞ ***Reduce the need for multiple components to lie handled at once:*** The preferred practice in automated assembly machine design is to separate the operations at different stations rather than to handle and fasten multiple components simultaneously at the same workstation. (It should be noted that robotics technology is causing a rethinking of this practice since robots can be programmed to perform more complex assembly tasks than a single station in a mechanized assembly system.
- ☞ ***Limit the required directions of access:*** This principle simply means that the number of directions in which new components are added to the existing subassembly should be minimized. If all of the components can be added vertically from above, this is the ideal situation. Obviously, the design of the subassembly module determines this.
- ☞ ***Require high quality in components:*** High performance of the automated assembly system requires consistently good quality of the components that are added at each workstation. Poor-quality components cause jams in the feeding and assembly mechanisms which cause downtime in the automated system.
- ☞ ***Implement hopperability:*** This is a term that is used to identify the ease with which a given component can be fed and oriented reliably for delivery from the parts hopper to the assembly workhead.

## TYPES OF AUTOMATED ASSEMBLY SYSTEMS

Based on the type of work transfer system that is used in the assembly system:

- Continuous transfer system
- Synchronous transfer system
- Asynchronous transfer system
- Stationary base part system

The first three types involve the same methods of workpart transport described in automated flow line. In the stationary base part system, the base part to which the other components are added is placed in a fixed location, where it remains during the assembly work.

Based on physical configuration:

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

The *dial-type machine*, the base part are indexed around a circular table or dial. The workstations are stationary and usually located around the outside periphery of the dial. The parts ride on the rotating table and are registered or positioned, in turn, at each station a new component is added to base part. This type of equipment is often referred to as an *indexing machine* or *dial index machine* and the configuration is shown in Figure 1 and example of six station rotary shown in figure 2.

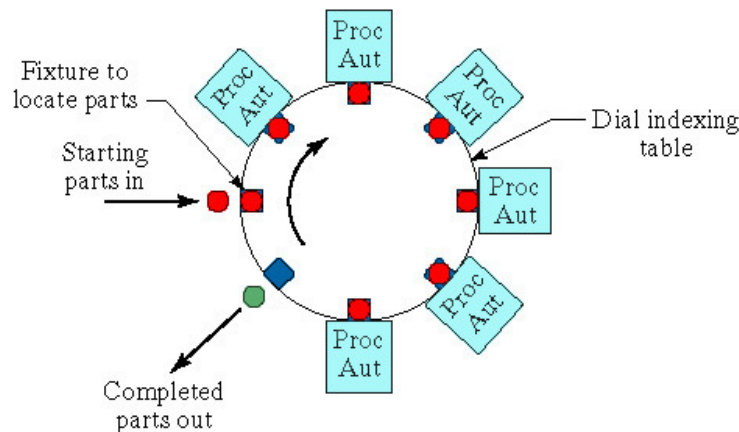


Figure 1 Rotary configuration



Figure 2 Example of 6 station rotary configuration for assembly

***In-line type configuration***

The *in-line* configuration assembly system consists of a sequence of workstations in a more-or-less straight-line arrangement as shown in figure 3. An example of an in-line transfer machine used for metal-cutting operations is illustrated in Figure 4. The *in-line assembly machine* consists of a series of automatic workstations located along an in-line transfer system. It is the automated version of the manual assembly line. Continuous, synchronous, or asynchronous transfer systems can be used with the in-line configuration.

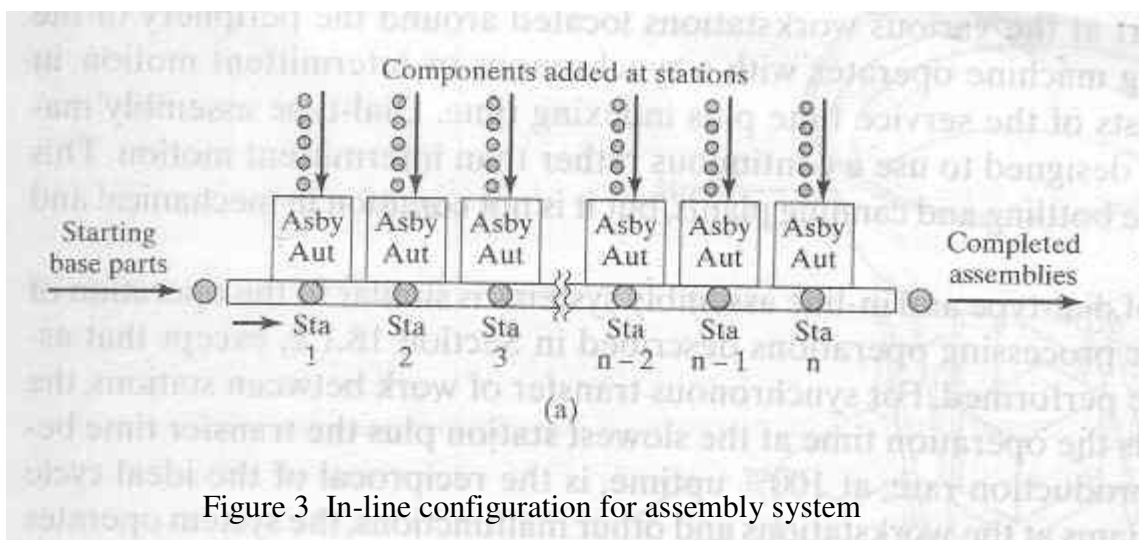


Figure 3 In-line configuration for assembly system

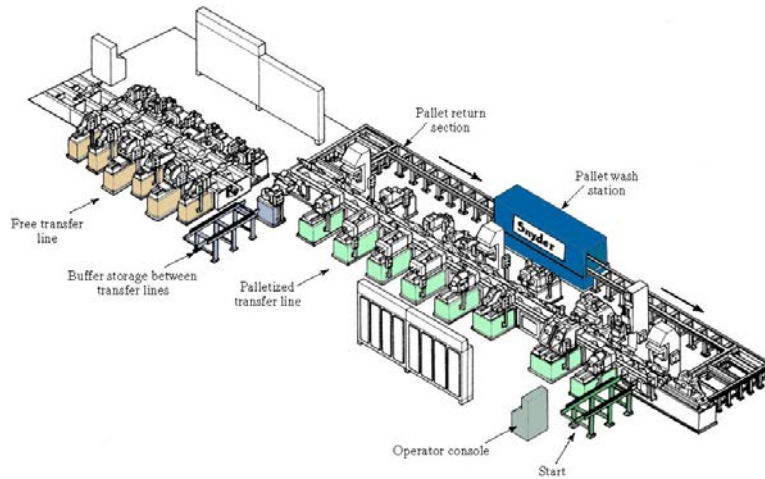


Figure 4 Example of 20 stations In-line configuration

**Segmented In-line type**

The segmented *in-line* configuration consists of two or more straight-line arrangement which are usually perpendicular to each other with L-Shaped or U-shaped or Rectangular shaped as shown in figure 5-7. The flow of work can take a few 90° turns, either for workpieces reorientation, factory layout limitations, or other reasons, and still qualify as a straight-line configuration.

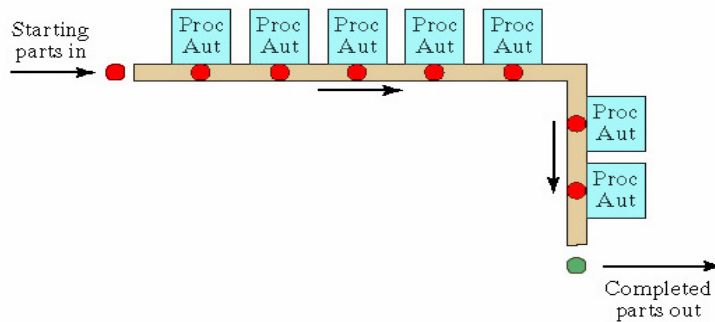


Figure 5 L-shaped configuration

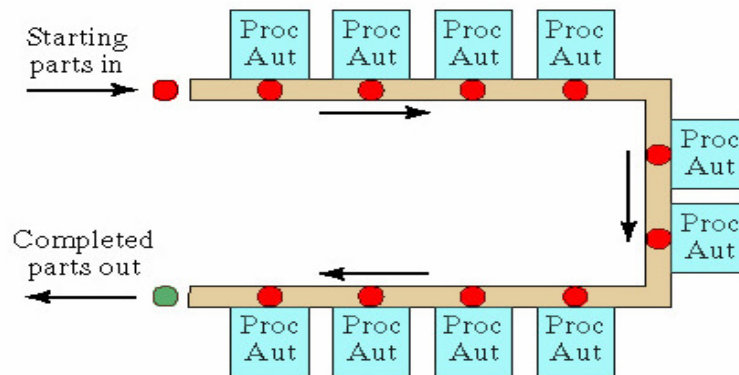


Figure 6 U-shaped configuration

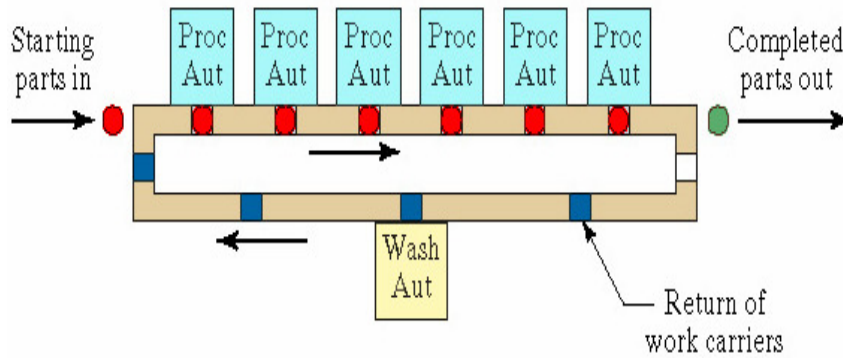


Figure 7 Rectangular-shaped configuration

**Carousel assembly system**

It represents a hybrid between the circular flow of work provided by the dial assembly machine and straight work flow of the in-line. It is as shown in the figure 8

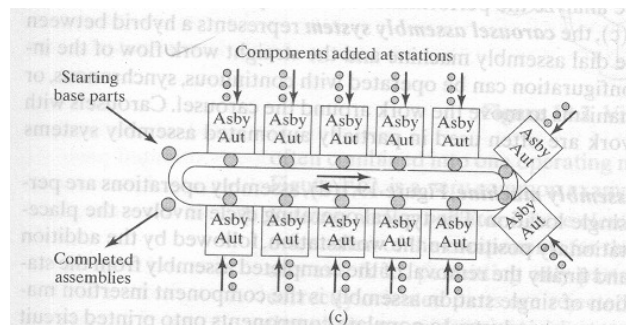


Figure 8 configuration of a carousel assembly system

**Single-station assembly machine**

In the single-station assembly machine, the assembly operations are performed at a single location (stationary base part system) as shown in figure 9. The typical operation involves the placement of the base part at the workstation where various components are added to the base. The components are delivered to the station by feeding mechanisms, and one or more workheads perform the various assembly and fastening operations.

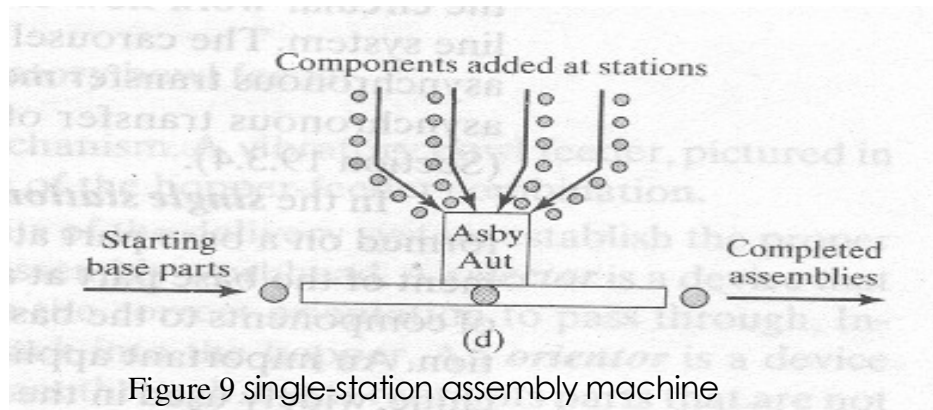


Figure 9 single-station assembly machine



## PARTS FEEDING DEVICES

In each of the configurations described above, a means of delivering the components to the assembly workhead must be designed. In this section we discuss these devices and their operation.

### *Elements of the parts delivery system*

The hardware system that delivers components to the workhead in an automated assembly system typically consists of the following elements as shown in figure 10:

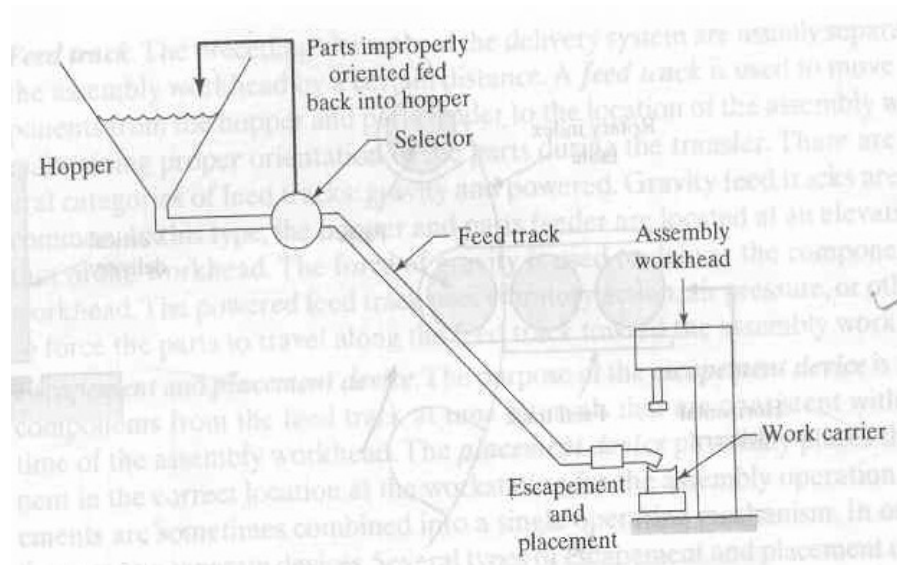


Figure 10 elements of part delivery system

☞ **Hopper:** This is the container into which the components are loaded at the workstation. A separate hopper is used for each component type. The components are usually loaded into the hopper in bulk. This means that the parts are randomly oriented initially in the hopper.

☞ **Parts feeder:** This is a mechanism that removes the components from the hopper one at a time for delivery to the assembly workhead. The hopper and parts feeder are often combined into one operating mechanism. The vibratory bowl feeder, pictured in Figure 11, is a very common example of the hopper-feeder combination.

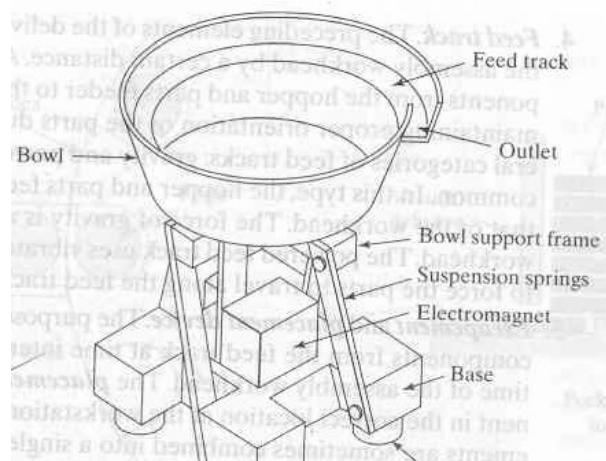


Figure 11 vibratory bowl feeder

☞ **Selector and/or orienter:** These elements of the delivery system establish the proper orientation of the components for the assembly workhead. A selector is a device that acts as a filter, permitting only parts that are in the correct orientation to pass through. Components that are not properly oriented are rejected back into the hopper. An orienter is a device that allows properly oriented parts to pass through but provides a reorientation of components that are not properly oriented initially. Several selector and orienter schemes are illustrated in Figure 12. Selector and orienter devices are often combined and incorporated into one hopper-feeder system.

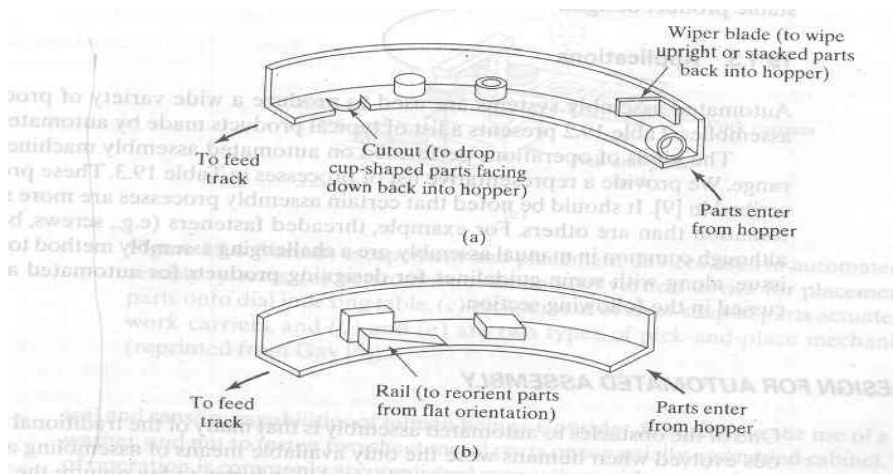


Figure 12 selector (a) and orienter (b)



☞ **Feed track:** The preceding elements of the delivery system are usually located some distance from the assembly workhead. A feed track is used to transfer the components from the hopper and parts feeder to the location of the assembly workhead, maintaining proper orientation of the parts during the transfer. There are two general categories of feed tracks: gravity and powered. The gravity feed track is most common. In this type the hopper and parts feeder are located at an elevation that is above the elevation of the workhead. The force of gravity is used to deliver the components to the workhead. The powered feed track uses vibratory action, air pressure, or other means to force the parts to travel along the feed track toward the assembly workhead.

☞ **Escapement and placement device:** The purpose of the escapement device is to remove components from the feed track at time intervals that are consistent with the cycle time of the assembly workhead. The placement device physically places the component in the correct location at the workstation for the assembly operation by the workhead. Several types of escapement and placement devices are shown in Figure 13.

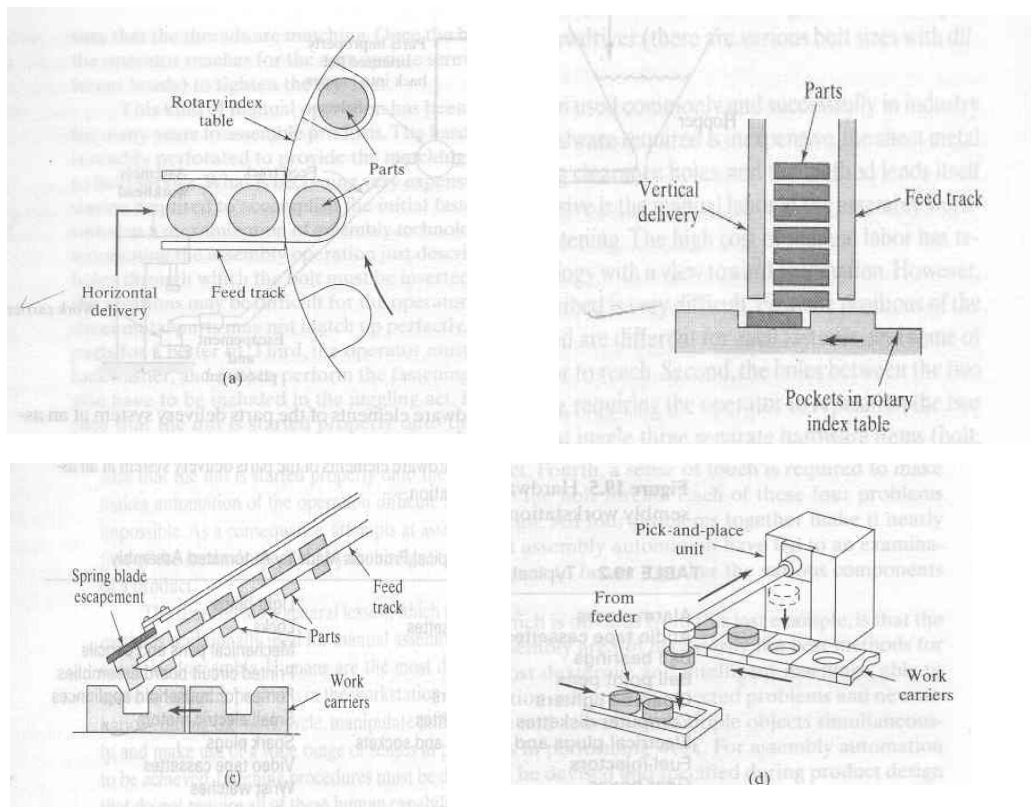


Figure 13 various escapement and placement devices

### *Quantitative analysis of the delivery system operation*

The parts feeding mechanism is capable of removing parts from the hopper at a certain rate  $f$ . These parts are assumed to be in random orientation initially, and must be presented to the selector or orientor to establish the correct orientation. In the case of the selector, a certain proportion of the parts will be correctly oriented initially and these will be allowed to pass through. The remaining proportion, which is incorrectly oriented, will be rejected back into the hopper. In the case of the orientor, the parts that are incorrectly oriented will be reoriented, resulting ideally in a 100% rate of parts passing through the orientor device. In many delivery system designs, the functions of the selector and the orientor will be combined. Let us define  $\theta$  to be the proportion of components that pass through the selector-orientor process and are correctly oriented for delivery into the feed track. Hence the effective rate of delivery of components from the hopper into the feed track will be  $f\theta$ . The remaining proportion,  $(1 - f\theta)$ , will be recirculated back into the hopper.

Assuming that the delivery rate of components  $f\theta$  is greater than the cycle rate  $R_c$  of the assembly machine, a means of limiting the size of the queue in the feed track must be established. This is generally accomplished by placing a sensor (e.g., limit switch, optical sensor, etc.) near the top of the feed track, which is used to turn off the feeding mechanism when the feed track is full. This sensor is referred to as the high-level sensor, and its location defines the active length  $L_{f2}$  of the feed track. If the length of a component in the feed track is  $L_c$ , the number of parts that can be held in the feed track is  $n_{f2} = L_{f2}/L_c$ . The length of the components must be measured from a point on a given component to the corresponding point on the next component in the queue to allow for possible overlap of parts. The value of  $n_{f2}$  is the capacity of the feed track.

Another sensor is placed along the feed track at some distance from the first sensor and is used to restart the feeding mechanism-again. Defining the location of this low-level sensor as  $L_{f1}$ , the number of components in the feed track at this point is  $n_{f1} = L_{f1}/L_c$ .

The rate at which the quantity of parts in the buffer will be reduced when the high-level sensor is actuated =  $R_c$ , where  $R_e$  is the theoretical cycle rate of the assembly machine. On average, the rate at which the quantity of parts will increase upon actuation of the low-level sensor is  $f\theta - R_c$ . However, the rate of increase will not be uniform due to the random nature of the feeder-selector operation.

Accordingly, the value of  $n_{f1}$  must be made large enough to virtually eliminate the probability of a stockout after the low-level sensor has turned on the feeder.

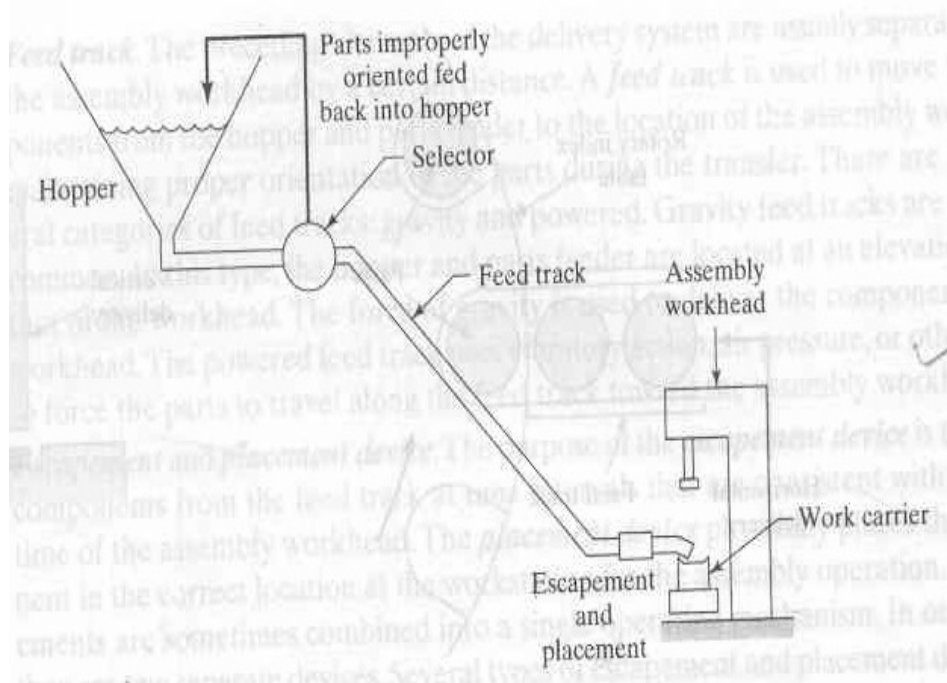


Figure 14 elements of the parts delivery system at an assembly workstation

$R_C$	→ Cycle rate of Assembly System	$n_{f_2} = \frac{L_{f_2}}{L_C}$	→ Number of component in feed track
$L_C$	→ Length of component	$n_{f_1} = \frac{L_{f_1}}{L_C}$	→ Number of components at low level sensors
$L_{f_2}$	→ Length of feed track (High level sensors)		
$L_{f_1}$	→ Length of low level sensors		
$f$	→ The rate at which parts are removed from hopper		
$\theta$	→ Proportionate of components that passes through selector-orientor		
$f\theta$	→ Effective rate of delivery of components		
$f\theta - R_C$	→		

In this section we examine the operation and performance of automated assembly machines that have several workstations and use a synchronous transfer system. The types include the dial indexing machine, many in-line assembly systems, and certain carousel systems. The measures of performance are production rate, uptime efficiency, and cost. The analysis of an automated assembly machine with multiple stations shares much in common with the upper-bound approach used for metal machining transfer lines. Some modifications in the analysis must be made to account for the fact that components are being added at the various workstations in the assembly system. The general operation of the assembly system is pictured in Figure 15. In developing the equations that govern the operation of the system, we shall follow the general approach suggested by Boothroyd and Redford.

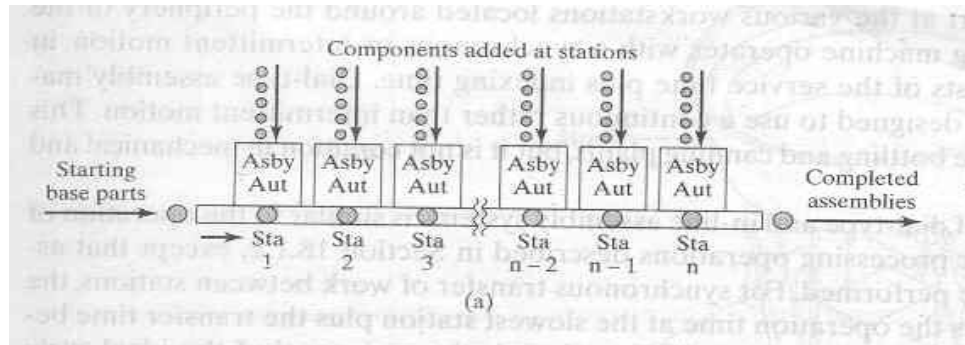


Figure 15 Multistation assembly line

We assume that the typical operation occurring at a workstation of an assembly machine is one in which a component is added or joined in some fashion to an existing assembly. The existing assembly consists of a base part plus the components assembled to it at previous stations. The base part is launched onto the line either at or before the first workstation. The components that are added must be clean, uniform in size and shape, of high quality, and consistently oriented. When the feed mechanism and assembly workhead attempt to join a component that does not meet these specifications, the station can jam. When this occurs, it can result in the shutdown of the entire machine until the fault is corrected. Thus, in addition to the other mechanical and electrical failures that interrupt the operation of a flow line, the problem of defective components is one that specifically plagues the operation of an automatic assembly machine. This is the problem we propose to deal with.

*The assembly machine as a game of chance*

Defective parts are a fact of manufacturing life. Defects occur with a certain fraction defective rate,  $q$ . In the operation of an assembly workstation,  $q$  can be considered as the probability that the next component is defective. When an attempt is made to feed and assemble a defective component, the defect might or might not cause the station to jam. Let  $m$  equal the probability that a defect will result in the malfunction and stoppage of the workstation. Since the values of  $q$  and  $m$  may be different for different stations, we subscript these terms as  $q_i$  and  $m_i$ , where  $i = 1, 2, \dots, n$  the number of stations on the assembly machine.

Considering what happens at a particular workstation, station  $i$ , there are three possible events that might occur when the feed mechanism attempts to feed the component and the assembly device attempts to join it to the existing assembly:

1. The component is defective and causes a station jam,
2. The component is defective but does not cause a station jam.
3. The component is not defective.

The probability of the first event is the product of the fraction defective rate for the station,  $q_i$ , multiplied by the probability that a defect will cause the station to stop,  $m_i$ , the probability that a part will jam at station  $i$ . For an assembly machine,

$$P_i = m_i q_i$$

The second possible event, when the component is defective but does not cause a station jam, has a probability given by

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

With this outcome, a bad part is joined to the existing assembly, perhaps rendering the entire assembly defective.

The third possibility is obviously the most desirable. The probability that the component is not defective is equal to the proportion of good parts

$$P_i = (1 - q_i)$$

The probabilities of the three possible events must sum to unity.

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

To determine the complete distribution of possible outcomes that can occur on an n-station assembly machine, we can multiply the terms of above Equation together for all stations;

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

In the special case of Eq., where all  $m_i$  are equal and all  $q_i$  are equal, then equation becomes

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

### Measures of performance

Fortunately, we are not required to calculate every term to make use of the concept of assembly machine operation provided by above Equations. One of the characteristics of performance that we might want to know is the proportion of assemblies that contain one or more defective components. Two of the three terms in above Equation represent events that result in the addition of good components at a given station. The first term is  $m_i q_i$ , which indicates a line stop but also means that a defective component has not been added to the assembly. The other term is  $(1 - q_i)$ , which means that a good component has been added at the station. The sum of these two terms represents the probability that a defective component will not be added at station  $i$ . Multiplying these probabilities for all stations, we get the proportion of acceptable product coming off the line,  $P_{ap}$

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

In the special case where all  $m_i$  are equal and all  $q_i$  are equal, then equation becomes

$$P_{ap} = [m q + (1 - q)]^n$$



If this is the proportion of assemblies with no defective components, the proportion of assemblies that contain at least one defect is given by

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

In the special case where all  $m_i$  are equal and all  $Q_i$  are equal, then equation becomes

$$P_{qp} = 1 - [m_i q_i + (1 - q_i)]^n$$

In addition to the proportions of good and bad assemblies as measures of performance for an assembly machine, we are also interested in the machine's production rate, proportions of uptime and downtime, and average cost per unit produced.

To calculate production rate we must first determine the frequency of downtime occurrences per cycle,  $f$ . If each station jam results in a machine downtime occurrence,  $f$  can be found by taking the expected number of station jams per cycle.

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

In the special case where all  $m_i$  are equal and all  $Q_i$  are equal, then equation becomes

$$F = nm q$$

Average production time per assembly is therefore given by

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

$T_c$  = ideal cycle time

$T_d$  = average downtime per occurrence

In the special case where all  $m_i$  are equal and all  $Q_i$  are equal, then equation becomes

$$T_P = T_C + nm q T_D$$

The rate of production of acceptable product is given by equation

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

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

In the special case where all  $m_i$  are equal and all  $Q_i$  are equal, then equation becomes

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

The line efficiency is calculated as the ratio of ideal cycle time to average production time.

$$E = \frac{T_c}{T_p} = \frac{T_c}{T_c + nm q T_D}$$

The proportion of downtime,  $D$ , is the average downtime per cycle divided by the average production time is given by

$$D = \frac{nm q T_D}{T_p} = \frac{nm q T_D}{T_c + nm q T_D}$$

The cost per assembly produced, is given by

$$C_{pc} = \frac{C_m + C_L \times T_p + C_t}{(mq + (1 - q))^n} = \frac{C_m + C_L \times T_p + C_t}{P_{ap}}$$

1. A 10 station in-line assembly machine has a 6-s ideal cycle time. The base part is automatically loaded prior to the first station. The fraction defect rate at each of 10 stations is equal to 0.01 and the probability that a defect will jam is 0.5. when jam occurs, the average down time is 2 minutes. Determine the average production rate, the yield of good assemblies, and the uptime efficiency of the assembly machine.

*The average production cycle time =  $T_p = T_c + nm q T_D$*

$$T_p = 0.1 + 10 \times 0.5 \times 0.01 \times 2.0 = 0.2 \text{ min}$$

$$R_p = \frac{1}{T_p} = \frac{1}{0.2} = 5 \times 60 = 300 \text{ assemblies / Hr}$$

The yield of good products

$$P_{ap} = [m_i q_i + (1 - q_i)]^n$$

$$P_{ap} = [0.5 \times 0.01 + (1 - 0.01)]^{10} = 0.9511$$

Uptime efficiency

$$E = \frac{T_c}{T_p} = \frac{0.1}{0.2} = 0.50 = 50\%$$

### 7.5 ANALYSIS OF A SINGLE-STATION ASSEMBLY MACHINE

The single-station assembly machine can be pictured as shown in Figure 16. We assume a single workhead, with several components feeding into the station to be assembled. Let us use  $n$  to represent the number of distinct assembly elements that are performed on the machine. Each element has an element time,  $T_{ei}$ , where  $i = 1, 2, \dots, n$ . The ideal cycle time for the single-station assembly machine is the sum of the individual element times of the assembly operations to be performed on the machine, plus the handling time to load the base part into position and unload the completed assembly. We can express this ideal cycle time as

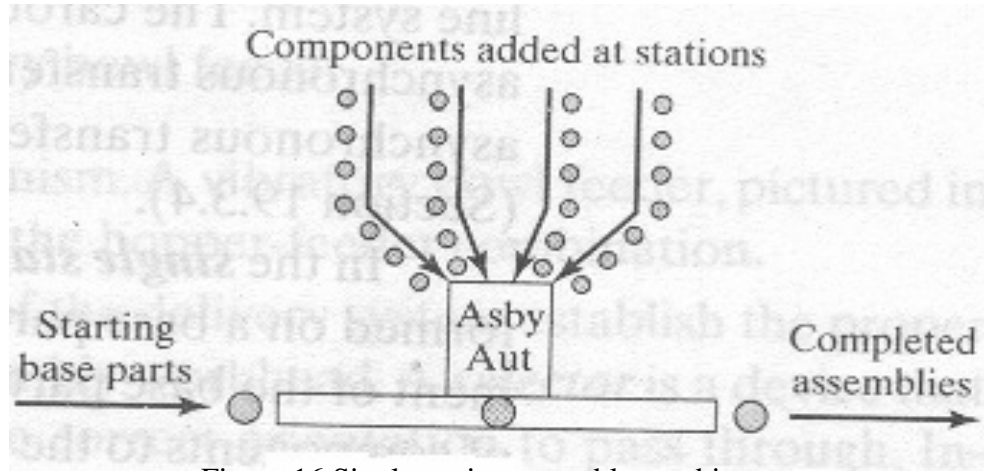


Figure 16 Single station assembly machine

where  $T_h$  is the handling time,

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

Many of the assembly elements involve the addition of a component to the existing subassembly. As in our analysis of the multiple-station assembly system, each component type has a certain fraction defect rate,  $q_i$  and there is a certain probability that a defective component will jam the workstation,  $m_i$ . When a jam occurs, the assembly machine stops, and it takes an average  $T_d$  to clear the jam and restart the system. The inclusion of downtime resulting from jams in the machine cycle time gives.

Average production time per assembly is therefore given by

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

$T_c$  = ideal cycle time

$T_d$  = average downtime per occurrence

In the special case where all  $m_i$  are equal and all  $Q_i$  are equal, then equation becomes

$$T_p = T_c + nm q T_d$$

The rate of production of acceptable product is given by equation

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

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

In the special case where all  $m_i$  are equal and all  $Q_i$  are equal, then equation becomes

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$$E = \frac{T_c}{T_p} = \frac{T_c}{T_c + nm q T_d}$$

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The cost per assembly produced, is given by

$$C_{pc} = \frac{C_m + C_L \times T_p + C_t}{(mq + (1 - q))^n} = \frac{C_m + C_L \times T_p + C_t}{P_{ap}}$$

## AUTOMATED GUIDED VEHICLE SYSTEMS

An automated or automatic guided vehicle system (AGVS) is a materials handling system that uses independently operated, self-propelled vehicles that are guided along defined pathways in the floor. The vehicles are powered by means of on-board batteries that allow operation for several hours (8 to 16 hours is typical) between recharging. The definition of the pathways is generally accomplished using wires embedded in the floor or reflective paint on the floor surface. Guidance is achieved by sensors on the vehicles that can follow the guide wires or paint.

Automated guided vehicles (AGVs) increase efficiency and reduce costs by helping to automate a manufacturing facility or warehouse.

AGVS can carry loads or tow objects behind them in trailers to which they can autonomously attach. The trailers can be used to move raw materials or finished product. The AGV can also store objects on a bed. The objects can be placed on a set of motorized rollers (conveyor) and then pushed off by reversing them. Some AGVs use forklifts to lift objects for storage. AGVs are employed in nearly every industry, including, pulp, paper, metals, newspaper, and general manufacturing. Transporting materials such as food, linen or medicine in hospitals is also done.

There are a number of different types of AGVS all of which operate according to the preceding description. The types can be classified as follows:

- ☞ *Driverless* trains: This type consists of a towing vehicle (which is the AGV) that pulls one or more trailers to form a train. It was the first type of AGVS to be introduced and is still popular. It is useful in applications where heavy payloads must be moved large distances in warehouses or factories with intermediate pickup and drop-off points along the route. Figure 17 illustrates the driverless-train AGVS.

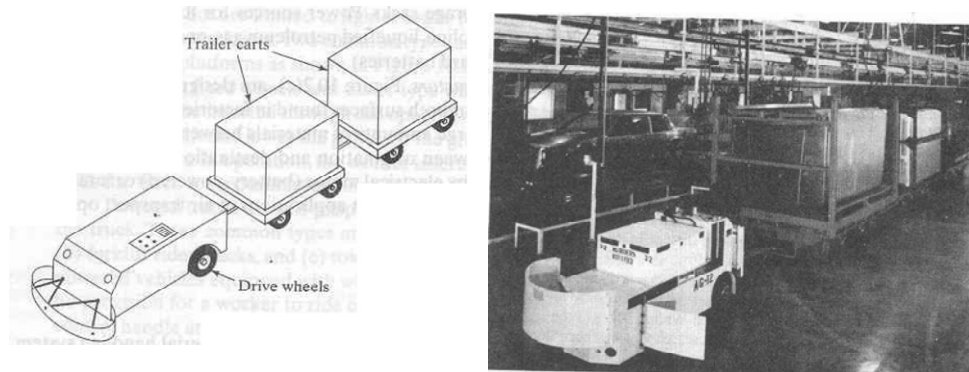


Figure 17 Driverless trains



☞ *AGVS pallet trucks:* Automated guided pallet trucks are used to move palletized loads along predetermined routes. In the typical application the vehicle is backed into the loaded pallet by a human worker who steers the truck and uses its forks to elevate the load slightly. Then the worker drives the pallet truck to the guideway, programs its destination, and the vehicle proceeds automatically to the destination for unloading. The capacity of an AGVS pallet truck ranges up to 6000 lb, and some trucks are capable of handling two pallets rather than one. A more recent introduction related to the pallet truck is the forklift AGV. This vehicle can achieve significant vertical movement of its forks to reach loads on shelves. Figure 18 illustrates this vehicle type.



Figure 19 AGV pallet trucks

☞ *AGVS unit load carriers.* This type of AGVS is used to move unit loads from one station to another station. They are often equipped for automatic loading and unloading by means of powered rollers, moving belts, mechanized lift platforms, or other devices. The unit load carrier is pictured in Figure 20. Variations of the unit load carrier include light-load AGVs and assembly line AGVs. The light-load AGV is a relatively small vehicle with a corresponding light load capacity (typically 500 lb or less). It does not require the same large aisle width as the conventional AGV. Light-load guided vehicles are designed to move small loads (single parts, small baskets or tote pans of parts, etc.) through plants of limited size engaged in light manufacturing. The assembly line AGVS is designed to carry a partially completed subassembly through a sequence of assembly workstations to build the product.



Figure 21 AGV unit load carrier

## Vehicle guidance and routing

There are several functions that must be performed to operate any automated guided vehicle system successfully. These functions are:

- 1, Vehicle guidance and routing
- 2, Traffic control and safety
- 3, System management

We describe these functions in this and the following two subsections.

The term *guidance system* refers to the method by which the AGVS pathways are defined and the vehicle control systems that follow the pathways. As indicated above, there are two principal methods currently in use to define the pathways along the floor: embedded guide wires and paint strips. Of the two types, the guide wire system is the more common in warehouse and factory applications.

In the guide wire method the wires are usually embedded in a small channel cut into the surface of the floor. The channel is typically about 1/8 in. wide and 1/2 in. deep. After the guide wires are installed, the channel slot is filled so as to eliminate the discontinuity in the floor surface as shown in figure 22. An alternative but less permanent way to install the guide wires is to tape them to the floor. A frequency generator provides the guidance signal carried in the wire. The signal is of relatively low voltage (less than 40 V), low current (less than 400 mA), and has a frequency in the range 1 to 15 kHz. This signal level creates a magnetic field along the pathway that is followed by sensors on-board each vehicle. The operation of a typical system is illustrated in Figure 22 Two sensors (coils) are mounted on the vehicle on either side of the guide wire. When the vehicle is moving along a course such that the guide wire is directly between the two coils, the intensity of the magnetic field measured by each coil will be equal. If the vehicle strays to one side or the other, or if the guide wire path curves, the magnetic field intensity at the two sensors will be different. This difference is used to control the steering motor, which makes the required changes in vehicle direction to equalize the two sensor signals, thereby tracking the defined pathway.

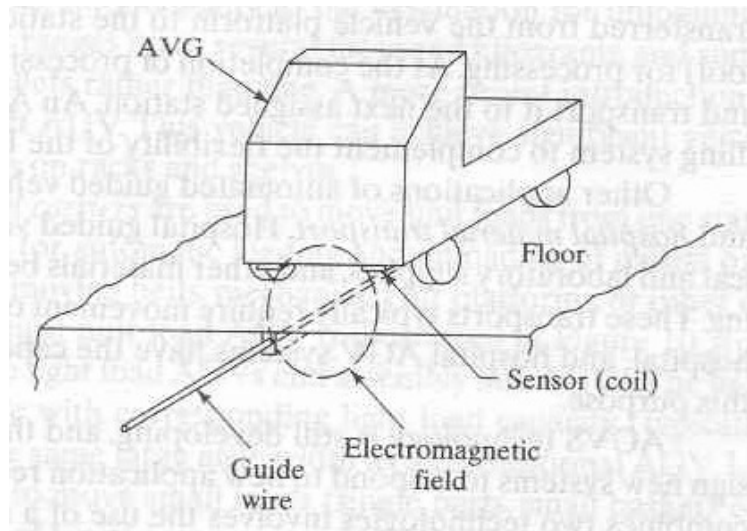


Figure 22 wire guided AGV

When paint strips are used to define the vehicle pathways, the vehicle possesses an optical sensor system that is capable of tracking the paint. The strips can be taped, sprayed, or painted on the floor. One system uses a 1-in.-wide paint strip containing fluorescent particles that reflect an ultraviolet (UV) light source on the vehicle. An on-board sensor detects the reflected light in the strip and controls the steering mechanism to follow it. The paint guidance system is useful in environments where electrical noise would render the guide wire system unreliable or when the installation of guide wires in the floor surface would not be appropriate. One problem with the paint strip guidance method is that the paint strip must be maintained (kept clean and unscratched).

A safety feature used in the operation of most guidance systems is automatic stopping of the vehicle in the event that it accidentally strays more than a few inches (typically 2 to 6 in.) from the guide path. This automatic-stopping feature prevents the vehicle from running wild in the building. Alternatively, in the event that the vehicle is off the guide path (e.g., for manual loading of a pallet truck), it is capable of locking onto the guide wire or paint strip if moved within the same few inches of it. The distance is referred to as the vehicle's *acquisition distance*.

The use of microprocessor controls on-board the vehicles has led to the development of a feature called *dead reckoning*. This term refers to the capability of the vehicle to travel along a route that does not follow the defined pathway in the floor. The microprocessor computes the number of wheel rotations and the operation of the steering motor required to move along the desired path. Dead reckoning might be employed by the vehicle to cross a steel plate in the factory floor (where guide wires cannot be

installed), or to depart from the guide path for positioning at a load/unload station. At the completion of the dead-reckoning maneuver, the vehicle is programmed to return to within (the acquisition distance of the guide path to resume normal guidance control.

Routing in an AGVS is concerned with the problem of selecting among alternative pathways available to a vehicle in its travel to a defined destination point in the system. A typical guided vehicle layout, one that exploits the capabilities of modern AGVS technology, contains features such as multiple loops, branches, side tracks, and spurs, in addition to the required pickup and drop-off stations. Vehicles in the system must decide which path to take to reach a defined destination point.

When a vehicle approaches a branching point in which the guide path splits into two (or more) directions, a decision must be made as to which path the vehicle should take. This is sometimes referred to as a *decision point* for the vehicle. There are two methods used in commercial AGV systems to permit the vehicle to decide which path to take:

1. Frequency select method
2. Path switch select method

In the *frequency select method*, the guide wires leading into the two separate paths at the branch have different frequencies. As the vehicle enters the decision point, it reads an identification code on the floor to identify its location. Depending on its programmed destination, the vehicle selects one of the guide paths by deciding which frequency to track. This method requires a separate frequency generator for each frequency that is used in the guide path layout. This usually means that two or three generators are needed in the system. Additional channels must often be cut into the floor with the frequency select method to provide for bypass channels where only the main channel needs to be powered for vehicle tracking.

The *path switch select method* uses a single frequency throughout the guide path layout. In order to control the path of a vehicle at a decision point, the power is switched off in all branches except the one on which the vehicle is to travel. To accomplish routing by the path switch select method, the guide path layout must be divided into blocks that can be independently turned on and off by means of controls mounted on the floor near their respective blocks. These control units are operated by the vehicles as they move in the various blocks. As a vehicle enters a decision point, it activates a floor-mounted switching device connected to the control unit for the relevant block. The control unit activates the desired guide path and turns off the alternative branch or branches.

### Traffic control and safety

The purpose of traffic control for an AGVS is to prevent collisions between vehicles traveling along the same guide path in the layout. This purpose is usually accomplished by means of a control system called the *blocking system*. The term "blocking" suggests that a vehicle traveling along a given guide path is in some way prevented from hitting any vehicle ahead of it. There are several means used in commercial AGV systems to accomplish blocking. They are:

1. On-board vehicle sensing
2. Zone blocking

On-board vehicle sensing and zone blocking are often used in combination to implement a comprehensive blocking system.

*On-board vehicle sensing* (sometimes called *forward sensing*) involves the use of some form of sensor system to detect the presence of vehicles and carts ahead on the same guide wire. The sensors used on commercial guided vehicles include optical sensors and ultrasonic systems. When the on-board sensor detects an obstacle (e.g, another guided vehicle) in front of it, the vehicle stops. When the obstacle is removed, the vehicle proceeds. Assuming that the sensor system is 100% effective, collisions between vehicles are avoided and traffic is controlled. Unfortunately, the effectiveness of forward sensing is limited by the capability of the sensor system to detect vehicles in front of it on the guide path. Since the sensors themselves are most effective in detecting obstacles directly ahead of the vehicle, these systems are most appropriate on layouts that contain long stretches of straight pathways. They are less effective at turns and convergence points where forward vehicles may not be directly in front of the sensor.

The concept of *zone* control is simple. The AGVS layout is divided into separate zones, and the operating rule is that no vehicle is permitted to enter a zone if that zone is already occupied by another vehicle. The length of a zone is sufficient to hold one vehicle (or a train in driverless train systems) plus an allowance for safety and other considerations. These other considerations include the number of vehicles in the system, the size and complexity of the layout, and the objective of minimizing the number of separate zone controls. When one vehicle occupies a given zone, any trailing vehicle is not allowed into that zone. The leading vehicle must proceed into the next zone before the trailing vehicle can occupy the given zone.



By controlling the forward movement of vehicles in the separate zones, collisions are prevented and traffic in the overall system is controlled. The concept is illustrated in Figure 23 in its simplest form. More complicated zone control schemes separate any two vehicles by a blocked zone.

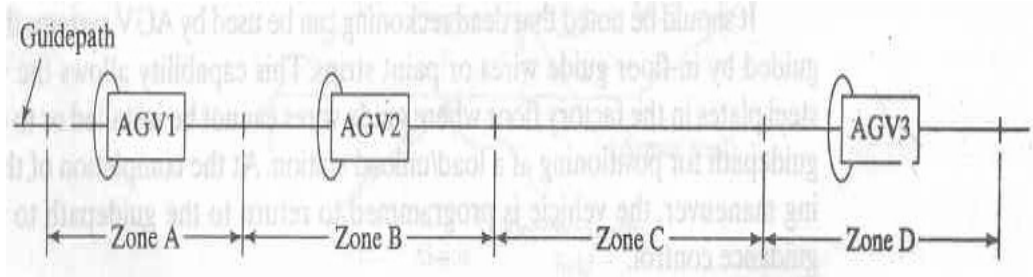


Figure 23 zone control

One means of implementing zone control is to use separate control units for each zone. These controls are mounted along the guide path and are actuated by the vehicle in the zone. When a vehicle enters a given zone, it activates the block in the previous (upstream) zone to block any trailing vehicle from moving forward and colliding with the present vehicle. As the present vehicle moves into the next (downstream) zone, it activates the block in that zone and deactivates the block in the previous zone. In effect, zones are turned on and off to control vehicle movement by the blocking system.

In addition to avoiding collisions between vehicles, a related objective is the safety of human beings who might be located along the route of the vehicles traveling in the system. There are several devices that are usually included on an automatic guided vehicle to achieve this safety objective. One of the safety devices is an obstacle-detection sensor located at the front of each vehicle. This is often the same on-board sensor as that used in the blocking system to detect the presence of other vehicles located in front of the sensor. The sensor can detect not only other vehicles, but also people and obstacles in the path of the vehicle. These obstacle-detection systems are usually based on optical, infrared, or ultrasonic sensors. The vehicles are programmed either to stop when an obstacle is sensed ahead of it, or to slow down. The reason for slowing down is that the sensed object may be located off to the side of the vehicle path, or directly ahead of the vehicle beyond a turn in the guide path. In either of these cases, the vehicle should be permitted to proceed at a slower (safer) speed until it has passed the object or rounded the turn.

Another safety device included on virtually all commercial AG vehicles is an emergency bumper. This bumper surrounds the front of the vehicle and protrudes ahead of it by a distance which can be a foot or more. When the bumper makes contact with an object, the vehicle is programmed to brake immediately. Depending on the speed of the vehicle, its load, and other conditions, the braking distance will vary

from several inches to several feet. Most vehicles are programmed to require manual restarting after an obstacle encounter has occurred with the emergency bumper.

Other safety devices on the vehicles include warning lights (blinking or rotating lights) and/or warning bells. These devices alert people that the vehicle is present.

Finally, another safety feature that prevents runaway vehicles is the inherent operating characteristic of the guidance system: If the vehicle strays by more than a few inches from the defined path, the vehicle is programmed to stop.

### **System management**

Managing the operations of an AGVS deals principally with the problem of dispatching vehicles to the points in the system where they are needed (e.g., to perform pickups and deliveries) in a timely and efficient manner. The system management function depends on reliable operation of the other system functions discussed above (guidance, routing, traffic control). There are a number of methods used in commercial A.GV systems for dispatching vehicles. These methods are generally used in combination to maximize responsiveness and effectiveness of the overall system. The dispatching methods include:

- \* On-board control panel
- \* Remote call stations
- \* Central computer control

Each guided vehicle is equipped with some form of control panel for the purpose of manual vehicle control, vehicle programming, and other functions. Most commercial vehicles have the capacity to be dispatched by means of this control panel to a given station in the AGVS layout. Dispatching with an on-board control panel represents the lowest level of sophistication among the possible methods. Its advantage is that it provides the AGVS with flexibility and responsiveness to changing demands on the handling system. Its disadvantage is that it requires manual attention.

The use of remote call stations is another method that allows the AGVS to respond to changing demand patterns in the system. The simplest form of call station is a press button mounted near the load/unload station. This provides a signal to any passing vehicle to stop at the station in order to accomplish a load transfer operation. The vehicle might then be dispatched to the desired location by means of the on-board control panel.

More sophisticated call stations consist of control panels mounted near the various stations along the layout. This method permits a vehicle to be stopped at a given station, and its next destination to be programmed from the remote call panel. This represents a more automated approach to the dispatching function and is useful in AGV systems that are capable of automatic loading and unloading operations.

Both of the call station methods described here involve a human interface with the AGVS at the load/unload station. It is also possible to automate the call function at an automatic load/unload station. One example is an automated production workstation that receives raw materials and sends completed parts by means of the AGVS. The workstation is interfaced with the AGVS to call for vehicles as needed to perform the loading and unloading procedures.

In large factory and warehouse systems involving a high level of automation, the AGVS servicing the factory or warehouse must also be highly automated to achieve efficient operation of the entire production-storage-handling system. Central computer control is used to accomplish automatic dispatching of vehicles according to a preplanned schedule of pickups and deliveries in the layout and/or in response to calls from the various load/unload stations in the system. In this dispatching method, the central computer issues commands to the vehicles in the system concerning their destinations and operations to perform. To accomplish the dispatching function, the central computer must possess real-time information about the location of each vehicle in the system so that it can make appropriate decisions concerning which vehicles to dispatch to what locations. Hence, the vehicles must continually communicate their whereabouts to the central controller.

There are differences in the way these central computer dispatching systems operate. One of the differences involves the distribution of the decision-making responsibilities between the central controller and the individual vehicles. At one extreme, the central computer makes nearly all the decisions about routing of vehicles and other functions. The central computer plans out the routes for each vehicle and controls the operation of the guide path zones and other functions. At the opposite extreme, each individual vehicle possesses a substantial decision-making capability to make its own routing selections and to control its own operations. The central computer is still needed to control the overall scheduling and determine which vehicles should go to the various demand points in the system. However, the vehicles themselves decide which routes to take and control their own load transfer operations. Vehicles in this second category are often referred to as "smart" vehicles.

To accomplish the system management function, it is helpful to monitor the overall operations of the AGVS by means of some form of graphics display. Even with central computer control it is still desirable for human managers to be able to see the overall system operations, in order to monitor its general status and to spot problems (e.g., traffic jams, breakdowns, etc.). A CRT color graphics display is often used for these purposes in modern guided vehicle systems.

Another useful tool in carrying out the systems management function is a system performance report for each shift (or other appropriate time period) of AGVS operation. These periodic reports of system performance provide summary information about proportion uptime, downtime, number of transactions (deliveries) made during a shift, and more detailed data about each station and each vehicle in the system. Hard-copy reports containing this type of information permit the system managers to compare operations from shift to shift and month to month to maintain a high level of overall system performance.

### **Applications**

Automated Guided Vehicles can be used in a wide variety of applications to transport many different types of material including pallets, rolls, racks, carts, and containers.

AGVs excel in applications with the following characteristics:

- Repetitive movement of materials over a distance
- Regular delivery of stable loads
- Medium throughput/volume
- When on-time delivery is critical and late deliveries are causing inefficiency
- Operations with at least two shifts
- Processes where tracking material is important

Driverless train operations

Storage/distribution

Assembly line operations

FMS

Mail delivery in offices

Hospitals

Raw Material Handling

Work-in-Process Movement

Pallet Handling

Finished Product Handling

Trailer Loading

Roll Handling

## Battery Charging

1. ***Driverless train operations:*** These applications involve the movement of large quantities of materials over relatively large distances. For example, the moves are within a large warehouse or factory building, or between buildings in a large storage depot. For the movement of trains consisting of 5 to 10 trailers, this becomes an efficient handling method,
2. ***Storage/distribution systems:*** Unit load carriers and pallet trucks are typically used in these applications. These storage and distribution operations involve the movement of materials in unit loads (sometimes individual items are moved) from or to specific locations. The applications often interface the AGVS with some other automated handling or storage system, such as an automated storage/retrieval system (AS/RS) in a distribution center. The AGVS delivers incoming items or unit loads (contained on pallets) from the receiving dock to the AS/RS, which places the items in storage, and the AS/RS retrieves individual pallet loads or items from storage and transfers them to vehicles for delivery to the shipping dock. When the rates of incoming loads and the outgoing loads are in balance, this mode of operation permits loads to be carried in both directions by the AGVS vehicles, thereby increasing the handling system efficiency.

This type of storage/distribution operation can also be applied in light manufacturing and assembly operations in which work-in-progress is stored in a central storage area and distributed to individual workstations for assembly or processing. Electronics assembly is an example of these types of applications. Components are "kitted" at the storage area and delivered in tote pans or trays by the guided vehicles to the assembly workstations in the plant. Light-load AGV systems are used in these applications.

3. ***Assembly-line operations:*** AGV systems are being used in a growing number of assembly-line applications, based on a trend that began in Europe. In these applications, the production rate is relatively low (perhaps 4 to 10 min per station in the line) and there are a variety of different models made on the production line. Between the work stations, components are kitted and placed on the vehicle for the assembly operations that are to be performed on the partially completed product at the next station. The workstations are generally arranged in parallel configurations to add to the flexibility of the line. Unit load carriers and light-load guided vehicles are the type of AGVS used in these assembly lines.
4. ***Flexible manufacturing systems:*** Another growing application of AGVS technology is in flexible manufacturing systems (FMS). In this application, the guided vehicles are used as the materials handling system in the FMS. The

vehicles deliver work from the staging area (where work is placed on pallet fixtures, usually manually) to the individual workstations in the system. The vehicles also move work between stations in the manufacturing system. At a workstation, the work is transferred from the vehicle platform into the work area of the station (usually, the table of a machine tool) for processing. At the completion of processing by that station a vehicle returns to pick up the work and transport it to the next area. AGV systems provide a versatile material handling system to complement the flexibility of the FMS operation.

5. **Miscellaneous applications:** Other applications of automated guided vehicle systems include non manufacturing and non warehousing applications, such as mail delivery in office buildings and hospital material handling operations. Hospital guided vehicles transport meal trays, linen, medical and laboratory supplies, and other materials between various departments in the building. These applications typically require movement of the vehicles between different floors of the hospital, and hospital AGV systems have the capability to summon and use elevators for this purpose.