14. Automated Assembly Systems

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14.1 Introduction

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

BULLETLIST
- 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
ENDLIST

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.

KEYPOINT
Automated assembly refers to the use of mechanized and automated devices to perform the various assembly tasks in an assembly line or cell.
END KEYPOINT
In this unit a general overview of automated assembly systems is offered, which examines both the fundamentals of automated assembly systems and quantitative analysis.

14.2 Learning Objectives

After completing this unit you will be able to:

BULLET LIST
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

ENDLIST

14.3 Fundamentals of Automated Assembly Systems

Our discussion here examines possible configurations for the automated assembly system, how parts are delivered to the workstation, and a brief examination of potential applications for automated assembly systems. These follow in the sub-sections below.

LEARNING ACTIVITY 14.1
For a more general discussion of the history, development, and influence of assembly lines, the learner is directed to the following web-sites:
http://en.wikipedia.org/wiki/Assembly_line
http://www.ideafinder.com/history/inventions/assbline.htm

Also, watch the video on automotive assembly lines at:
http://www.youtube.com/watch?v=WPxr2DvWUsM
And automated assembly lines, at:
http://www.youtube.com/watch?v=_rwWFqvoxE

Write a 1 page report on your findings, and post it to the discussion forum.  
**END LEARNING ACTIVITY 14.1**

### 14.3.1 System Configurations

Possible system configurations are outlined and described in Table 14.1.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-line</strong></td>
<td>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.</td>
</tr>
<tr>
<td><img src="image.png" alt="In-line Diagram" /></td>
<td></td>
</tr>
<tr>
<td><strong>Dial-type</strong></td>
<td>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.</td>
</tr>
<tr>
<td><img src="image.png" alt="Dial-type Diagram" /></td>
<td></td>
</tr>
<tr>
<td><strong>Carousel Assembly System</strong></td>
<td>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 used.</td>
</tr>
<tr>
<td><img src="image.png" alt="Carousel Assembly System" /></td>
<td></td>
</tr>
</tbody>
</table>
operated with continuous, synchronous, or asynchronous transfer mechanisms.

**KEYPOINT**
System configurations for automated assembly systems include: in-line assembly; dial-type assembly; carousel assembly; and single-station assembly.
**END KEYPOINT**

14.4 Parts Delivery at Workstations

Parts delivery to workstations depends upon specific pieces of delivery equipment, particularly associated with automatic assembly. These pieces of equipment are connected together to create the parts delivery system. The following hardware for parts delivery consists of:

**BULLETLIST**
Hopper—a container into which components are loaded at the workstation, and which passes components to the parts feeder
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 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.

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.

**KEYPOINT**
Parts delivery at workstations is dependent on the following hardware components: the hopper; the parts feeder; selector and/or orientor devices; the feed track; and escapement and placement devices.

**END KEYPOINT**

The general arrangement of this hardware is shown in Figure 14.1.

![Figure 14.1: Hardware elements used to delivery parts to workstations](image-url)
The hopper and parts feeder device are often combined, as shown schematically and pictorially in Figure 14.2.

Figure 14.2: Hopper and parts feeder

**KEYPOINT**
The hopper and parts feeder device are often combined as one entity.
**END KEYPOINT**

Typical selector and orientor devices are shown in Figure 14.3.

Figure 14.3: (a) Selector and (b) orientor devices used upon the feedtrack

**KEYPOINT**
Selector and orientor devices are small simple devices built onto the feed track to force the removal of unacceptable components, or the re-orientation of misaligned ones.
**END KEYPOINT**

Meanwhile, depending upon the assembly system type, various escapement and placement devices may be favoured; Table 14.2 outlines just some of these.
Table 14.2: Escapement and placement devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal placement device</td>
<td>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.</td>
</tr>
<tr>
<td>Vertical placement device</td>
<td>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.</td>
</tr>
<tr>
<td>Escapement device</td>
<td>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.</td>
</tr>
<tr>
<td>Pick-and-place mechanism (1)</td>
<td>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.</td>
</tr>
<tr>
<td>Pick-and-place mechanism (2)</td>
<td>This mechanism uses a pick-and-place unit with a revolving arm, so that parts may be removed from the feed track, and...</td>
</tr>
</tbody>
</table>
KEYPOINT
Escapement and placement devices include mechanisms with various designs to suit the needs of the workstation in question; they include: horizontal and vertical placement devices; work-carrier actuated escapement devices; and pick-and-place mechanisms.
END KEYPOINT

14.5 Quantitative Analysis of Assembly Systems

Here we examine four cases of quantitative analysis in the sub-sections below:

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

14.5.1 Parts delivery system at workstations

We have reviewed how parts are delivered to workstations above. The rate at which parts are removed from the hopper is \( f \), and—once removed from the hopper—the parts are presented to the selector or orientor. In the case of the selector, a certain proportion of the parts will be rejected back into the hopper, while a certain proportion will pass the selector and continue down the feed track. For the orientor, 100% of the parts will pass the device (as it only re-orient parts, but doesn’t remove them). The selector and orientor devices are often combined.

If we let \( \Theta \) be the proportion of parts that pass the selector/orientor test, then the effective rate of delivery is \( f\Theta \). The remaining proportion, returned to the hopper, is given by \( (1 - \Theta) \). The delivery rate \( (f\Theta) \) must keep up with the cycle rate of the assembly machine.
If we let $R_c$ be the cycle rate of the assembly machine, and 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. A sensor, called 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 ($n_{f2}$) is given by:

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

This value is the capacity of the feed track. A second sensor, called the low level sensor (LLS) that 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:

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

The rate at which parts in the feed track are reduced when the HLS turns off the feed track is the same as $R_c$. On average, when the LLS is activated, the rate at which parts will increase in the feed track is $f\Theta - R_c$. However this value is not uniform, owing to the random operation of the selector; thus, the value of $n_{f1}$ must be large enough to eliminate the possibility of stockouts.

**KEYPOINT**

In the operation of the parts delivery system at workstations, sensors are used to avoid the problem of overloading the workstation with parts. Two sensors are used: the high level sensor, for stopping the feeding mechanism when the feed track is at full capacity; and the low level sensor 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.

**END KEYPOINT**

**EXAMPLE 14.1**

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) 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

(b) Time to resupply from $n_{f1}$ to $n_{f2}$

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

(c) Total cycle of depletion and resupply = 41.667 min

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

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

**END EXAMPLE 14.1**

### 14.5.2 Multi-Station Assembly Machines

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

-BULLETLIST
- 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
-ENDLIST

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.

There are three possible events that can occur when a defective part is fed into the workstation system, with scenario 3 being the most desirable; these are:

NUMLIST
1. The defective component causes a station jam, expressed by the equation (where \( p_i \) is the probability of this event occurring):
   \[ p_i = m_i q_i \]

2. The defective component does not cause a station jam, expressed by the equation:
   \[ p_i = (1-m_i)q_i \]

3. The component is not defective, expressed by the equation:
   \[ p_i = 1-q_i \]
ENDLIST

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 \( m_i \) is the same as \( m \), and \( q_i \) 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 \( m_i \) is the same as \( m \), and \( q_i \) 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.

END KEYPOINT

Related performance metrics include the following.
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:

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

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

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

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:

$$F = nmq$$

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:

$$T_p = T_c + nmq T_d$$

The average actual production time ($R_p$):

$$R_p = \frac{1}{T_p}$$
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 ($R_{ap}$):

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

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:

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

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 ($C_{pc}$):

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

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

**KEYPOINT**

A variety of performance metrics can be assessed for multi-station assembly machines, where—owing to the existence of defective components in the system—assembly is a game of change; these include: the proportion of acceptable product coming off the line; the proportion of assemblies containing at least one defective component; the frequency of downtime occurrences per cycle; the average actual production time per assembly; the average actual production time; the average actual production rate of acceptable product; line efficiency; the proportion downtime; and the cost per assembled product.

**END KEYPOINT**
EXAMPLE 14.2

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, the yield of good product (final assemblies containing no defective components), and proportion uptime of the system.

Solution:

\[
T_p = 0.1 + 8(1.0)(0.015)(1.0) = 0.22 \text{ min/asby.}
\]

\[
R_p = \frac{60}{0.22} = 272.7 \text{ asbys/hr}
\]

If defects always jam the affected station, then \( m = 1.0 \)

\[
P_{ap} = (1 - 0.015 + 1 \times 0.015)^8 = 1.0 \text{ = yield}
\]

\[
E = \frac{0.1}{0.22} = 0.4545 = 45.45\%
\]

END EXAMPLE 14.2

14.5.3 Single-Station Assembly Machines

The single-station assembly machine consists of one workstation where several components are assembled onto a base unit. The assumptions in the following analysis include: 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 \( j = 1, 2, 3, \ldots, n_e \). 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:

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

Each component type has a certain fraction defect rate \( q_{ij} \), 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:

\[ T_p = T_c + \sum_{j=1}^{n_j} q_j m_j T_d \]

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

\[ T_p = T_c + nmq T_d \]

To determine the proportion of assemblies that contain no defective components, use the equation specified for multi-station assembly machines; while uptime efficiency \((E)\) is computed as:

\[ E = \frac{T_c}{T_p} \]

**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.

**END KEYPOINT**

**EXAMPLE 14.3**

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, and (d) proportion of the output that contains a defective type 3 component.

**Solution:**

(a)
\[ T_p = T_c + nmqT_d \]

\[ T_c = 4 + 5(4.5) = 26.5 \text{ sec} = 0.44167 \text{ min} \]

\[ T_p = 0.44167 + 5(0.7)(0.005)(2.5) = 0.48542 \text{ min} \]

\[ R_p = \frac{1}{0.48542} = 2.06 \text{ asbys/min} = 123.6 \text{ asbys/hr} \]

(b)
\[ P_{ap} = (1 - 0.005 + 0.7(0.005))^5 = (0.9985)^5 = 0.9925 \]

(c)
\[ E = \frac{0.44167}{0.48542} = 0.90386 = 91.0\% \]

(d)
Type 3 defect = \(1 - (1 - 0.005 + 0.7(0.005)) = 0.005 - 0.7(0.005) = 0.3(0.005) = 0.0015\)

**END EXAMPLE 14.3**

### 14.6 Partial Automation

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

**NUMLIST**
1. Automation may be introduced gradually on an existing manual line
2. Certain manual operations are too difficult or too costly to automate

**ENDLIST**

**KEYPOINT**
Partial automation may be favoured in cases where it is ideal to introduce automation gradually on an existing manual line; or where full automation cannot be considered because certain manual operations are too difficult or too costly to automate.

**END KEYPOINT**

In our analysis here we make the following assumptions:

**BULLETLIST**
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.

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.

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. Thus, the average actual production time \( T_p \) is given by:

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

For those automated stations that perform assembly operations in which a part is added:

\[
p_i = m_i q_i
\]

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

\[
T_p = T_c + n_a p T_d
\]

and \( p = m q \) for those stations that perform assembly consisting of the addition of a part.

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:

\[
C_o = C_{at} + \sum_{i \in \mathcal{A}} C_{asi} + \sum_{i \in \mathcal{W}} C_{wi}
\]

where \( C_{at} \) is the cost to operate the automatic transfer mechanism; \( C_{asi} \) is the cost to operate the automatic workstation \( i \); and \( C_{wi} \) is the cost to operate manual workstation \( i \). This can be simplified to (assuming that all \( C_{asi} = C_{as} \) and all \( C_{wi} = C_w \)):

\[
C_o = C_{at} + n_a C_{as} + n_w C_w
\]

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

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

**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.

**END KEYPOINT**

**EXAMPLE 14.4**
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 accompanying table.

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Cost of transfer mechanism ( C_{at} )</th>
<th>Cost to run each automated station ( C_{as} )</th>
<th>Labor cost to operate each manual station ( C_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0.10/min</td>
<td>$0.12/min</td>
<td>$0.17/min</td>
</tr>
<tr>
<td>2</td>
<td>$0.10/min</td>
<td>$0.12/min</td>
<td>$0.17/min</td>
</tr>
<tr>
<td>3</td>
<td>$0.10/min</td>
<td>$0.12/min</td>
<td>$0.17/min</td>
</tr>
<tr>
<td>4</td>
<td>$0.10/min</td>
<td>$0.12/min</td>
<td>$0.17/min</td>
</tr>
<tr>
<td>5</td>
<td>$0.10/min</td>
<td>$0.12/min</td>
<td>$0.17/min</td>
</tr>
<tr>
<td>6</td>
<td>$0.10/min</td>
<td>$0.12/min</td>
<td>$0.17/min</td>
</tr>
</tbody>
</table>

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 \( \rho_5 = 0.02, \) 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.

Determine the following for the current line and the proposed line: (a) production rate, (b) proportion uptime, and (c) cost per unit.
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.

<table>
<thead>
<tr>
<th>Station</th>
<th>Type</th>
<th>Process time</th>
<th>$p_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manual</td>
<td>36 sec</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Automatic</td>
<td>15 sec</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>Automatic</td>
<td>20 sec</td>
<td>0.02</td>
</tr>
<tr>
<td>4</td>
<td>Automatic</td>
<td>25 sec</td>
<td>0.01</td>
</tr>
<tr>
<td>5</td>
<td>Manual</td>
<td>54 sec</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Manual</td>
<td>33 sec</td>
<td>0</td>
</tr>
</tbody>
</table>

**Solution:**

For the 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.$

For the proposed line in which station 5 is automated,

(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.$
14.7 What the Equations Tell Us

BULLET LIST
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.

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.

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.

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

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.

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.

Storage buffers should be used on partially automated production lines to isolate the manual stations from breakdowns of the automated stations.

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.

ENDLIST

Section 14.8 Unit Review

BULLET LIST
Automated assembly refers to the use of mechanized and automated devices to perform the various assembly tasks in an assembly line or cell.
System configurations for automated assembly systems include: in-line assembly; dial-type assembly; carousel assembly; and single-station assembly.

Parts delivery at workstations is dependent on the following hardware components: the hopper; the parts feeder; selector and/or orientor devices; the feed track; and escapement and placement devices.

The hopper and parts feeder device are often combined as one entity.

Selector and orientor devices are small simple devices built onto the feed track to force the removal of unacceptable components, or the re-orientation of misaligned ones.

Escapement and placement devices include mechanisms with various designs to suit the needs of the workstation in question; they include: horizontal and vertical placement devices; work-carrier actuated escapement devices; and pick-and-place mechanisms.

Automated assembly systems are used in a wide variety of contexts to assemble products that range from alarm clocks to electric motors.

Typical assembly processes that are used in automated assembly must be easy-to-automate operations, such as component insertion, spot welding, and snap fitting. Difficult-to-automate operations include processes that rely on threaded fasteners.

In the operation of the parts delivery system at workstations, sensors are used to avoid the problem of overloading the workstation with parts. Two sensors are used: the high level sensor, for stopping the feeding mechanism when the feed track is at full capacity; and the low level sensor 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.

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.

A variety of performance metrics can be assessed for multi-station assembly machines, where—owing to the existence of defective components in the system—assembly is a game of change; these include: the proportion of acceptable product coming off the line; the proportion of assemblies containing at least one defective component; the frequency of downtime occurrences per cycle; the average actual production time per assembly; the average actual production time; the average actual production rate of acceptable product; line efficiency; the proportion downtime; and the cost per assembled product.
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.

Partial automation may be favoured in cases where it is ideal to introduce automation gradually on an existing manual line; or where full automation cannot be considered because certain manual operations are too difficult or too costly to automate.

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.

Section 14.9 Self-Assessment Questions

What are automated assembly systems? What system configurations can automated assembly systems take?

List the hardware components used for parts delivery at workstations.

What would generally be seen as typical automated assembly processes?

How do the high level sensor and the low level sensor in parts delivery at workstations function?

Why is automated assembly sometimes considered a “game of chance”?

List performance metrics associated with multi-station assembly machines.

For what reasons would partial automation be used?

Section 14.10 Answers to Self-Assessment Questions

Automated assembly refers to the use of mechanized and automated devices to perform the various assembly tasks in an assembly line or cell. System
configurations for automated assembly systems include: in-line assembly; dial-type assembly; carousel assembly; and single-station assembly.

Parts delivery at workstations is dependent on the following hardware components: the hopper; the parts feeder; selector and/or orientor devices; the feed track; and escapement and placement devices.

Typical assembly processes that are used in automated assembly must be easy-to-automate operations, such as component insertion, spot welding, and snap fitting. Difficult-to-automate operations include processes that rely on threaded fasteners; these are not seen as typical automated assembly processes.

In the operation of the parts delivery system at workstations, sensors are used to avoid the problem of overloading the workstation with parts. Two sensors are used: the high level sensor, for stopping the feeding mechanism when the feed track is at full capacity; and the low level sensor 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.

Owing to the possibility of potentially defective components, delivered to individual workstations, which may or may not cause individual workstations to jam, the assembly machine and the delivery of parts to its multiple stations is sometimes considered a game of chance.

Performance metrics for multi-station assembly machines include: the proportion of acceptable product coming off the line; the proportion of assemblies containing at least one defective component; the frequency of downtime occurrences per cycle; the average actual production time per assembly; the average actual production time; the average actual production rate of acceptable product; line efficiency; the proportion downtime; and the cost per assembled product.

Partial automation may be favoured in cases where it is ideal to introduce automation gradually on an existing manual line; or where full automation cannot be considered because certain manual operations are too difficult or too costly to automate.

END LIST