8.1 Unit Introduction

Material transport systems are used in manufacturing and production environments to take materials from one location to another. According to the Material Handling Industry of America (MHIA), material handling is the movement, storage, protection and control of materials throughout the manufacturing and distribution process, including their consumption and disposal. It should consist of the following desirable characteristics:

BULLETLIST
Be designed with safety in mind
Be developed for performing efficiently
Be developed to operate at low cost
Be designed to perform in a timely manner
Be developed to operate accurately, delivering the right materials in the right quantities to the right locations
Be designed to deliver materials without damage
ENDLIST

KEYPOINT
Material handling is the movement, storage, protection and control of materials throughout the manufacturing and distribution process, including their consumption and disposal.
END KEYPOINT

Coordination and control is required to move materials that act as inputs to the process and remove materials as outputs from the process. Material handling is often overlooked in the general scheme of production. The cost of material handling is significant and averages around 20-25% of total manufacturing labour cost.
In this unit general material handling principles are introduced, with discussions on material handling equipment and their design considerations. The varieties of material transport equipment are presented. This is followed by an analysis of material transport systems, which examines quantitative models of vehicle-based systems of transport, and of conveyor-systems.

8.2 Unit Learning Objectives

After completing this unit you will be able to:

BULLET LIST
Define the concept of material handling, and specify material handling equipment

List the factors that can influence the design of the material handling system

Specify the five types of material transport equipment that may be identified

Define what an Automated Guided Vehicle System is, and its principle applications

Specify examples of rail-guided systems, and their versatility

Define what a conveyor is, and the various types that exist

Define the uses made of cranes and hoists

Determine the analysis equations that can be derived for vehicle-based systems

Determine the analysis equations that can be derived for conveyor systems
ENLIST

8.3 Material Handling Equipment

Logistics is the term used to denote the broader system for the general movement of materials into and out-of the production environment. It includes all transport and handling of products and materials—such as the acquisition, movement, storage, and distribution of materials and products, and also the production planning and control required to complete these transport and handling processes satisfactorily. In general there are two types of logistics:

BULLETLIST
External logistics—this occurs outside of the production facility, and includes all transportation and related activities required to move material and products to
various geographical locations. The five modes of transportation are rail, truck, air, ship, and pipeline.

Internal logistics—also known as material handling, is the focus of this unit. It involves the movement and storage of materials inside a given production environment. See Figure 8.1.

**KEYPOINT**

Logistics describes the general movement of materials into and out-of the production environment.

**END KEYPOINT**

External Logistics

![External Logistics Image]

Internal Logistics

![Internal Logistics Image]

Figure 8.1: External and internal logistics

For material handling procedures, four categories of equipment are available commercially; these are described in detail Table 8.1.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Transport Equipment</td>
<td>Five types may be generally identified: industrial trucks; automated guided vehicles; rail-guided vehicles; conveyors; and hoists and cranes.</td>
</tr>
<tr>
<td>Storage Systems</td>
<td>Raw materials and work-in-process generally spend time being stored, even if only temporarily. Finished products may also be stored subject to final delivery. Storage methods include bulk storage; rack systems; shelving and bins.</td>
</tr>
<tr>
<td>Unitising Equipment</td>
<td>Containers and pallets are used to group and hold individual items during handling. Containers include pallets, boxes, baskets, pails, and drums. Equipment used include: palletisers and depalletisers</td>
</tr>
<tr>
<td>Identification and Tracking Systems</td>
<td>Identifying and tracking materials is usually done by affixing an identifier to the item, carton, or unit load. Identifiers include: bar codes, radio frequency identification (RFID) tags, and sensors.</td>
</tr>
</tbody>
</table>

**KEYPOINT**
Material handling equipment can be categorised into four areas: material transport equipment; storage systems; unitising equipment; and identification and tracking systems.

**KEYPOINT**

8.3.1. Design Characteristics

Design considerations for specifying material handling equipment are detailed in Table 8.2.

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Characteristics</td>
<td>Physical state (solid, liquid, or gas); size (volume, length, width, height); weight (per piece, and per unit volume); shape (long and flat, round, square, etc.); condition (hot, cold, wet, dry, dirty, sticky); risk of damage (fragile, brittle, sturdy); and safety risk (explosive, flammable, toxic, corrosive, etc.).</td>
</tr>
<tr>
<td>Flow Rate, Routing, and Scheduling</td>
<td>Quantities and flow rates of materials to be moved; routing factors; and scheduling of the moves. Large dedicated handling systems are appropriate for large quantities. Conversely, if the quantity of a material types is small and variety is large, then the material handling system needs to be general purpose. The amount of material moved must also be considered within the context of time; this gives us the flow rate. Routing factors include pick-up and drop-off locations, move distances, routing variations, and conditions that exist along routes. Scheduling relates to the timing of each delivery.</td>
</tr>
<tr>
<td>Plant Layout</td>
<td>Total area of the facility; total area within specific departments; relative locations of departments; arrangement of equipment in the layout; locations of load stations and unload stations; possible routes between locations; and distances travelled.</td>
</tr>
<tr>
<td>Unit Load Principle</td>
<td>Unit loads are designed to be as large as the material handling system can practically manage, subject to obvious conditions—such as safety, convenience and access.</td>
</tr>
</tbody>
</table>

**KEYPOINT**

The factors that can influence the design of the material handling system are: the characteristics of the material to be handled; issues of flow rate, routing, and scheduling; considerations arising from the plant layout that is chosen; and the application of the unit load principle.

**END KEYPOINT**

8.4 Material Transport Equipment

Five types of material transport equipment can be identified: industrial trucks; automated guided vehicles; monorails and rail-guided vehicles; conveyors; and hoists and cranes. We shall look at each type in more detail in this section.

**KEYPOINT**

There are five types of material transport equipment that may be identified; these are: industrial trucks; automated guided vehicles; monorails and rail-guided vehicles; conveyors; and hoists and cranes.
8.4.1 Industrial Trucks

For industrial trucks, these consist of non-powered and powered categories; these are outlined in Table 8.3.

<table>
<thead>
<tr>
<th>Type</th>
<th>Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-powered</td>
<td><img src="image1" alt="Non-powered" /> <img src="image2" alt="Non-powered" /> <img src="image3" alt="Non-powered" /></td>
</tr>
<tr>
<td>Powered</td>
<td><img src="image4" alt="Powered" /> <img src="image5" alt="Powered" /> <img src="image6" alt="Powered" /></td>
</tr>
</tbody>
</table>

**LEARNING ACTIVITY 8.1**
Learn more about industrial trucks at the following web-sites:
http://en.wikipedia.org/wiki/Hand_truck
http://en.wikipedia.org/wiki/Forklift
http://en.wikipedia.org/wiki/Pallet_jack

**END LEARNING ACTIVITY 8.1**

8.4.2. Automated Guided Vehicles

An Automated Guided Vehicle System (AGVS) uses independently operated, self-propelled vehicles that are guided along pre-defined paths, and are powered by means of on-board batteries. AGVS use unobtrusive pathways, unlike rail systems or conveyors where the pathways are predefined and must be built into the plant layout.

**KEYPOINT**
An Automated Guided Vehicle System (AGVS) is a material handling system that uses independently operated, self-propelled vehicles that are guided along pre-defined paths to achieve their objectives.

KEYPOINT

Three types of vehicles are typically deployed in an AGVS; these are presented in Table 8.4.

Table 8.4: Vehicle types for Automated Guided Vehicle Systems

<table>
<thead>
<tr>
<th>Type</th>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guided driverless trains</td>
<td><img src="image" alt="Driverless Train" /></td>
<td>This consists of a towing vehicle pulling one or more trailer carts to form a train. It is often used to move heavy payloads over long distances in warehouses or factories with or without intermediate pick-up or drop-off points along the route.</td>
</tr>
<tr>
<td>Guided pallet trucks</td>
<td><img src="image" alt="Pallet Truck" /></td>
<td>The pallet is loaded by the operator who then steers the truck to the guide-path, and proceeds to programme its destination. The pallet truck can then move automatically to its destination for unloading.</td>
</tr>
<tr>
<td>Guided unit load carriers</td>
<td><img src="image" alt="Unit Load Carrier" /></td>
<td>Unit load carriers move unit loads from one station to another. They may be equipped with automatic loading and unloading devices that are built into the vehicle deck to assist with material handling at each station.</td>
</tr>
</tbody>
</table>

KEYPOINT
An AGVS may deploy three types of vehicle: driverless trains; automated guided pallet trucks; and automated guided vehicle unit load carriers.

END KEYPOINT

LEARNING ACTIVITY 8.2
Learn more about AGVs by searching [www.youtube.com](http://www.youtube.com) with some of the key words mentioned in the text.

END LEARNING ACTIVITY 8.2
AGVS uses specific types of vehicle guidance technology to achieve operation of the system. The approaches used are outlined in detail in Table 8.5.

Table 8.5: Vehicle Guidance Technology for AGVS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embedded guide wires</td>
<td>Electrical wires are placed in a small channel cut in the plant floor that follows the required path. The buried guide wire is connected to a frequency generator that produces a low-voltage, low-current frequency signal; this creates a magnetic field along the pathway that may be followed by two sensors built into the AGV. Steering of the AGV is controlled by the use of the sensors, and the relative strength of the magnetic field on each sensor.</td>
</tr>
<tr>
<td>Paint strips</td>
<td>The AGV can use optical sensors to follow a painted strip. Strips can be painted, taped or sprayed onto the floor. One problem is that paint strips wear out over time. They are particularly advantageous in environments with high electrical interference, where embedded wires cannot be used.</td>
</tr>
<tr>
<td>Self-guided (autonomous) vehicles</td>
<td>The latest AGVS technology, they operate without continuously defined pathways. Instead they use a combination of dead reckoning and beacons located throughout the factory that can be identified by on-board sensors on the AGV.</td>
</tr>
</tbody>
</table>

KEYPOINT

AGVS uses specific types of vehicle guidance technology to achieve operation of the system including: embedded guide wires; paint strips; and self-guided or autonomous vehicles.

END KEYPOINT

Two issues arise with the management and coordination of unmanned vehicles. These are: traffic control, and vehicle dispatching. Traffic control minimises interference between vehicles and prevents collisions. Two systems may be used to achieve these objectives: on-board vehicle sensing; and zone control. In a functioning AGVS, vehicles must be dispatched in a timely manner, as and when they are needed; this can be done via three different methods: on-board control panels; remote call stations; and central computer control. These aspects of vehicle management are outlined in Table 8.6.

Table 8.6: Vehicle management for AGVS

<table>
<thead>
<tr>
<th>Management Issue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic control using On Board Sensing</td>
<td>In on-board vehicle sensing, also known as forward sensing, sensors are deployed to detect the presence of other vehicles in the vicinity, especially on the guide path. Sensor types used include optical and ultrasonic devices that cause the AGV to stop when the presence of another vehicle is detected. Movement only occurs again when the obstacle is removed. On-board vehicle sensing is limited by only sensing vehicles directly in front of it. It cannot, for example, detect vehicles that may be approaching from the side, as in cases where guide paths are curved, or separate paths are converging together.</td>
</tr>
<tr>
<td>Traffic control using Zone Control</td>
<td>In zone control the AGVS layout is split into separate zones, with each zone having potentially one AGV. If one AGV is already present in a zone that another AGV wishes to enter, it cannot do so until the first AGV moves to a new zone. Zone length is generally enough for one vehicle and some additional space allowance for safety, and other, considerations. Zone control is implemented by means of control units implemented along the guide path. When a zone is full it activates a block on the zone until it becomes a free zone again; this occurs when the AGV moves into the next adjacent zone—thus activating its control system, and deactivating the control in the zone it leaves, which frees it up for the oncoming AGV. Zone control may also be implemented by means of a central computer tasked with monitoring the location of each AGV in the system.</td>
</tr>
<tr>
<td>Vehicle dispatching using On-board Control Panel</td>
<td>All AGVs have an on-board control panel which may be used to send an instruction to the AGV to move to a given station. This dispatching by means of the on-board control panel represents the lowest level of sophistication among possible methods.</td>
</tr>
<tr>
<td>Vehicle dispatching using Remote Call Stations</td>
<td>Remote call stations operate as a 'call' system, whereby the nearest available vehicle in the AGVS is hailed by means of either a simple push button mounted at each load/unload station, or by means of more sophisticated call stations. Vehicles that arrive on request of the summons can be programmed to a particular destination by the on-board control panel, or they may actually be programmed, in more sophisticated methods, while the vehicle is being called.</td>
</tr>
<tr>
<td>Vehicle dispatching using Supervisory central control computer</td>
<td>A central control computer may be used to control the AGVS in highly automated environments. It can be used to accomplish automatic dispatching of vehicles according to a pre-planned schedule of pick-ups and deliveries in the layout and/or in response to calls from the various load/unload stations.</td>
</tr>
</tbody>
</table>

**KEYPOINT**
Issues of vehicle management concerning the AGVS include issues of traffic control, and issues of vehicle dispatching.

**END KEYPOINT**
As AGVS tends to operate as a system independent of constant and recurring human assistance. It must be designed with the safety of human personnel in mind. Among the safety features that the system is noted for is the following:

BULLETLIST
Movement speeds of less-than-walking-pace—this ensures that the AGV does not injure personnel by overtaking them unawares as they walk along the guide path.

Automatic stopping of the vehicle—this is initiated if it strays a short distance from the guide-path (this off-set distance is called the acquisition distance).

Obstacle detection sensor on the vehicle—this on-board sensor is used to detect obstacles along the path ahead, including humans.

Emergency bumper—virtually all commercial AGVs are equipped with safety devices such as emergency bumpers. When the bumper makes contact with an object, the AGV is programmed to brake automatically.

Additional features—other available safety devices that may be found on AGVs include warning lights and warning bells.
ENDLIST

KEYPOINT
Safety features associated with the AGVS include: movement speeds of less-than-walking-pace; automatic stopping of the vehicle; obstacle detection sensors; emergency bumpers; and warning lights and bells.
END KEYPOINT

8.4.3. Rail Guided Vehicles

Motorised vehicles that are guided by a fixed rail system constitute a third category of material transport systems. If the system uses just one rail it is called a monorail system; whereas it can also consist of a two-rail system. Monorails typically operate from a suspended position overhead, while two-rail systems are generally found on the plant floor. Vehicles operate asynchronously and are driven by an on-board electric motor, with power being supplied by an electrified rail. This removes the necessity of stoppages owing to battery-power wear-out, as with AGVs, but it presents a new safety hazard in the form of the electrified rail.

Routing variations are possible in rail systems through a combination of turntables, switches, and other specialised track sections. This allows different loads to travel different routes, in a similar manner to an AGVS. Rail-guided systems are generally considered to be more versatile than conveyor systems, but less versatile than AGVS. Considerable use is made of the system in the
automotive industry where overhead monorails move large components and sub-assemblies in its manufacturing operations.

**KEYPOINT**
Rail-guided systems are generally considered to be more versatile than conveyor systems, but less versatile than AGVS.

**END KEYPOINT**

8.4.4. Conveyors

Conveyors are mechanical equipment for moving items or bulk materials between specific locations over a fixed path. Conveyors are either powered or non-powered, and they may run in the floor, on the floor, or overhead. Powered conveyors use a system of chains, belts, rotating rolls, or other devices to propel loads along the fixed path; while non-powered conveyors are propelled manually by human workers who push the loads along the fixed path, or by gravity from higher to lower elevations. Different types of conveyors exist; some common types are outlined in Table 8.7.

**KEYPOINT**
Conveyors are mechanical apparatuses for moving items or bulk materials between specific locations over a fixed path.

**END KEYPOINT**

<table>
<thead>
<tr>
<th>Conveyor Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller</td>
<td>Pathway consists of rollers, or cylindrical tubes, perpendicular to the direction of travel, and contained within a fixed frame that is elevated above the floor. Flat-bottomed loads, traversing several rollers at once, are moved forward by the turning motion of the rollers. Loads may be pallets, tote pans, or cartons. The rollers themselves may be powered or non-powered, with non-powered rollers using the force of gravity to operate effectively.</td>
</tr>
<tr>
<td>Skate-wheel</td>
<td>Similar in operation to roller conveyors. Instead of rollers, however, rows of small skate-like wheels are used to propel the load forward. The load in this case has more surface contact with the skate wheels, when compared against the roller conveyor, and so lighter loads are favoured. Sometimes built as portable units for light-weight loading and unloading in logistics stations.</td>
</tr>
<tr>
<td>Belt</td>
<td>Belt conveyors consist of a belt of reinforced elastomer (rubber) passed, in a forward loop, over two positional rollers, and returned, to complete the loop, on the other side of the rollers. One roller is the drive roller that drives the belt; the other roller is called the idler roller: it is turned by the belt and changes the direction of the belt run, from forward to return.</td>
</tr>
</tbody>
</table>
The forward run is supported by a frame with support sliders that underpin the belt itself.

Four-wheel carts are powered by chains or cables located in channels in the floor. The pathway is defined by the direction of the channel and cable, and the cable is powered by a powered pulley system. It is possible to switch between powered pathways to achieve flexibility in routing. The carts are connected to the channel cable via pins from the front of the cart that project down into the channel. It may be released from the cable for unloading, loading, switching, accumulating parts, and to allow the cart to be moved manually.

A trolley is a wheeled carriage running on an overhead rail from which loads are suspended. A chain system, through the links of which an individual trolley passes, provides the motion power to propel the trolleys along the overhead rail track. Connected to each trolley is a load, so—as the trolleys move along the track—the individual loads move also. The chain and trolley system forms a complete loop, such that when a load arrives at its destination it may be unloaded from the trolley which returns to the back of the queue ready for loading again.

Consists of individual carts that ride on a track a few feet above floor level. The carts use a rotating shaft for propulsion, while a drive wheel—attached to the cart’s bottom, and at an angle to the rotating shaft—drives the cart forward. By regulating the contact between drive wheel and rotating shaft, the cart is controlled. This system allows the cart to be positioned with high accuracy.

**KEYPOINT**

Types of conveyors include: roller; skate-wheel; belt; chain; in-floor towline; overhead trolley; power-and-free overhead trolley; cart-on-track; and others.

**END KEYPOINT**

Conveyors can be synchronous or asynchronous and they are outlined in detail in Table 8.8.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>Move at a constant velocity ( (v_c) ) along the pathway, and include conveyor types belt, roller, skate-wheel, and overhead trolley. These conveyors form a circuit consisting of a delivery loop and a return loop. A continuous loop system allows materials to be moved between any two stations along the pathway. They are used in conjunction to various types of carriers (e.g. hooks or baskets), which move materials on the conveyor system by being attached to the conveyor loop; empty carriers are automatically released from the cable for unloading, loading, switching, accumulating parts, and to allow the cart to be moved manually.</td>
</tr>
</tbody>
</table>
Asynchronous handling allows independent movement of each carrier in the system. Examples include power-and-free trolley, in-floor towline, and cart-on-track, and—for some models—roller and skate-wheel. Reasons for their use include: load accumulation, temporary storage, to equalise production rates on different conveyors in adjacent processing areas, to smooth production cycle times along a production line, and to accommodate different conveyor speeds along the pathway.

---

**KEYPOINT**

Powered conveyors may be classified according to the types of motion characteristics they display - continuous and asynchronous.

**END KEYPOINT**

Conveyors may also be described as single direction, continuous loop, or re-circulating. Single direction conveyors are used to transport loads in one direction from a starting point to a finishing point; continuous loop conveyors form a complete circuit; while re-circulating conveyors allow parts or products to remain on the return loop of the continuous loop configuration for one or more revolutions. Re-circulating conveyors thus makes more economical use of the return loop than the continuous loop configuration, which often only returns empty contains, or trolleys (or nothing at all) to the start of the system. Re-circulating conveyors take the opportunity offered by the return loop to utilise it to store as well as deliver items.

**KEYPOINT**

Conveyors may also be described as single direction, continuous loop, or re-circulating.

**END KEYPOINT**

Two problems, however, may be noted with re-circulating conveyor systems:

**BULLETLIST**

- There may be times during the operation when no empty carriers are immediately available at the loading station when needed

- There may be times during the operation when no loaded carriers are immediately available at the unloading station when needed

**ENDLIST**

One possible way to overcome these shortcomings is to construct branching and merging points into a conveyor track to permit routing of different loads moving in the system. This can supplement shortfalls associated with the traditional operation of the re-circulating conveyor system.
8.4.5. Cranes and Hoists

Cranes and hoists are the fifth category of material transport system. Cranes are used for horizontal movement of materials in a facility; while hoists are used for vertical lifting. A crane includes a hoist, which lifts the material, while the crane part of the mechanism transports the load horizontally to the desired destination by means of a series of overhead supporting beams. Cranes may be sub-divided into three classes: bridge cranes; gantry cranes; and jib cranes. Equipment in this category is described further in Table 8.9.

**KEYPOINT**

Cranes and hoists are the fifth category of material transport system. Cranes are used for horizontal movement of materials in a facility; while hoists are used for vertical lifting.

**END KEYPOINT**

<table>
<thead>
<tr>
<th>Equipment type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoist</td>
<td>Used to raise and lower loads, it consists of one or more fixed pulleys, one or more moving pulleys, and a rope/chain/cable that connects the pulley system together. The load is attached to the moving pulley(s) by means of a hook, or other mechanism. The more pulleys a hoist has, the greater the mechanical advantage it can display; whereby mechanical advantage is formulated as the ratio of the load weight to the driving force required to lift the weight. The driving force is applied either manually, or by electric or pneumatic motor.</td>
</tr>
<tr>
<td>Bridge cranes</td>
<td>Consist of one or two horizontal suspended beams fixed between rails on either end, the whole structure being held in place by the building structure. The hoist trolley moves the length of the bridge, while the bridge itself can be moved the length of the rails in the building. This provides x- and y-axis motion capabilities, whilst the hoist provides z-axis motions. Vertical lifting is achieved by the hoist, and orthogonal movement by the rail system along which the hoist trolley travels.</td>
</tr>
<tr>
<td>Gantry cranes</td>
<td>Distinguished from a bridge crane by the presence of one or two vertical legs that support the horizontal bridge. The hoist again provides for vertical lifting, while orthogonal movement is again provided by the rail system, as in the bridge crane construction. A double gantry crane has two vertical legs; a half-gantry crane has one vertical leg, with the other part of the crane supported by the building; while a cantilever gantry has a bridge that extends beyond the span created by the supporting legs.</td>
</tr>
<tr>
<td>Jib cranes</td>
<td>Consist of a hoist supported on a horizontal beam that is cantilevered from a vertical column or wall support. The horizontal beam can pivot about the vertical axis formed by the column or wall support; this provides a horizontal sweep for the crane. This forms a semi-circular or circular area in which the horizontal beam can move. The horizontal beam also serves as the track along which the</td>
</tr>
</tbody>
</table>
hoist trolley moves. The hoist provides vertical lift and lower motions.

KEYPOINT
There are three crane types: bridge cranes, gantry cranes, and jib cranes.
END KEYPOINT

8.5 Analysis of Material Transport Systems

Quantitative models for analysing aspects of material transport systems can be created under two general headings: analysis of vehicle-based systems, and analysis of conveyor systems. In this unit we focus our attention on vehicle based systems. For vehicle-based systems the delivery equipment used can include industrial trucks, AGVs, monorails, and certain types of conveyor systems (for example, in-floor towline conveyors). Two graphical tools are used to capture delivery data: from-to charts, and network diagrams. The from-to chart is a table that can be used to indicate material flow data and distances between multiple locations. Network diagrams can also display the same sorts of information, by means of nodes and arrows, where the arrows indicate the relationships among the nodes. In material handling nodes represent load/unload stations, while the arrows represent material flows between the stations. See Example later in this section for examples of both of these types of diagrams.

KEYPOINT
For vehicle-based system analysis, two graphical tools are used to capture delivery data: from-to charts, and network diagrams.
END KEYPOINT

8.5.1. Total Cycle Time

If we assume that a vehicle works at a constant velocity throughout its operation, and we ignore speed differences (e.g. owing to acceleration, deceleration, etc.), then the time for a typical delivery cycle in the operation of a vehicle-based transport system consists of:

BULLET LIST
- Pick-up station loading
- Travel time to drop-off station
- Unloading at drop-off station
Empty travel time of the vehicle between deliveries

This gives a total cycle time per delivery per vehicle of:

$$T_c = T_L + \frac{L_d}{v_c} + T_U + \frac{L_e}{v_c}$$

where $T_c$ is delivery cycle time; $T_L$ is the time to load at a load station; $L_d$ is the distance the vehicle travels between load and unload station; $v_c$ is the carrier velocity; $T_U$ is the time to unload at unload station; and $L_e$ is the distance the vehicle travels empty until the start of the next delivery cycle. Delivery cycle time calculated in this way must be considered an ideal value, as it ignores not only speed effects, but also traffic congestion, reliability issues, and other factors. In addition, load and unload stations may be in different locations, which will change the values of $L_d$ and $L_e$ in the equation; thus these terms are generally taken to be averages of the distances involved.

Delivery cycle time can help us calculate the rate of deliveries per vehicle; and the number of vehicles required to satisfy a specified total delivery requirement, based upon hourly rates and requirements. The hourly rate of deliveries per vehicle is simply:

$$\frac{60}{T_c}$$

where 60 represents minutes in an hour and is divided by delivery cycle time, and adjusted for any time losses during the hour. Potential time losses may be due to: availability, traffic congestion, and efficiency of manual drivers in manually operated trucks.

8.5.2. Available Time

Availability ($A$) is defined as the proportion of total shift time that the vehicle is operational and not broken down, or being repaired.

For traffic congestion, a traffic factor ($F_t$) is first defined that estimates losses caused by congestion. This factor covers waiting at intersections, blockages by other vehicles, and queues. If no congestion occurs, then $F_t = 1.0$; if congestion occurs then the value of $F_t$ drops. Traffic congestion is a function of the number of other vehicles in the system. Typical values of $F_t$ for AGVS range between 0.85 and 1.0.
The primary cause of low operating performance in industrial truck systems is not traffic congestion, but work efficiency of the operators who drive the trucks. Worker efficiency is defined as the actual work rate of the human operator relative to the expected work rate under standard or normal performance conditions; this is symbolised as $E_w$. Thus, from the discussion above, the available time, per hour, per vehicle is:

$$AT = 60AF_tE_w$$

This equation does not account for poor vehicle routing, poor guide-path layout, or poor vehicle management. These factors should be minimised, but if present they should be accounted for in the factors $L_d$ and $L_e$.

8.5.3. Rate of Deliveries

We can formulate the rate of deliveries per vehicle as:

$$R_{dv} = \frac{AT}{T_c}$$

where $R_{dv}$ is the hourly delivery rate per vehicle; $T_c$ is the delivery cycle time; and $AT$ is the time available in one hour with time loss adjustments. The total number of vehicles, of all kinds, needed to satisfy a specified total delivery schedule, $R_f$, in the system is estimated by deriving the total workload and dividing it by the available time per vehicle. Workload ($WL$) is the total amount of work, expressed in time, which must be accomplished by the material transport system in one hour; this comes to:

$$WL = R_fT_c$$

8.5.4. Required Vehicles

The number of work vehicles required ($n_c$) to meet this workload is:

$$n_c = \frac{R_f}{R_{dv}} \quad \text{or} \quad n_c = \frac{WL}{AT}$$

These equations do not consider idle time at load/unload stations, where stations are waiting for vehicles to arrive. If idle time is minimised, then more vehicles may be needed than the number computed from the equations above.
KEYPOINT
For vehicle-based system analysis the following equations can be developed: the total cycle time per delivery per vehicle; the hourly rate of deliveries per vehicle; the available time per hour per vehicle; the rate of deliveries per vehicle; the material transport system workload; and the number of work vehicles required to meet the material transport system workload.

END KEYPOINT

EXAMPLE 8.1
A flexible manufacturing system (FMS) is being planned. It has a ladder layout as pictured in Figure 8.2. It uses a rail guided vehicle (RGV) system to move parts between stations in the layout.

![Diagram of FMS layout](image)

All workparts are loaded into the system at station 1, moved to one of three processing stations (2, 3, or 4), and then brought back to station 1 for unloading. Once loaded onto its RGV, each workpart stays onboard the vehicle throughout its time in the FMS. Load and unload times at station 1 are each 1.0 min. Processing times are: 5.0 min at station 2; 7.0 min at station 3; and 9.0 min at station 4. Hourly production of parts through the system is: 7 parts through station 2; 6 parts through station 3 and; 5 parts through station 4. (a) Develop the from-to Chart for trips and distances; (b) Develop the network diagram. (c) Determine the number of rail guided vehicles that are needed to meet the requirements of the flexible manufacturing system, if vehicle speed = 60 m/min and the anticipated traffic factor = 0.85. Assume reliability = 100%.

Solution:
(a) First develop the distances from the FMS layout.
Distance from 1 to 2: 10 + 10 + 10 = 30 m
Distance from 2 to 1: 5 + 10 + 5 = 20 m
Distance from 1 to 3: 10 + 20 + 10 = 40 m
Distance from 3 to 1:  5 + 20 + 5 = 30 m  
Distance from 1 to 4:  10 + 30 + 10 = 50 m  
Distance from 4 to 1:  5 + 30 + 5 = 40 m

From-To chart:

<table>
<thead>
<tr>
<th>From:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0/0</td>
<td>7/30</td>
<td>6/40</td>
<td>5/50</td>
</tr>
<tr>
<td>2</td>
<td>7/20</td>
<td>0/0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>6/30</td>
<td>-</td>
<td>0/0</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>5/40</td>
<td>-</td>
<td>-</td>
<td>0/0</td>
</tr>
</tbody>
</table>

(b) Network diagram:

(c) \( L_d = \frac{7(30 + 20) + 6(40 + 30) + 5(50 + 40)}{7 + 6 + 5} = 67.7 \text{ m}; \quad L_e = 0 \)

Average handling and processing time = 1.0 + \( \frac{7(5.0) + 6(7.0) + 5(9.0)}{7 + 6 + 5} \) + 1.0 = 8.78 min

\( T_c = 8.78 + \frac{67.7}{60} + \frac{0}{60} = 9.91 \text{ min} \)

\( R_{dv} = \frac{60(0.85)}{9.91} = 5.15 \text{ pc/hr per vehicle} \quad n_c = \frac{7 + 6 + 5}{5.15} = 18/5.15 = 3.5 \)

\( \rightarrow 4 \text{ vehicles} \)

END EXAMPLE 8.1

LEARNING ACTIVITY 8.3
A planned fleet of forklift trucks has an average travel distance per delivery of 500m loaded and an average empty travel distance = 350m. The fleet must make a total of 60 deliveries per hour. Load and unload times are each 0.5 min and the speed of the vehicles = 100m/min. The traffic factor for the system = 0.85.
Availability = 0.95, and worker efficiency = 90%. Determine (a) ideal cycle time per delivery, (b) the resulting average number of deliveries per hour that a forklift truck can make, and (c) how many trucks are required to accomplish the 60 deliveries per hour.

**LEARNING ACTIVITY 8.4**

An AGVS (see Figure 8.3) will be used to satisfy material flows indicated in the from-to Chart in the table below, which shows deliveries per hour between stations (above the slash) and distances in meters between stations (below the slash). Moves indicated by "L" are trips in which the vehicle is loaded, while "E" indicates moves in which the vehicle is empty. It is assumed that availability is 0.90, traffic factor is 0.85, and efficiency is 1.0. Speed of an AGV is 0.9 m/s. If load handling time per delivery cycle is 1.0 min, determine the number of vehicles needed to satisfy the indicated deliveries per hour? Assume that availability is 0.90.

<table>
<thead>
<tr>
<th>To:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>From:</td>
<td>1 0/0</td>
<td>9L/90</td>
<td>7L/120</td>
<td>5L/75</td>
</tr>
<tr>
<td></td>
<td>2 5E/90</td>
<td>0/0</td>
<td>0/NA</td>
<td>4L/80</td>
</tr>
<tr>
<td></td>
<td>3 7E/120</td>
<td>0/NA</td>
<td>0/0</td>
<td>0/NA</td>
</tr>
<tr>
<td></td>
<td>4 9E/75</td>
<td>0/NA</td>
<td>0/NA</td>
<td>0/0</td>
</tr>
</tbody>
</table>

Figure 8.3: Automated Guided Vehicle

**END LEARNING ACTIVITY 8.4**

8.6 Unit Review

BULLETLIST
Material handling is the movement, storage, protection and control of materials throughout the manufacturing and distribution process, including their consumption and disposal.

Logistics describes the general movement of materials into and out-of, and throughout, the general productive environment.

Material handling is also known as internal logistics; it involves the movement and storage of materials inside a given production environment.

Material handling equipment comes in four categories: material transport equipment; storage systems; unitising equipment; and identification and tracking systems.

The factors that can influence the design of the material handling system are: the characteristics of the material to be handled; issues of flow rate, routing, and scheduling; considerations arising from the plant layout that is chosen; and the application of the unit load principle.

An Automated Guided Vehicle System (AGVS) is a material handling system that uses independently operated, self-propelled vehicles that are guided along pre-defined paths to achieve their objectives.

An AGVS may deploy three types of vehicle: driverless trains; automated guided pallet trucks; and automated guided vehicle unit load carriers.

AGVS uses specific types of vehicle guidance technology to achieve operation of the system; these include: imbedded guide wires; paint strips; and self-guided vehicles.

Issues of vehicle management concerning the AGVS include issues of traffic control, and issues of vehicle dispatching.

Rail-guided systems, such as monorails and two-rail systems, constitute a third category of material transport systems.

Types of conveyors include: roller; skate-wheel; belt; chain; in-floor towline; overhead trolley; power-and-free overhead trolley; cart-on-track; and others.

There are three crane types: bridge cranes, gantry cranes, and jib cranes.

For vehicle-based system analysis, two graphical tools are used to capture delivery data: from-to charts, and network diagrams.

For vehicle-based system analysis the following equations can be developed: the total cycle time per delivery per vehicle; the hourly rate of deliveries per vehicle;
the available time per hour per vehicle; the rate of deliveries per vehicle; the material transport system workload; and the number of work vehicles required to meet the material transport system workload.

In conveyor analysis three principal types of conveyance systems may be investigated: single direction conveyors; continuous-loop conveyors; and recirculating conveyors.

8.7 Self-Assessment Questions

What is meant by the concept of material handling? Specify the types of material handling equipment that exist.

List the factors that can influence the design of the material handling system.

What are the five types of material transport equipment that may be identified?

What is an Automated Guided Vehicle System? What are its principle applications?

What are the safety features associated with Automated Guided Vehicle Systems?

Specify examples of rail-guided systems, and their versatility.

What is a conveyor? What types of conveyor exist?

What types of conveyors can be specified if we examine their direction of movement?

What uses are made of cranes and hoists?

What analysis equations can be derived for vehicle-based systems?

8.8 Answers to Self-Assessment Questions

Material handling is the movement, storage, protection and control of materials throughout the manufacturing and distribution process, including their
consumption and disposal. Material handling equipment comes in four categories: material transport equipment; storage systems; unitising equipment; and identification and tracking systems.

The factors that can influence the design of the material handling system are: the characteristics of the material to be handled; issues of flow rate, routing, and scheduling; considerations arising from the plant layout that is chosen; and the application of the unit load principle.

There are five types of material transport equipment that may be identified; these are: industrial trucks; automated guided vehicles; monorails and rail-guided vehicles; conveyors; and hoists and cranes.

An Automated Guided Vehicle System (AGVS) is a material handling system that uses independently operated, self-propelled vehicles that are guided along pre-defined paths to achieve their objectives. Its principle applications are in driverless train operations; for storage and distribution; in assembly line applications; and in flexible manufacturing systems.

The safety features associated with the Automated Guided Vehicle Systems include: movement speeds of less-than-walking-pace; automatic stopping of the vehicle if it strays from the guide-path; obstacle detection sensors; emergency bumpers; and additional features such as warning lights and warning bells.

Rail-guided systems include such systems as monorails and two-rail systems. They are generally considered to be more versatile than conveyor systems, but less versatile than Automated Guided Vehicle Systems.

Conveyors are mechanical apparatuses for moving items or bulk materials between specific locations over a fixed path. Types of conveyors include: roller; skate-wheel; belt; chain; in-floor towline; overhead trolley; power-and-free overhead trolley; cart-on-track; and others.

Three types of conveyor may be specified if we examine their direction of movement; these are: single direction conveyors, continuous loop conveyors, and recirculating conveyors.

Cranes are used for horizontal movement of materials in a facility. Hoists are used for vertical lifting.

For vehicle-based system analysis the following analysis equations can be derived: the total cycle time per delivery per vehicle; the hourly rate of deliveries per vehicle; the available time per hour per vehicle; the rate of deliveries per vehicle; the material transport system workload; and the number of work vehicles required to meet the material transport system workload.