Factory Automation and Control Methods
Lecture 9: Material Transport Systems

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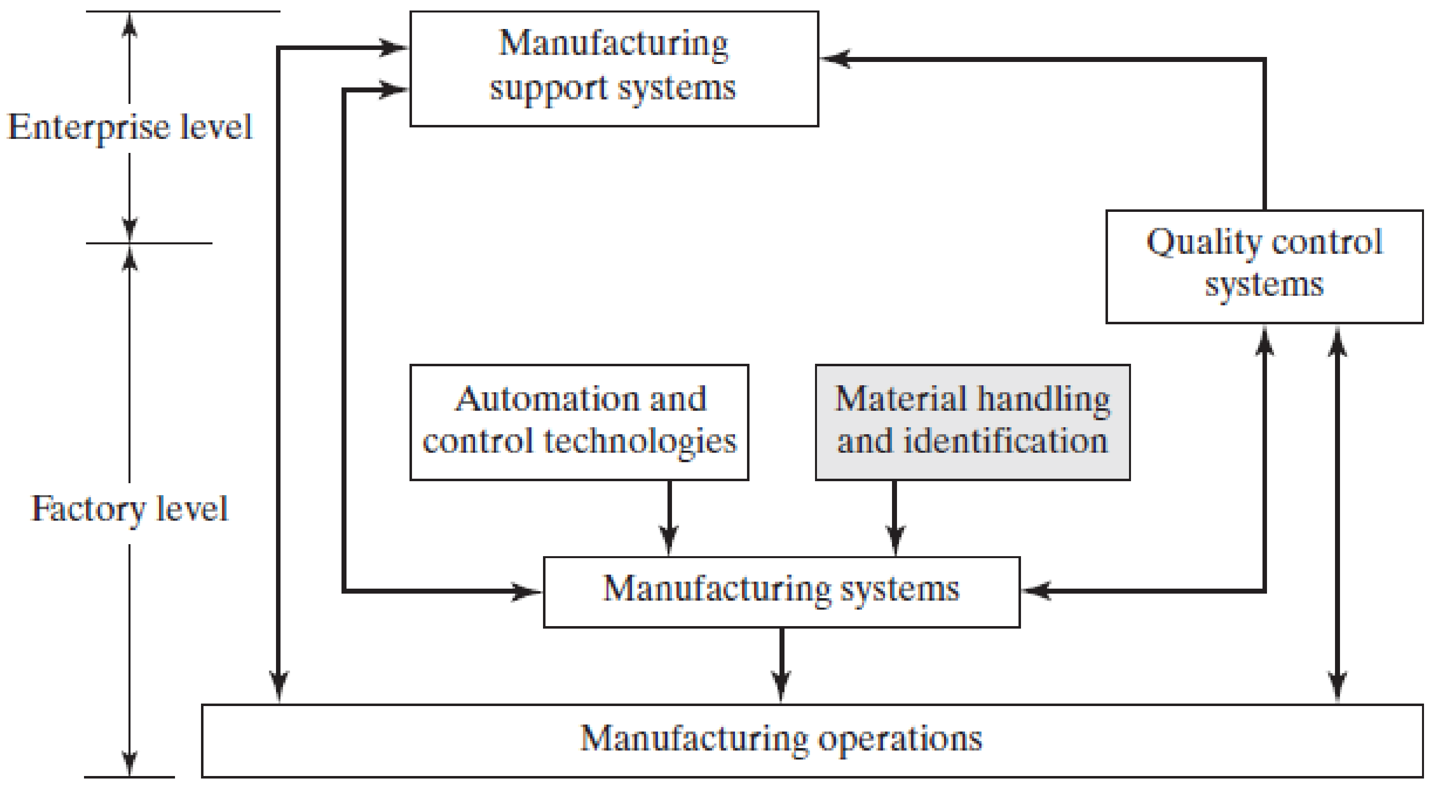
Outline

- Overview of Material Handing
  - Material handling equipment
  - Design considerations in material handling
- Material Transport Equipment
  - Industrial trucks
  - Automated guided vehicle
  - Rail-guided vehicles
  - Conveyors, cranes and hoists
- Analysis of Material Transport Systems
  - Analysis of vehicle-based systems
  - Conveyor analysis

Overview of Material Handing



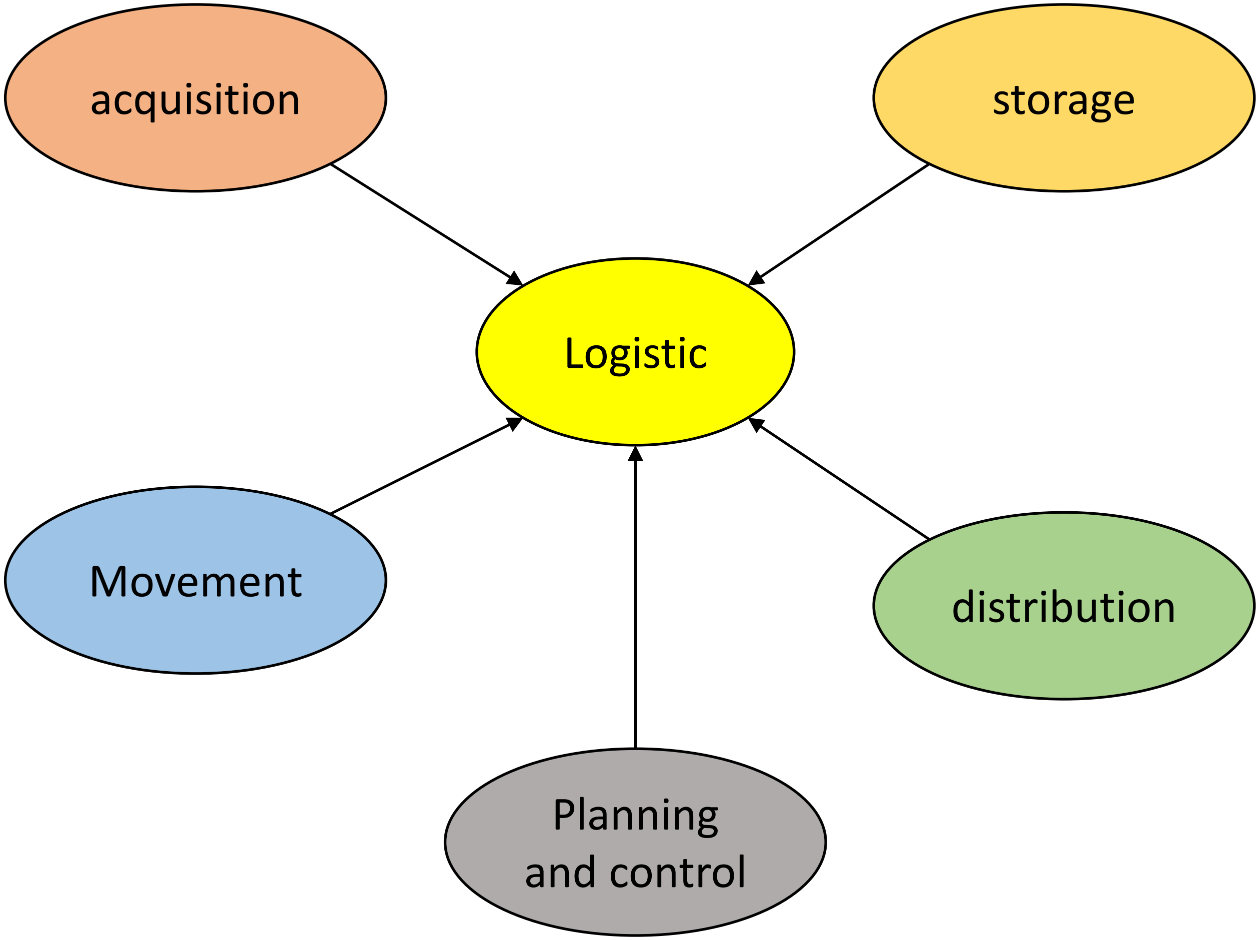
Overview of Material Handing

“the movement, protection, storage and control of materials and products throughout the process of manufacture and distribution, consumption and disposal”

The handling of materials must be performed

- safely,
- efficiently,
- at low cost,
- in a timely manner,
- accurately (the right materials in the right quantities to the right locations), and
- without damage to the materials.

Overview of Material Handing



Overview of Material Handing

Logistics operations can be divided into two basic categories:

External logistics is concerned with transportation and related activities that occur outside of a facility.

Internal logistics, more popularly known as material handling, involves the movement and storage of materials inside a given facility

Overview of Material Handing

Material Handling Equipment

The equipment can be classified into five categories :

- transport equipment,
- positioning equipment,
- unit load formation equipment,
- storage equipment,
- Identification and control equipment.

Overview of Material Handing

Material Handling Equipment

Transport Equipment is used to move material inside the factory, warehouse or other facility.

Five main types of equipment are

- industrial trucks,
- automated guided vehicles,
- rail-guided vehicles,
- conveyors,
- hoists and cranes.

Overview of Material Handing

Material Handling Equipment

Position Equipment is used to handle parts and other materials at a single location.

- Loading and unloading part from a production machine in the cell.
- Positioning is accomplished by industrial robots that perform material handling
- Part feeders in automated assembly
- Etc …

Overview of Material Handing

Material Handling Equipment

Unit Load Formation Equipment refers to

- containers used to hold individual items during handling
  - Ex. tote pans, boxes, baskets, barrels and more.
- equipment used to load and package the containers.

Overview of Material Handing

Material Handling Equipment

Storage Equipment

Storage methods and equipment can be classified into two major categories:

(1) conventional storage methods
  - bulk storage (storing items in an open floor area),
  - rack systems (for pallets),
  - shelving and bins, and
  - drawer storage.

(2) automated storage systems.

Overview of Material Handing

Material Handling Equipment

Identification and Control Equipment : keep track of the materials being moved and stored.

This is usually done by affixing some kind of label to the item, carton, or unit load that uniquely identifies it.

Overview of Material Handing

Design Consideration in Material Handling

The system must be specified and configured to satisfy the requirements of a particular application.

Design of the system depends on

- the materials to be handled,
- quantities and
- distances to be moved,
- type of production facility served by the handling system, and
- other factors, including available budget.

Overview of Material Handing

Design Consideration in Material Handling

Physical characteristics

Category	Measures or Descriptors
Physical state	Solid, liquid, or gas
Size	Volume, length, width, height
Weight	Weight per piece, weight per unit volume
Shape	Long and flat, round, square, etc.
Condition	Hot, cold, wet, dirty, sticky
Risk of damage	Fragile, brittle, sturdy
Safety risk	Explosive, flammable, toxic, corrosive, etc.

Overview of Material Handing

Design Consideration in Material Handling

Flow Rate, Routing, and Scheduling

The amount of material moved per unit time is referred to as the *flow rate*.

Depending on the form of the material, flow rate is measured in pieces per hour, pallet loads per hour, tons per hour, or similar units.

Whether the material must be moved as individual units, in batches, or continuously has an effect on the selection of handling method.

Overview of Material Handing

Design Consideration in Material Handling

Flow Rate, Routing, and Scheduling

Routing factors include pickup and drop-off locations, move distances, routing variations, and conditions that exist along the routes.

Given that other factors remain constant, handling cost is directly related to the distance of the move: The longer the move distance, the greater the cost

Overview of Material Handing

Design Consideration in Material Handling

Flow Rate, Routing, and Scheduling

Scheduling relates to the timing of each individual delivery.

The material must be picked up and delivered promptly to its proper destination to maintain peak performance and efficiency of the overall system.

Scheduling urgency is often mitigated by providing space for buffer stocks of materials at pickup and drop-off points.

Overview of Material Handing

Design Consideration in Material Handling

Plant Layout

The material handling system is an important factor in plant layout design. When a new facility is being planned, the handling system should be considered part of the layout.

In this way, there is greater opportunity to create a layout that optimizes material flow in the building and utilizes the most appropriate type of handling system.

Material Transport Equipment

Material transport equipment commonly used to move parts and other materials in manufacturing and warehouse facilities:

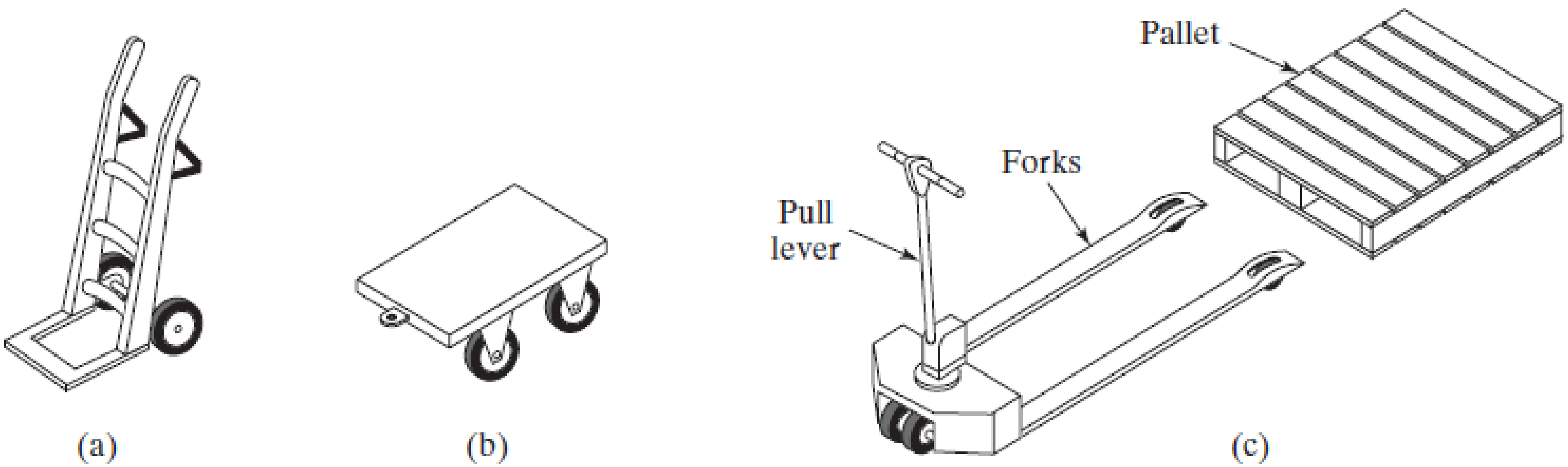
(1) Industrial trucks, manual and powered;
(2) automated guided vehicles;
(3) rail-guided vehicles;
(4) conveyors; and
(5) cranes and hoists.

Material Transport Equipment

Handling Equipment	Features	Typical Applications
Industrial trucks, manual	Low cost Low rate of deliveries	Moving light loads in a factory
Industrial trucks, powered	Medium cost	Movement of pallet loads and palletized containers in a factory or warehouse
Automated guided vehicle systems	High cost Battery-powered vehicles Flexible routing Non-obstructive pathways	Moving pallet loads in factory or warehouse Moving work-in-process along variable routes in low and medium production
Rail-guided vehicles	High cost Flexible routing On-the-floor or overhead types	Moving assemblies, products, or pallet loads along variable routes in factory or warehouse Moving large quantities of items over fixed routes in a factory or warehouse
Conveyors, powered	Great variety of equipment In-floor, on-the-floor, or overhead Mechanical power to move loads resides in pathway	Sortation of items in a distribution center Moving products along a manual assembly line
Cranes and hoists	Lift capacities of more than 100 tons possible	Moving large, heavy items in factories, mills, warehouses, etc.

Material Transport Equipment

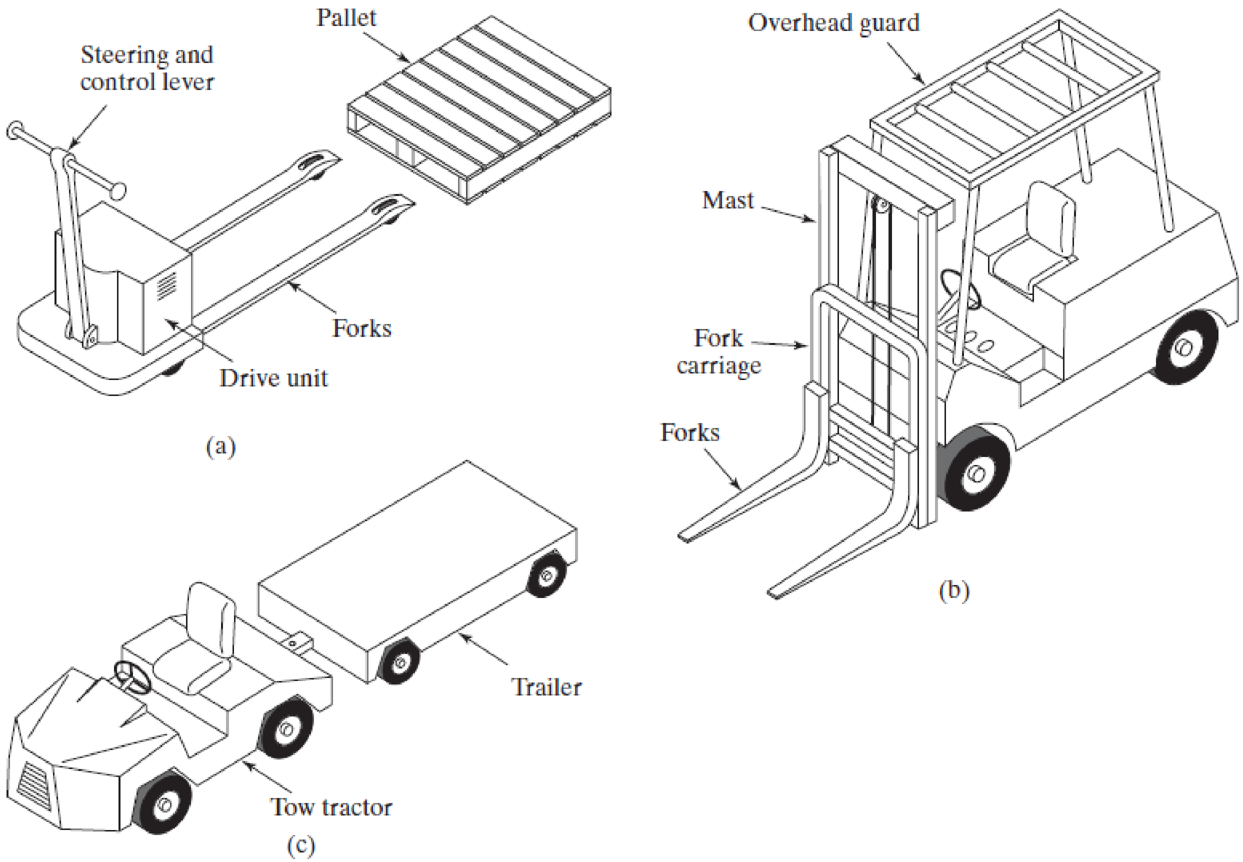
Industrial Trucks



nonpowered industrial trucks (hand trucks): (a) two-wheel hand truck, (b) four-wheel dolly, and (c) hand-operated low-lift pallet truck.

Material Transport Equipment

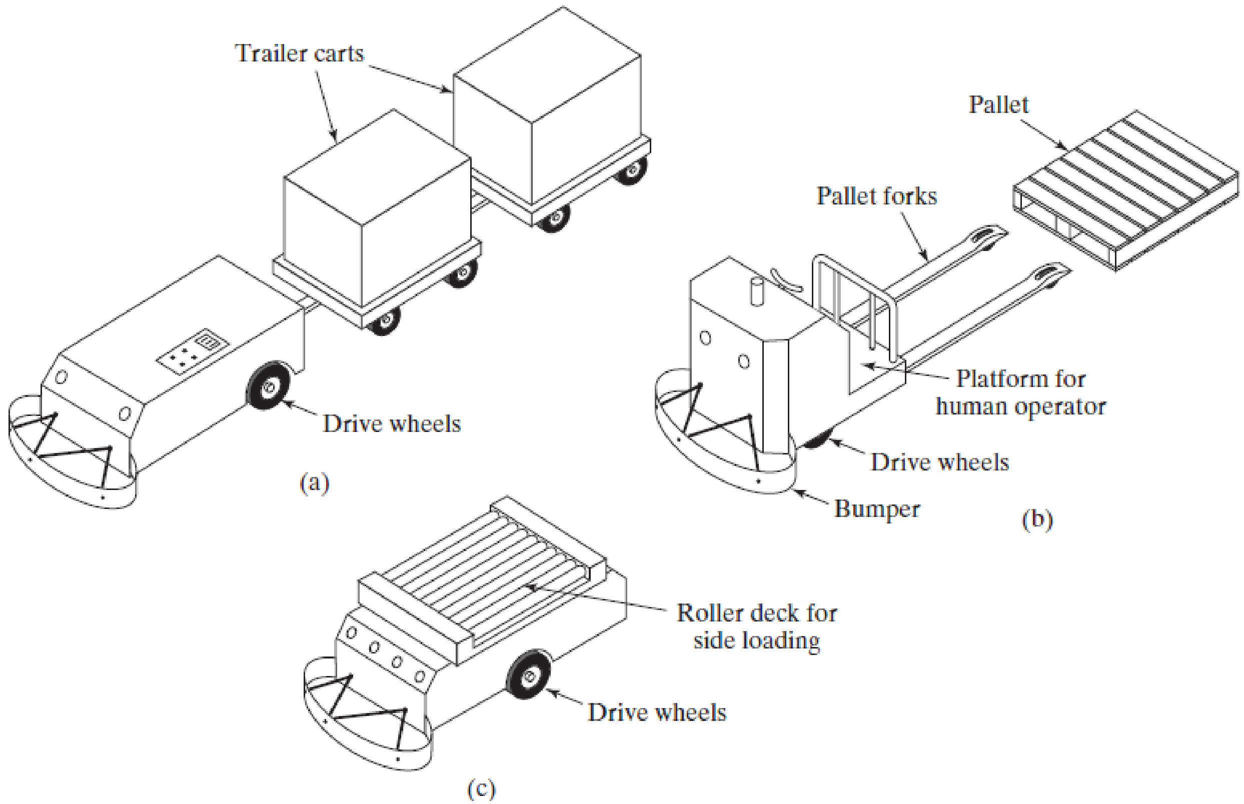
Industrial Trucks



Three principal types of powered trucks: (a) walkie truck, (b) forklift truck, and (c) towing tractor

Material Transport Equipment

Automated Guided Vehicles



Three types of automated guided vehicles: (a) driverless automated guided train, (b) AGV pallet truck, and (c) unit load carrier.

Material Transport Equipment

Rail-Guided Vehicles

The rail system consists of either one rail, called a monorail, or two parallel rails.

Material Transport Equipment

Conveyors

A conveyor is a mechanical apparatus for moving items or bulk materials, usually inside a facility.

Conveyors are generally used when material must be moved in relatively large quantities between specific locations over a fixed path, which may be in the floor, above the floor, or overhead. Conveyors are either powered or nonpowered.

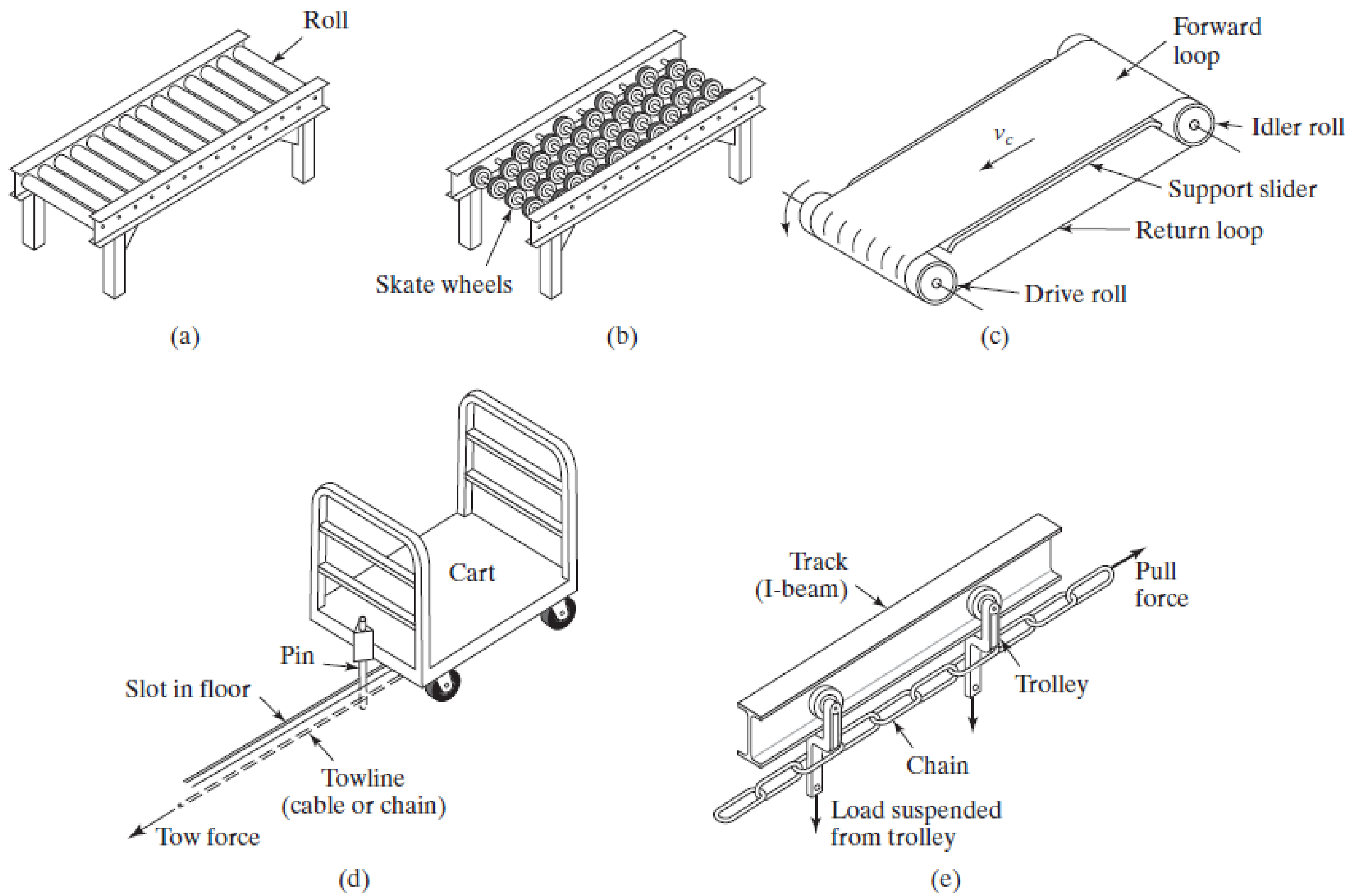
Material Transport Equipment

Conveyors

In powered conveyors, the power mechanism is contained in the fixed path, using chains, belts, rotating rolls, or other devices to propel loads along the path. Powered conveyors are commonly used in automated material transport systems in manufacturing plants, warehouses, and distribution centers.

In nonpowered conveyors, materials are moved either manually by human workers who push the loads along the fixed path or by gravity from one elevation
to a lower elevation.

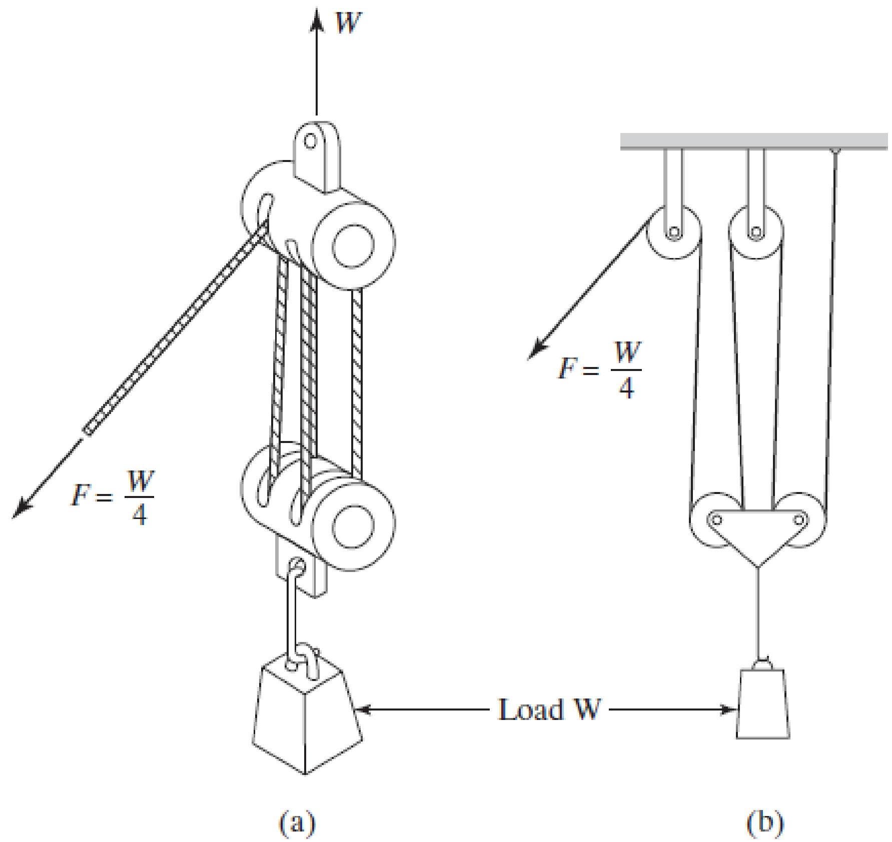
Material Transport Equipment



Types of Conveyors: (a) Roller conveyor, (b) skate-wheel conveyor, (c) belt (flat) conveyor (support frame not shown), (d) in-floor towline conveyor, and (e) overhead trolley conveyor.

Material Transport Equipment

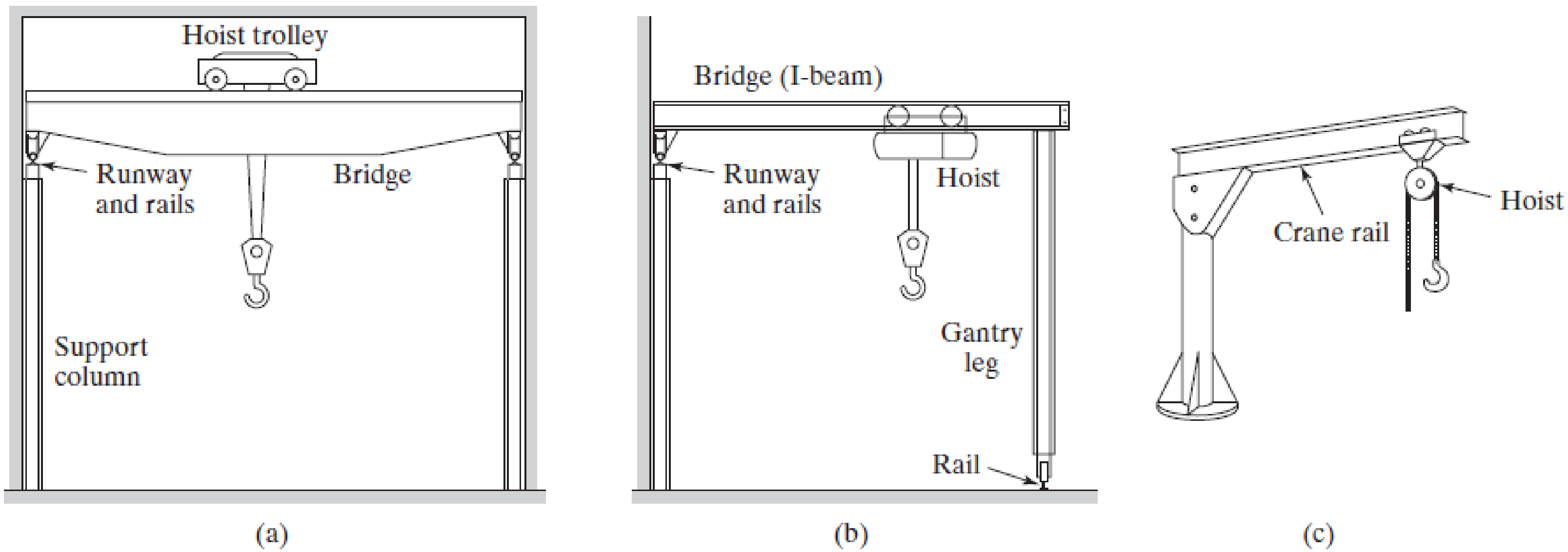
Cranes and Hoists



A hoist with a mechanical advantage of 4.0: (a) sketch
of the hoist and (b) diagram to illustrate mechanical advantage

Material Transport Equipment

Cranes and Hoists



Three types of cranes: (a) bridge crane, (b) gantry crane (a half gantry crane is shown), and (c) jib crane

Analysis of Material Transport Systems

Quantitative models are useful for analyzing material flow rates, delivery cycle times, and other aspects of system performance.

The analysis may be useful in determining equipment requirements

- how many forklift trucks will be required to satisfy a specified flow rate.
- Material transport systems can be classified as vehicle-based systems or conveyor systems
- …etc

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Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

Two graphical tools that are useful for displaying and analyzing data in these deliveries are the

- The **from-to chart** is a table that can be used to indicate material flow data and/or distances between multiple locations.
- **Network diagrams** can also be used to indicate the same type of information. A ***network diagram*** consists of nodes and arrows, and the arrows indicate relationships among the nodes.

  In material handling, the nodes represent locations (e.g., load and unload stations), and the arrows represent material flows and/or distances between the stations.

Analysis of Material Transport Systems

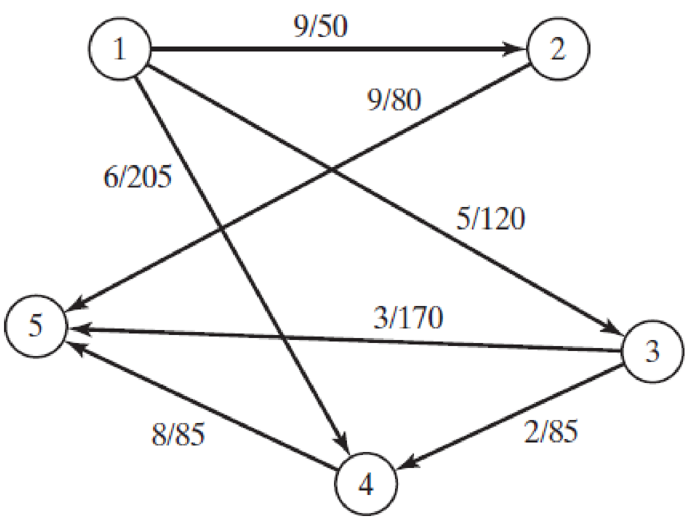
Analysis of Vehicle-Based Systems

From-To Chart Showing Flow Rates, loads/hr (Value Before the Slash), and Travel Distances, m (Value After the Slash), Between Stations in a Layout

	To	1	2	3	4	5
From	1	0	9/50	5/120	6/205	0
	2	0	0	0	0	9/80
	3	0	0	0	2/85	3/170
	4	0	0	0	0	8/85
	5	0	0	0	0	0

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems



Network diagram showing material deliveries between load/unload stations. Nodes represent the load/unload stations, and arrows are labeled with flow rates, loads/hr, and distances m.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

The time for a typical delivery cycle in the operation of a vehicle-based transport system consists of

(1) loading at the pickup station,
(2) Travel time to the drop-off station,
(3) unloading at the drop-off station, and
(4) empty travel time of the vehicle between deliveries.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

The total cycle time per delivery per vehicle is given by

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

where T_c= delivery cycle time, min/del; T_L= time to load at load station, min; L_d= distance the vehicle travels between load and unload station, m ; v_c = carrier velocity, m/min , T_U = time to unload at unload station, min; and L_e= distance the vehicle travels empty until the start of the next delivery cycle, m .

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

The delivery cycle time *Tc* can be used to determine two values of interest in a vehicle-based transport system:

(1) rate of deliveries per vehicle
(2) number of vehicles required to satisfy a specified total delivery requirement.

The analysis is based on hourly rates and requirements, but the equations can readily be adapted for other time periods.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

- The hourly rate of deliveries per vehicle is 60 min divided by the delivery cycle time *Tc*, adjusting for any time losses during the hour.

- The possible time losses include
  - availability,
  - traffic congestion, and
  - efficiency of manual drivers in the case of manually operated trucks.

Note :Availability *A* is a reliability factor defined as the proportion of total shift time that the vehicle is operational and not broken down or being repaired.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

Recall ***:Availability*** $\boldsymbol{A}$ is a reliability factor defined as the proportion of total shift time that the vehicle is operational and not broken down or being repaired.

the ***traffic factor*** $\boldsymbol{F_t}$ is defined as a parameter for estimating the effect of losses on system performance. Sources of inefficiency accounted for by the traffic factor include waiting at intersections, blocking of vehicles (as in an AGVS), and waiting in a queue at load/unload stations.

Worker efficiency is defined as the actual work rate of the human operator relative to the work rate expected under standard or normal performance. Let E_w symbolize worker efficiency.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

With these factors defined, **the available time per hour per vehicle** can now be expressed as 60 min adjusted by $A, F_t,$ and E_w. That is,

$$AT = 60AF_tE_w$$

where AT = available time, min/hr per vehicle; A = availability; F_t= traffic factor, and E_w= worker efficiency. The parameters A, F_t, and E_w do not take into account poor vehicle routing, poor guide-path layout, or poor management of the vehicles in the system.

These factors should be minimized, but if present they are accounted for in the values of L_d, L_e, T_L and T_u

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

The rate of deliveries per vehicle is given by

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

where R_{dv}= hourly delivery rate per vehicle, deliveries/hr per vehicle; T_c = delivery cycle time , min/del; and *AT* = the available time in 1 hour, adjusted for time losses, min/hr.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

Workload is defined as the total amount of work, expressed in terms of time, that must be accomplished by the material transport system in 1 hr. This can be expressed as

$$WL = R_f T_c$$

where WL = workload, min/hr; R_f = specified flow rate of total deliveries per hour for the system, deliveries/hr; and T_c= delivery cycle time, min/del.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems

The number of vehicles required to accomplish this workload can be written as

$$n_c = \frac{WL}{AT}$$

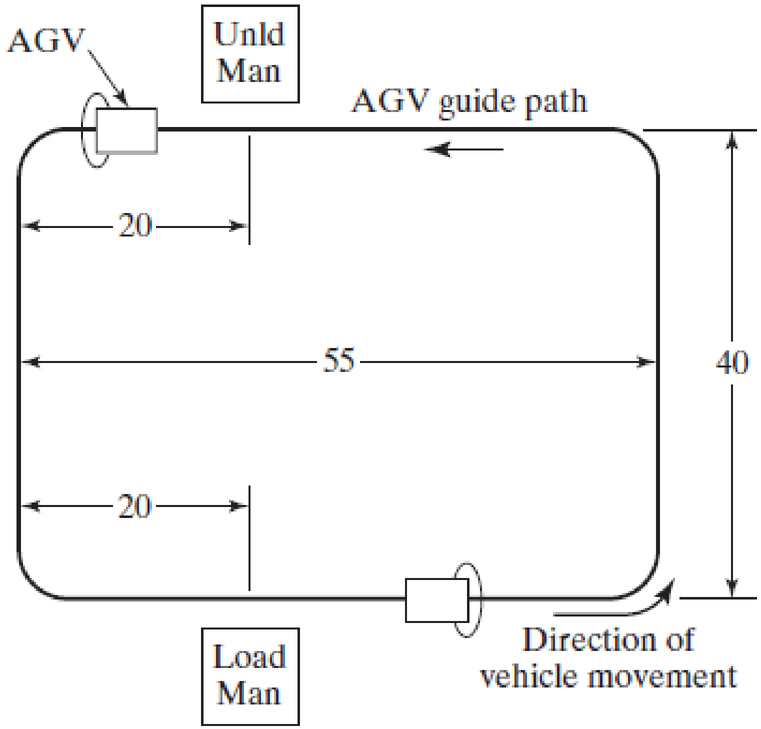
where n_c = number of carriers (vehicles) required, WL = workload, min/hr; and AT = available time per vehicle, min/hr per vehicle.

Another alternative way to determine n_c is

$$n_c = \frac{R_f}{R_{dv}}$$

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems



Consider the AGVS layout on the left. Vehicles travel counterclockwise around the loop to deliver loads from the load station to the unload station. Loading time at the load station = 0.75 min, and unloading time at the unload station = 0.50 min. The following performance parameters are given: vehicle speed = 50 m/min, availability = 0.95, and traffic factor = 0.90. Operator efficiency does not apply, so *Ew* = 1.0.

Determine

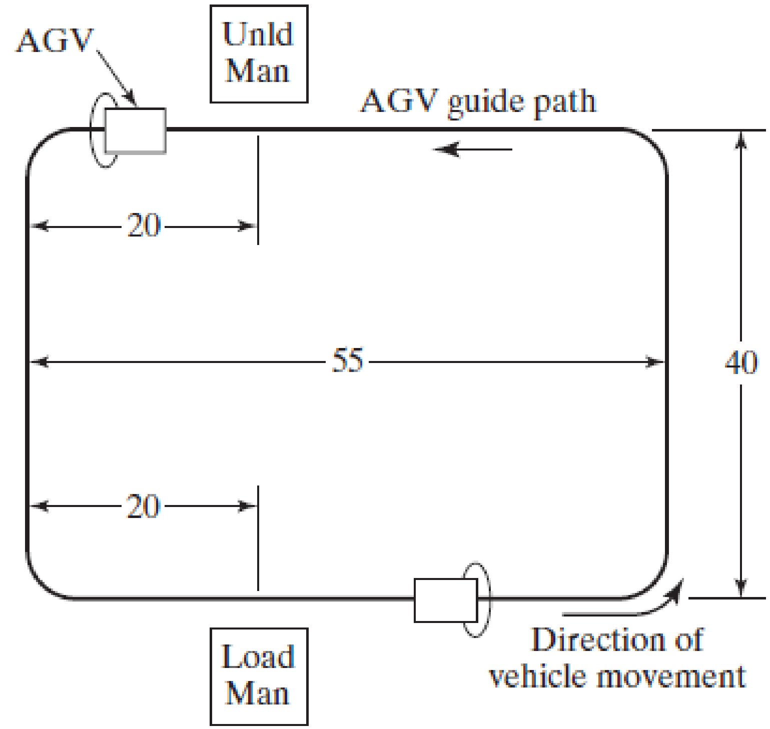
(a) travel distances loaded and empty,

(b) ideal delivery cycle time, and

(c) number of vehicles required to satisfy the delivery demand if a total of 40 deliveries per hour must be completed by the AGVS.

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems



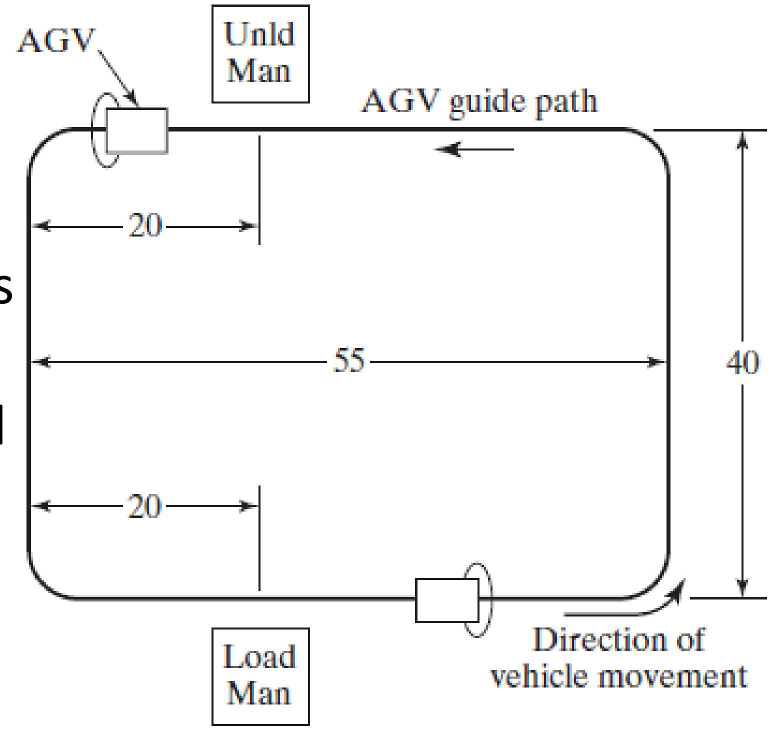
(a) Ignoring effects of slightly shorter distances around the curves at corners of the loop, the values of L_d and L_e are readily determined from the layout to be **110 m** and **80 m**, respectively.

(b) Ideal cycle time per delivery per vehicle is

$$T_c = 0.75 + \frac{110}{50} + 0.50 + \frac{80}{50} = 5.05\, min$$

Analysis of Material Transport Systems

Analysis of Vehicle-Based Systems



(c) To determine the number of vehicles required to make 40 deliveries/hr, compute the workload of the AGVS and the available time per hour per vehicle:

$$WL = 40(5.05) = 202\ min/hr$$

Therefore, the number of vehicles required is

$$n_c = \frac{202}{51.3} = 3.94 \text{ vehicles}$$

This value should be rounded up to **4 vehicles**, since the number of vehicles must be an integer.

References

Mikell P. Groover, “Automation, Production Systems and Computer-integrated Manufacturing” , 4th edition, Pearson, chapter 10