

Material Handling Equipment

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Contents

1. Overview of Material Handling.....	1
2. Major Equipment Categories	7
3. Load Formation Equipment	10
4. Positioning Equipment.....	20
5. Conveyors	25
6. Cranes	36
7. Industrial Trucks	39
8. Storage Equipment.....	55
9. MH Equipment Selection.....	65
10. References.....	67

1. Overview of Material Handling

Material handling (MH) involves “short-distance movement that usually takes place within the confines of a building such as a plant or a warehouse and between a building and a transportation agency.”¹ It can be used to create “time and place utility” through the handling, storage, and control of material, as distinct from manufacturing (i.e., fabrication and assembly operations), which creates “form utility” by changing the shape, form, and makeup of material.²

It is often said that MH only adds to the cost of a product, it does not add to the value of a product. Although MH does not provide a product with form utility, the time and place utility provided by MH can add real value to a product, i.e., the value of a product can increase after MH has taken place; for example:

- The value (to the customer) added by the overnight delivery of a package (e.g., Federal Express) is greater than or equal to the additional cost of the service as compared to regular mail service—otherwise regular mail would have been used.
- The value added by having parts stored next to a bottleneck machine is the savings associated with the increase in machine utilization minus the cost of storing the parts at the machine.

Design of MH Systems

A common approach to the design of MH systems (MHSs) is to consider MH as a cost to be minimized. This approach may be the most appropriate in many situations because, while MH can add real value to a product, it is usually difficult to identify and quantify the benefits associated with MH; it is much easier to identify and quantify the costs of MH (e.g., the cost of MH equipment, the cost of indirect MH labor, etc.). Once the design of a production process (exclusive of MH considerations) is completed, alternate MHS designs are generated, each of which satisfies the MH requirements of the production process. The least cost MHS design is then selected.

The appropriateness of the use of MHS cost as the sole criterion to select a MHS design depends on the degree to which the other aspects of the production process are able to be changed. If a completely new facility and production process is being designed, then the total cost of production is the most appropriate criterion to use in selecting a MHS—the lowest cost MHS may not result in the lowest total cost of production. If it is too costly to even consider changing the basic layout of a facility and the production process, then MHS cost is the only criterion that need be considered. In practice, it is difficult to consider all of the components of total production cost simultaneously, even if a new facility and production process is being designed. Aspects of the design that have the largest impact on total cost are at some point fixed and become constraints with respect to the remaining aspects of the design.

Principles of Material Handling

Although there are no definite “rules” that can be followed when designing an effective MHS, the following “Ten Principles of Material Handling,”³ as compiled by the College-Industry Council on Material Handling Education (CIC-MHE) in cooperation with the Material Handling Institute (MHI), represent the distillation of many years of accumulated experience and knowledge of many practitioners and students of material handling:

1. **Planning Principle.** All MH should be the result of a deliberate plan where the needs, performance objectives, and functional specification of the proposed methods are completely defined at the outset.
2. **Standardization Principle.** MH methods, equipment, controls and software should be standardized within the limits of achieving overall performance objectives and without sacrificing needed flexibility, modularity, and throughput.
3. **Work Principle.** MH work (defined as material flow multiplied by the distance moved) should be minimized without sacrificing productivity or the level of service required of the operation.
4. **Ergonomic Principle.** Human capabilities and limitations must be recognized and respected in the design of MH tasks and equipment to ensure safe and effective operations.
5. **Unit Load Principle.** Unit loads shall be appropriately sized and configured in a way that achieves the material flow and inventory objectives at each stage in the supply chain.

6. **Space Utilization Principle.** Effective and efficient use must be made of all available (cubic) space.
7. **System Principle.** Material movement and storage activities should be fully integrated to form a coordinated, operational system which spans receiving, inspection, storage, production, assembly, packaging, unitizing, order selection, shipping, and transportation, and the handling of returns.
8. **Automation Principle.** MH operations should be mechanized and/or automated where feasible to improve operational efficiency, increase responsiveness, improve consistency and predictability, decrease operating costs, and to eliminate repetitive or potentially unsafe manual labor.
9. **Environmental Principle.** Environmental impact and energy consumption should be considered as criteria when designing or selecting alternative equipment and MHS.
10. **Life Cycle Cost Principle.** A thorough economic analysis should account for the entire life cycle of all MHE and resulting systems.

Characteristics of Materials

The characteristics of materials affecting handling include the following: *size* (width, depth, height); *weight* (weight per item, or per unit volume); *shape* (round, square, long, rectangular, irregular); and *other* (slippery, fragile, sticky, explosive, frozen).

Table 1. Material Categories

Material Category	Physical State		
	Solid	Liquid	Gas
Individual units	Part, subassembly	—	—
Containerized items	Carton, bag, tote, box, pallet, bin	Barrel	Cylinder
Bulk materials	Sand, cement, coal, granular products	Liquid chemicals, solvents, gasoline	Oxygen, nitrogen, carbon dioxide

The impact of the material category listed in Table 1 on the type of MH equipment is as follows:

- Individual units and containerized items ⇒ discrete material flow ⇒ unit loads ⇒ unit handling equipment
- Bulk materials ⇒ continuous material flow ⇒ bulk handling equipment

Figure 1 shows an example of alternate ways of handling a dry bulk material: as containerized (bagged) items on pallets handled using unit handling equipment (boxcar, pallet, fork truck), or as bulk material handled using bulk handling equipment (hopper car, pneumatic conveyor, bulk storage bin).

The Unit Load Concept

A *unit load* is either a single unit of an item, or multiple units so arranged or restricted that they can be handled as a single unit and maintain their integrity.

Advantages of unit loads:

1. More items can be handled at the same time, thereby reducing the number of trips required and, potentially, reducing handling costs, loading and unloading times, and product damage.
2. Enables the use of standardized material handling equipment.

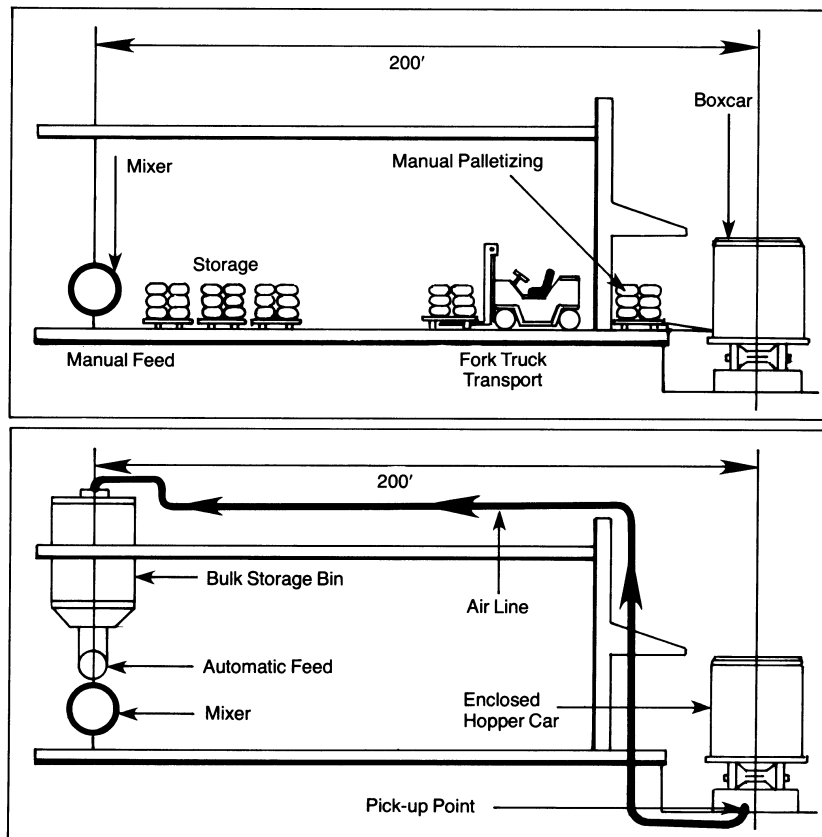


Figure 1. Unit vs. bulk handling of material.⁴

Disadvantages of unit loads:

1. Time spent forming and breaking down the unit load.
2. Cost of containers/pallets and other load restraining materials used in the unit load
3. Empty containers/pallets may need to be returned to their point of origin.

Basic ways of restraining a unit load:

- *Self-restraining*—one or more units that can maintain their integrity when handled as a single item (e.g., a single part or interlocking parts)

- *Platforms*—pallets (paper, wood, plastic, metal), skids (metal, plastic)
- *Sheets*—slipsheets (plastic, cardboard, plywood)
- *Reusable containers*—tote pans, pallet boxes, skid boxes, bins, baskets, bulk containers (e.g., barrels), intermodal containers
- *Disposable containers*—cartons, bags, crates
- *Racks*—racks
- *Load stabilization*—strapping, shrink-wrapping, stretch-wrapping, glue, tape, wire, rubber bands

Basic ways of moving a unit load:

- Use of a lifting device under the mass of the load (e.g., a pallet and fork truck)
- Inserting a lifting element into the body of the load (e.g., a coil of steel)
- Squeezing the load between two lifting surfaces (e.g., lifting a light carton between your hands, or the use of carton clamps on a lift truck)
- Suspending the load (e.g., hoist and crane)

Unit Load Design

Unit loads can be used both for in-process handling and for distribution (receiving, storing, and shipping).

Unit load design involves determining the:

1. Type, size, weight, and configuration of the load
2. Equipment and method used to handle the load
3. Methods of forming (or building) and breaking down the load.

Selecting unit load size for in-process handling:

- Unit loads should not be larger than the production batch size of parts in process—if the unit load size is larger, then a delay would occur if the load is forced to wait until the next batch of the part is scheduled to start production (which might be days or weeks) before it can be transported.
- Large production batches (used to increase the utilization of bottleneck operations) can be split into smaller *transfer batches* for handling purposes, where each transfer batch contains one or more unit loads, and small unit loads can be combined into a larger transfer batch to allow more efficient transport (e.g., several cartons at a time can be transported on a hand truck, although each carton is itself a unit load and could be transported separately); thus:

$$\text{Single part} \leq \text{Unit load size} \leq \text{Transfer batch size} \leq \text{Production batch size}$$

- When parts are transferred between adjacent operations, the unit load may be a single part.

- When operations are not adjacent, short distance moves \Rightarrow smaller unit load sizes, and long distance moves \Rightarrow larger unit load sizes.
- The practical size of a unit load (cf. the Unit Load Principle) may be limited by the equipment and aisle space available and the need for safe material handling (in accord with the Safety Principle).

Selecting unit load size for distribution (see Figure 2):

- Containers/pallets are usually available only in standard sizes and configurations.
- Truck trailers, rail boxcars, and airplane cargo bays are limited in width, length, and height.
- The existing warehouse layout and storage rack configuration may limit the number of feasible container/pallet sizes for a load.
- Customer package/carton sizes and retail store shelf restrictions can limit the number of feasible container/pallet sizes for a load.

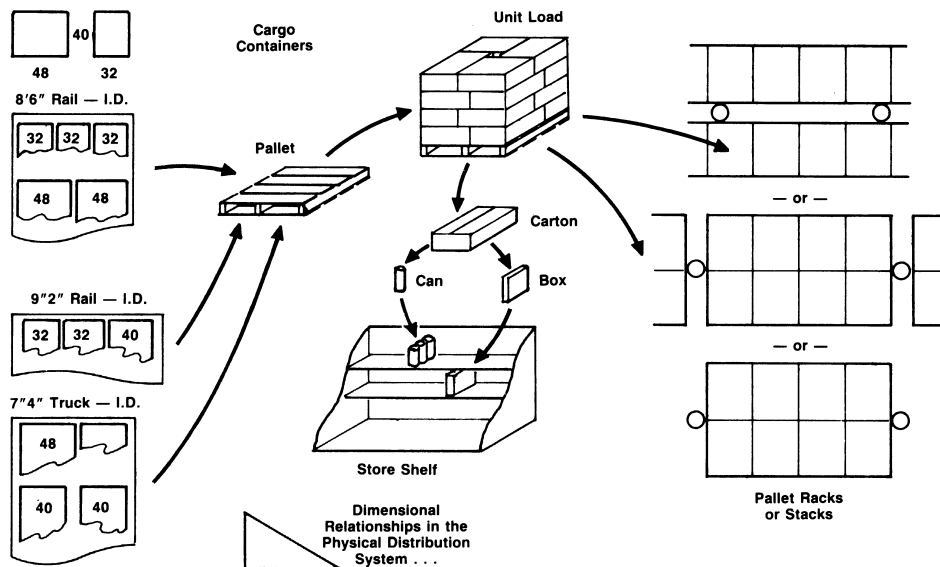


Figure 2. Unit load size for distribution.⁵

2. Major Equipment Categories

Old adage (that applies to a lack of MH equipment knowledge): “If the only tool you have is a hammer, it’s amazing how quickly all your problems seem to look like nails.”

The different types of MH equipment listed in Table 2 can be classified into the following five major categories [Chu]:⁶

- I. *Transport Equipment*. Equipment used to move material from one location to another (e.g., between workplaces, between a loading dock and a storage area, etc.). The major subcategories of transport equipment are conveyors, cranes, and industrial trucks. Material can also be transported manually using no equipment.
- II. *Positioning Equipment*. Equipment used to handle material at a single location (e.g., to feed and/or manipulate materials so that are in the correct position for subsequent handling, machining, transport, or storage). Unlike transport equipment, positioning equipment is usually used for handling at a single workplace. Material can also be positioned manually using no equipment.
- III. *Unit Load Formation Equipment*. Equipment used to restrict materials so that they maintain their integrity when handled a single load during transport and for storage. If materials are self-restraining (e.g., a single part or interlocking parts), then they can be formed into a unit load with no equipment.
- IV. *Storage Equipment*. Equipment used for holding or buffering materials over a period of time. Some storage equipment may include the transport of materials (e.g., the S/R machines of an AS/RS, or storage carousels). If materials are block stacked directly on the floor, then no storage equipment is required.
- V. *Identification and Control Equipment*. Equipment used to collect and communicate the information that is used to coordinate the flow of materials within a facility and between a facility and its suppliers and customers. The identification of materials and associated control can be performed manually with no specialized equipment.

Table 2. Material Handling Equipment

I. Transport Equipment			
A. Conveyors	B. Cranes	C. Industrial Trucks	D. No Equipment
1. Chute conveyor	1. Jib crane	1. Hand truck	1. Manual
2. Wheel conveyor	2. Bridge crane	2. Pallet jack	
3. Roller conveyor	3. Gantry crane	3. Walkie stacker	
4. Chain conveyor	4. Stacker crane	4. Pallet truck	
5. Slat conveyor		5. Platform truck	
6. Flat belt conveyor		6. Counterbalanced lift truck	
7. Magnetic belt conveyor		7. Narrow-aisle straddle truck	
8. Troughed belt conveyor		8. Narrow-aisle reach truck	
9. Bucket conveyor		9. Turret truck	
10. Vibrating conveyor		10. Order picker	
11. Screw conveyor		11. Sideloader	
12. Pneumatic conveyor		12. Tractor-trailer	
13. Vertical conveyor		13. Personnel and burden carrier	
14. Cart-on-track conveyor		14. Automatic guided vehicle	
15. Tow conveyor			
16. Trolley conveyor			
17. Power-and-free conveyor			
18. Monorail			
19. Sortation conveyor			
II. Positioning Equipment	III. Unit Load Formation Equipment	IV. Storage Equipment	V. Identification and Control Equipment
1. Manual (no equipment)	1. Self-restraining (no equipment)	1. Block stacking (no equipment)	1. Manual (no equipment)
2. Lift/tilt/turn table	2. Pallets	2. Selective pallet rack	2. Bar codes
3. Dock leveler	3. Skids	3. Drive-in rack	3. Radio frequency identification tags
4. Ball transfer table	4. Slipsheets	4. Drive-through rack	4. Voice recognition
5. Rotary index table	5. Tote pans	5. Push-back rack	5. Magnetic stripes
6. Parts feeder	6. Pallet/skid boxes	6. Flow-through rack	6. Machine vision
7. Air film device	7. Bins/baskets/racks	7. Sliding rack	7. Portable data terminals
8. Hoist	8. Cartons	8. Cantilever rack	
9. Balancer	9. Bags	9. Stacking frame	
10. Manipulator	10. Bulk load containers	10. Bin shelving	
11. Industrial robot	11. Crates	11. Storage drawers	
	12. Intermodal containers	12. Storage carousel	
	13. Strapping/tape/glue	13. Vertical lift module	
	14. Shrink-wrap/stretch-wrap	14. A-frame	
	15. Palletizers	15. Automatic storage/retrieval system	

Transport equipment (see Table 2) is used to move material from one location to another, while positioning equipment is used to manipulate material at a single location. The major subcategories of transport equipment are conveyors, cranes, and industrial trucks. Material can also be transported manually using no equipment.

The following general equipment characteristics can be used to describe the functional differences between conveyors, cranes, and industrial trucks (see Table 3):

Path: Fixed—move between two specific points
 Variable—move between a large variety of points

Area: Restricted—move restricted to a limited area
 Unrestricted—unlimited area of movement

Move frequency: Low—low number of moves per period, or intermittent moves
 High—high number of moves per period

Adjacent move: Yes—move is between adjacent activities
 No—move is between activities that are not adjacent

Table 3. Transport Equipment Characteristics

Path	Fixed			Variable		
Area	Restricted			Restricted		Unrestricted
Frequency	High	Low		High	Low	—
Adjacent	—	Yes	No	—	—	—
Equipment Category	<i>Conveyor</i>	<i>Conveyor</i>	<i>Industrial Truck/Crane</i>	<i>Industrial Truck</i>	<i>Crane</i>	<i>Industrial Truck</i>

3. Load Formation Equipment

Unit load formation equipment is used to restrict materials so that they maintain their integrity when handled a single load during transport and for storage. If materials are self-restraining (e.g., a single part or interlocking parts), then they can be formed into a unit load with no equipment.

Table 4. Unit Load Formation Equipment

1. Self-restraining (no equipment)	10. Bulk load containers
2. Pallets	11. Crates
3. Skids	12. Intermodal containers
4. Slipsheets	13. Strapping/tape/glue
5. Tote pans	14. Shrink-wrap/stretch-wrap
6. Pallet boxes/skid boxes	15. Palletizers
7. Bins/baskets/racks	(a) Manual palletizing
8. Cartons	(b) Robotic pick and place palletizers
9. Bags	(c) Conventional stripper plate palletizers

1. Self-restraining (no equipment)

One or more items that can maintain their integrity when handled as a single item (e.g., a single part or interlocking parts)

2. Pallets

Platform with enough clearance beneath its top surface (or face) to enable the insertion of forks for subsequent lifting purposes

Materials: Wood (most common), paper, plastic, rubber, and metal

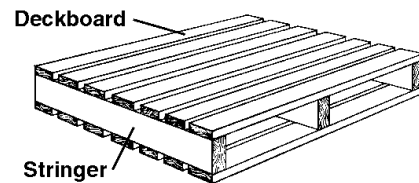
Size of pallet is specified by its depth (i.e., length of its stringers or stringer boards) and its width (i.e., length its deckboards)—pallet height (typically 5 in.) is usually not specified

Orientation of stringers relative to deckboards of pallet is specified by always listing its depth first and width last: *Depth* (stringer length) × *Width* (deckboard length)

48 × 40 in. pallet is most popular in the US (27% of all pallets—no other size over 5%) because its compatibility with railcar and truck trailer dimensions; e.g., the GMA (Grocery Manufacturers of America) pallet is four-way and made of hardwood

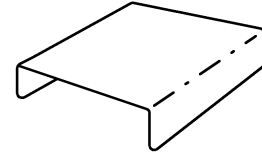
1200 × 800 mm “Euro-Pallet” is the standard pallet in Europe

Single-face pallets are sometimes referred to as “skids”



3. Skids

Platform (typically metal) with enough clearance beneath its top surface to enable a platform truck to move underneath for subsequent lifting purposes

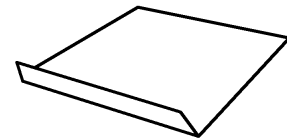


Forks can also be used to handle skids since the clearance of a skid is greater than that of a pallet
 Compared to a pallet, a skid is usually used for heavier loads and when stacking is not required

A metal skid can lift heavier loads than an equal-weight metal pallet because it enables a platform truck to be used for the lifting, with the platform providing a greater lifting surface to support the skid as compared to the forks used to support the pallet

4. Slipsheets

Thick piece of paper, corrugated fiber, or plastic upon which a load is placed



Handling method: tabs on the sheet are grabbed by a special push/pull lift truck attachment

Advantages: usually used in place of a pallet for long-distance shipping because their cost is 10–30% of pallet costs and their weight and volume is 1–5% of a pallet

Disadvantages: slower handling as compared to pallets; greater load damage within the facility; special lift truck attachment reduces the vehicle’s load capacity

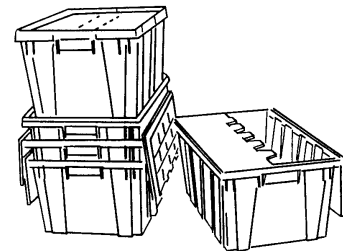
5. Tote pans

Reusable container used to unitize and protect loose discrete items

Typically used for in-process handling

Returnable totes provide alternative to cartons for distribution

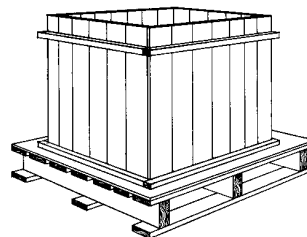
Can be nested for compact storage when not in use



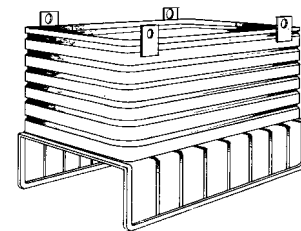
6. Pallet/skid boxes

Reusable containers used to unitize and protect loose items for fork/platform truck handling

Pallet box sometimes referred to as a “bin pallet”



Pallet box



Skid box

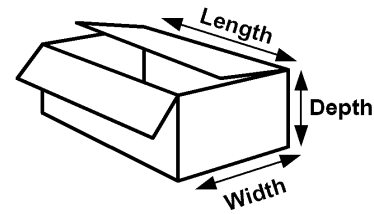
8. Cartons

Disposable container used to unitize and protect loose discrete items

Typically used for distribution

Dimensions always specified as sequence: *Length* × *Width* × *Depth*, where length is the larger, and width is the smaller, of the two dimension of the open face of the carton, and depth is the distance perpendicular to the length and width

Large quantities of finished carton blanks or knocked-down cartons can be stored on pallets until needed



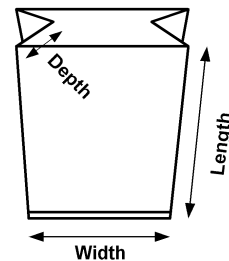
9. Bags

Disposable container used to unitize and protect bulk materials

Typically used for distribution

Polymerized plastic (“poly”) bags available from light weight (1 mil.) to heavy weight (6 mil.) in flat and gusseted styles

Dimensions of bag specified as: *Width* × *Length*, for flat bags, and *Width* × *Depth* (half gusset) × *Length*, for gusseted bags

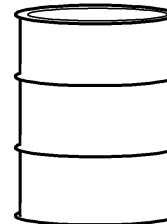


10. Bulk load containers

Reusable container used to unitize and protect bulk materials

Includes barrels, cylinders, etc.

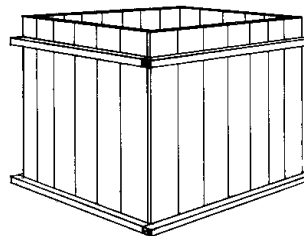
Used for both distribution and in-process handling



11. Crates

Disposable container used to protect discrete items

Typically used for distribution



12. Intermodal containers

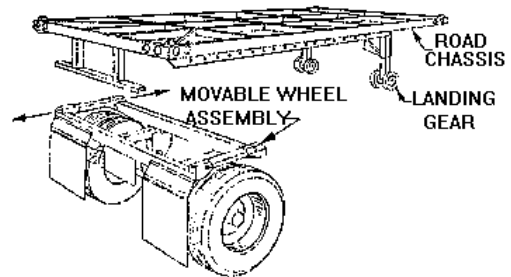
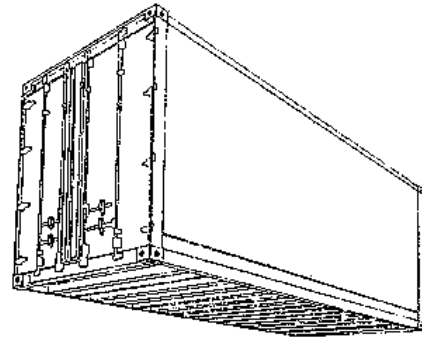
Reusable container used to unitize and protect loose discrete items

Enables a load to be handled as a single unit when it is transferred between road, rail, and sea modes of transport; e.g., the container can be unloaded from a cargo ship and loaded onto a truck as a single unit

It is not as common to use intermodal containers for airfreight transport because of aircraft shape and weight restrictions

Standard outside dimensions of intermodal containers are: 20 or 40 ft. in length; 8 ft. in width; and 8, 8.5, or 9.5 ft. in height; less 8 in. of length, 5 in. of width, and 9.5 in. of height to determine the inside dimensions

Typical sea transport costs per 40-ft. container are: \$3000–4000 from Japan to the US west coast, \$4000–5000 from Singapore to the US west coast, and \$2500–3500 from Europe to the US east coast; transport costs for a 20-ft. container is 70% of the costs of a 40-ft. container⁷

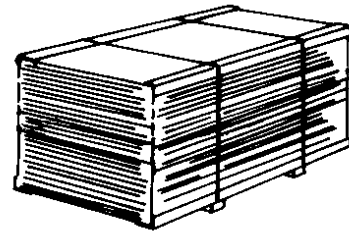


13. Strapping/tape/glue

Used for load stabilization

Straps are either steel or plastic

Plastic strapping that shrinks is used to keep loads from becoming loose during shipment



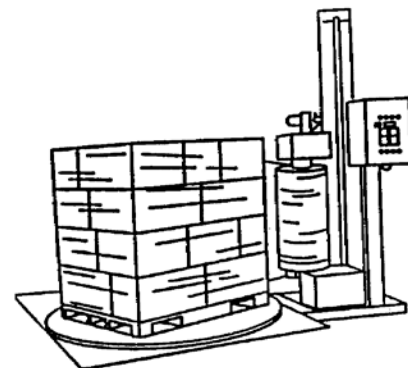
14. Shrink-wrap/stretch-wrap

Used for load stabilization

Allows irregular loads to be stabilized

In shrink-wrapping, a film or bag is placed over the load and then heat is applied to shrink the film or bag; manual or automatic; most shrink-wrap applications are being replaced by stretch-wrapping

In stretch-wrapping, a film is wound around the load while the film is stretched; as compared to shrink-wrapping, stretch-wrapping has lower material, labor, and energy costs



Stretch-wrap machine

15. Palletizers

Used for load formation

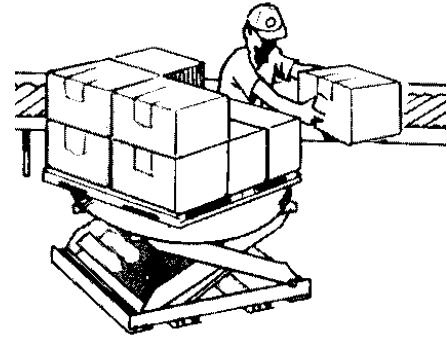
Three general methods of building (or “palletizing”) unit loads

15(a) Manual palletizing

Operators arrange items into the desired pattern used to form the unit load

Since the ergonomics of loading and unloading are important (e.g., vertically, the prime working zone is between the knees and the chest; horizontally, reaches of more than 24 in. with a load should be avoided), lift and turn tables are often used

Semi-mechanized palletizers use operators to arrange items into the desired pattern for each layer of the unit load and a powered device is used to transfer layers onto a pallet and then lower the load for the next layer

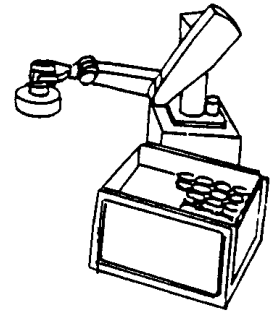


15(b) Robotic pick and place palletizers

Fully automated device to build unit loads

Used when flexibility is required (e.g., the “Distributor’s Pallet Loading Problem”)

Greatest limitation is capacity, typically 6 cycles per minute; capacity is determined by the number of items handled with each pick operation



15(c) Conventional stripper plate palletizers

Fully automated device to build unit loads

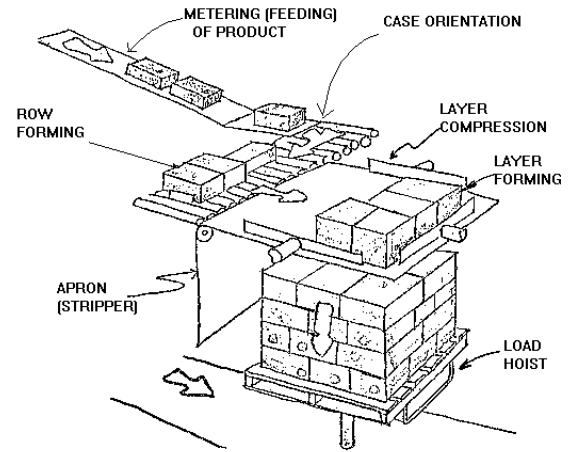
Used when high throughput of identical loads is required (e.g., the “Manufacturer’s Pallet Loading Problem”)

Capacity is typically greater (30–180 items per minute) than pick and place because an entire layer is placed on the load at one time; not as flexible as pick and place

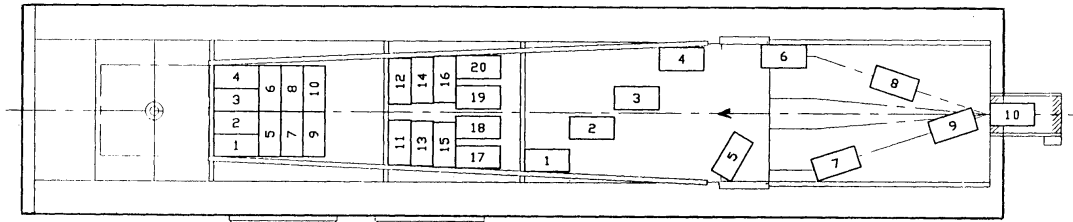
Preformed layer of items (cases) are indexed onto the stripper plate (or apron); when properly positioned over the pallet, the apron is pulled out from underneath the layer to deposit the layer onto the pallet

“Right angle” pattern formation—very flexible patterns are possible; can handle a wide variety of case sizes and types; limited capacity (up to 80 items per minute); compact design

“In-line” pattern formation—flexible patterns are not possible; ideal for high speed operation (up to 180 items per minute); takes up more room (larger machine) than right angle



Right-angle pattern formation



In-line pattern formation

Pallets

Pallet vs. Skid

As compared to a pallet, a skid is usually used for heavier loads and when stacking is not required. A metal skid can lift heavier loads than an equal-weight metal pallet because it enables a platform truck to be used for the lifting, with the platform providing a greater lifting surface to support the skid as compared to the forks used to support the pallet.

Pallet Characteristics

Material and cost:

- Paper—\$3–10; expendable, low cost, and lighter and smaller than wooden pallets (5.5 lb and 2 in high); usually used in shipping; furniture retailer Ikea switched from wooden to paper pallets to save \$193 million per year⁸.
- Wood—\$5–25; most common type of pallet; economical, reusable pallet; low initial cost; repair cost typically two-thirds the cost of a new pallet; estimated life of 5 trips.

- Plastic—\$45–90⁹; becoming more common (as lumber and repair costs of wood pallets increase); product protection, provide uniform “tare weight” (i.e., gross weight of the load less the weight of the product); can be steam cleaned for sanitary applications; durable; estimated life of 2–3 years.
- Rubber—used in spark-free environments.
- Metal—used for heavy loads.

Elements of wooden pallets:

- Deckboards—boards that make up the top and bottom surfaces (or faces) of the pallet.
- Stringers—boards (typically three per pallet), to which the deckboards are fastened, used to provide clearance for fork insertion; can be notched to allow four-way entry.
- Block legs—wooden blocks fastened to a stringer board, used in place of notched stringers.

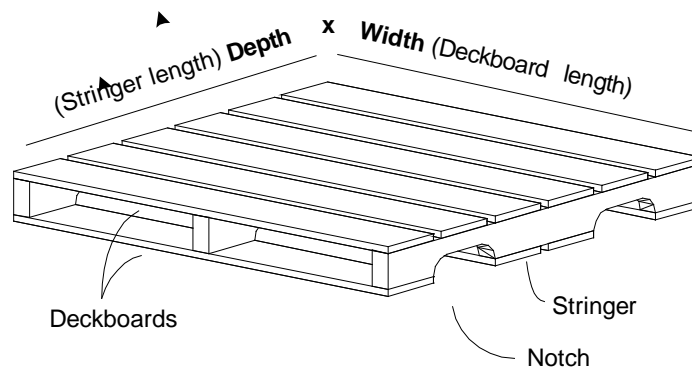


Figure 3. Elements of a wooden pallet.

Dimensions:

- The size of a pallet is specified by its depth (i.e., the length of its stringers or stringer boards) and its width (i.e., the length its deckboards)—pallet height (typically 5 in.) is usually not specified; the orientation of the stringers relative to the deckboards of the pallet is specified by always listing its depth first and width last:

$$\text{Depth (stringer length)} \times \text{Width (deckboard length)}$$

- Most popular standard ANSI pallet sizes:

32 × 40 in.	36 × 48 in.	40 × 48 in.
42 × 42 in.	48 × 40 in.	48 × 48 in.

- Other standard ANSI pallet sizes:

24 × 32 in.	32 × 48 in.	36 × 36 in.
36 × 42 in.	48 × 60 in.	48 × 72 in.

- 48 × 40 in. pallet is the most popular (27% of all pallets—no other size over 5%) because it can be placed two abreast across the 48 in. dimension in railroad freight cars and two

abreast across the 40 in. dimension in most trucks. (Note: the 48 × 40 in. pallet is not the same as a 40 × 48 in. pallet.)

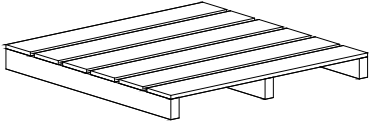
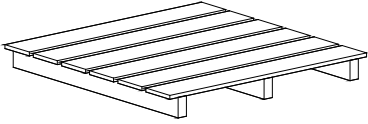
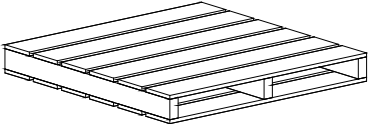
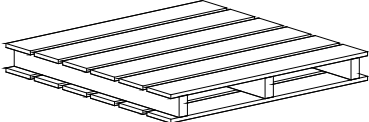
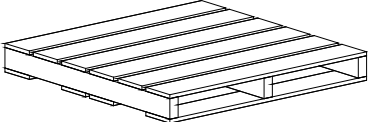
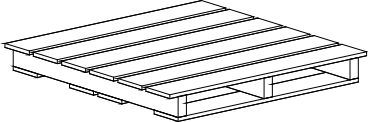
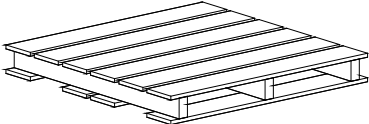
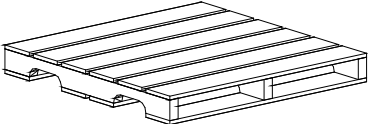
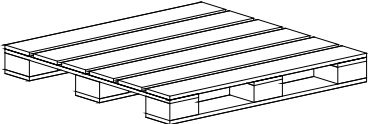
- Maximum depth of standard pallets is 48 in., which is why the rated load capacity of counterbalanced lift trucks is specified with respect to a 24 in. load center.

Design features (default value underlined):

1. Two-way vs. four-way entry—four-way entry enables the forks of a lift truck to be inserted into, and strapping to be run through, any of the four sides of the pallet, increasing the pallet’s flexibility and cost; four-way pallets are of either a notched or block-leg design.

Notched vs. block-leg designs—the notched-stringer design is less costly than the block-leg design, but it allows only two-way entry for pallet jacks and pallet trucks because their forks cannot be inserted into the notches; the block-leg design allows four-way entry for all fork trucks and, if nonreversible, requires less space for empty pallet storage as compared to a double-faced nonreversible notched-stringer design since the pallets can be nested inside of each other.
2. Single face vs. double face—the single-face design has only a single deckboard surface similar to a skid (although it cannot be handled like a skid due to its lower stringer height and the presence of a center stringer); the single-face design is less costly to purchase and requires less space for empty pallet storage since the pallets can be nested inside of each other; the additional bottom deckboard surface of the double-face design adds strength and stability, and provides more surface area for support when loaded pallets are stacked on top of each other. Most disposable wooden pallets are single-face designs due to their low cost, while most reusable wooden pallets are double-face designs due to their durability.
3. Reversible vs. nonreversible—the reversible design allows either face of the pallet to be used for load support (which is useful if the deckboards can be easily damaged or soiled by, e.g., leaking loads), but pallet jacks and pallet trucks cannot be used because the front wheels mounted inside the end of their forks cannot extend to the floor; the nonreversible design can be handled by all fork trucks since its bottom face does not have deckboards at the positions needed for front-wheel extension.
4. Flush stringer vs. single wing vs. double wing—single- and double-wing designs have their stringers recessed so that the ends of their deckboards overhang, forming “wings”; the flush stringer design has greater long-term structural integrity than either of the wing designs, the wings typically being the first point of pallet failure; the single-wing design allows pallets to be placed side-by-side on the floor while still providing the clearance required for the outriggers of a narrow-aisle straddle truck; the double-wing design (termed a “stevedore’s pallet”) allows bar slings to be placed in the space between the wings, thus allowing a crane to be used for handling. Double-face versions of both wing designs are used for very heavy loads (e.g., bricks) because they reduce the stringer-to-stringer span of the deckboards. Unless the single- or double-wing designs are necessary, the flush stringer design is preferred.

Table 5. Types of Wooden Pallets

		
Two way Single face Nonreversible Flush stringer	Two way Single face Nonreversible Single wing	Two way Double face Reversible Flush stringer
		
Two way Double face Reversible Double wing	Two way Double face Nonreversible Flush stringer	Two way Double face Nonreversible Single wing
		
Two way Double face Nonreversible Double wing	Four-way notched Double face Nonreversible Flush stringer	Four-way block leg Double face Nonreversible Flush stringer

Pallet type:

- Each pallet type is a combination of design features. Some of the design-feature combinations correspond to pallet types are either not feasible (e.g., a single-face reversible pallet) or, if feasible, very uncommon due to their providing no benefit (e.g., a single-wing reversible pallet) or their inherent structural weakness (e.g., a four-way-block-leg single-face flush-stringer pallet, or a four-way-notched double-face reversible flush-stringer pallet).
- The most common types of wooden pallets are listed in Table 5.
- The most popular type of pallet is the two-way double-face nonreversible flush pallet.

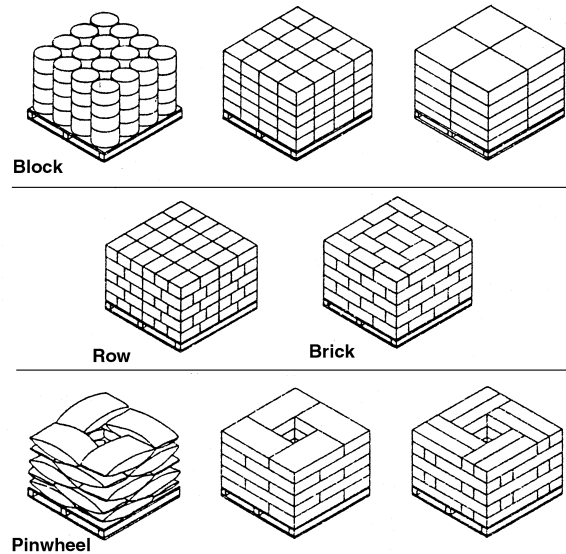


Figure 4. Basic pallet patterns.¹⁰

Special-purpose pallets:

The following terms are used to distinguish pallets used for specific purposes:¹¹

- *Take-it-or-leave-it pallet*—pallet fitted with fixed cleats on the top deckboards to permit forks to pass beneath the unit load and remove it from the pallet.
- *Slave pallet*—pallet or platform used as a support base for palletized loads in a rack or conveyor system.
- *Captive pallet*—pallet intended for use within a facility and not exchanged.
- *Exchange pallet*—pallet exchanged among a group of shippers and where ownership of the pallet is transferred with the ownership of the load.
- *Shipping pallet*—pallet used for a single one-way trip from shipping to receiving, after which it is disposed.

The Pallet Loading Problem

The pallet loading (or packing) problem refers to determining the “optimal” patterns (or layouts) of the items to be loaded onto pallets.

There are, at least, two different problems that can be identified as “the Pallet Loading Problem”:

- The *Manufacturer’s Pallet Loading Problem*—loading identical items onto a pallet so that the number of items per pallet is maximized.
- The *Distributor’s Pallet Loading Problem(s)*—(single pallet) loading various size items onto a pallet so that the volume of items loaded onto the pallet is maximized; (multiple pallets) loading various size items onto identical pallets so that the number of pallets required to load all of the items is minimized.

Unlike the Manufacturer’s Problem, the Distributor’s Problem is nonrepetitive (i.e., it requires a unique solution for each pallet loaded) \Rightarrow one should be willing to spend more time and effort to find a good solution to the Manufacturer’s Problem as compared to the Distributor’s Problem.

Manufacturer’s Problem \Rightarrow use of automatic stripper plate palletizer possible

Distributor’s Problem \Rightarrow manual or robotic (pick and place) palletization

Both problems are difficult optimization problems to solve (they are, in fact, both “NP-hard”), even with the following restrictions that are usually assumed:

1. All items and pallets are rectangular.
2. Items are placed orthogonally on a pallet (i.e., all item edges are parallel to pallet edges).

4. Positioning Equipment

Positioning equipment (see Table 2) is used to handle material at a single location. It can be used at a workplace to feed, orient, load/unload, or otherwise manipulate materials so that are in the correct position for subsequent handling, machining, transport, or storage. In many cases, positioning equipment is required for and can be justified by the ergonomic requirements of a task. As compared to manual handling, the use of positioning equipment can provide the following benefits:¹²

- raise the productivity of each worker when the frequency of handling is high,
- improve product quality and limit damage to materials and equipment when the item handled is heavy or awkward to hold and damage is likely through human error or inattention, and
- reduce fatigue and injuries when the environment is hazardous or inaccessible.

Table 6. Positioning Equipment

1. Manual (no equipment)	8. Hoist
2. Lift/tilt/turn table	9. Balancer
3. Dock leveler	10. Manipulator
4. Ball transfer table	(a) Rigid-link manipulator
5. Rotary index table	(b) Articulated jib crane manipulator
6. Parts feeder	(c) Vacuum manipulator
7. Air film device	11. Industrial robot

1. Manual (no equipment)

Under ideal circumstances, maximum recommended weight for manual lifting to avoid back injuries is 51 lbs.

Recommendation based on NIOSH (National Institute for Occupational Safety and Health) 1991

Lifting Equation, which uses six multipliers to reduce maximum recommended weight for less than ideal lifting tasks

2. Lift/tilt/turn table

Used when positioning involves the lifting, tilting, or turning of a load.

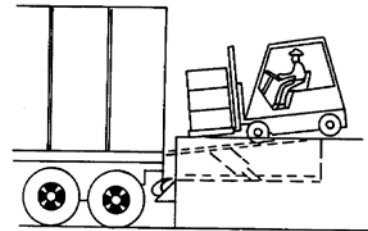
Can be used to reduce or limit a worker's lifting and/or reaching motions.

Pallet load levelers are lift and turn tables used in manual palletizing to reduce the amount of bending and stooping involved with manually loading a pallet by combining a lifting and turning mechanism with a device that lowers the table as each layer is completed so that loading always takes place at the optimal height of 30 in.



3. Dock leveler

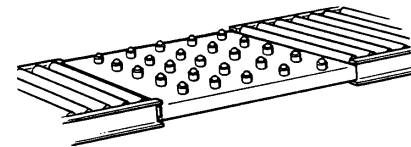
Used at loading docks to compensate for height differences between a truck bed and the dock



4. Ball transfer table

Used in conveyor systems to permit manual transfer to and from machines and conveyors and between different sections of conveyors

Since loads are pushed on the table, ball friction limits the maximum load weight to 600 lbs.

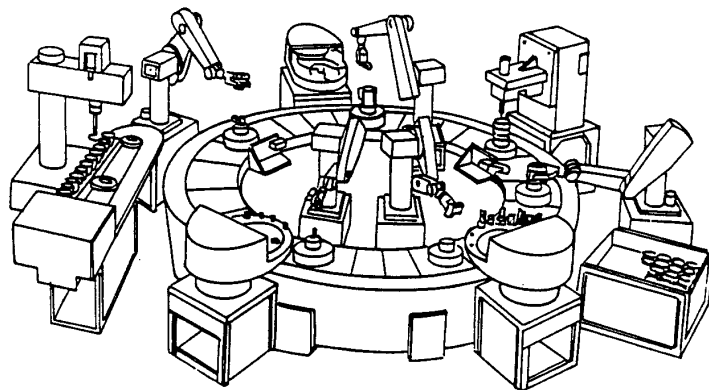


5. Rotary index table

Used for the synchronous transfer of small parts from station to station in a single workcenter

Circular table rotates in discrete intermittent steps to advance parts between stations located along its perimeter

Since each part moves between stations at the same time, it is difficult to put buffers between stations



Different from conveyors used as *in-line indexing machines*, where linear transfers can take place between multiple workcenters separated by long distances, since a rotary index table is restricted to circular transfers with a single compact workcenter

6. Parts feeder

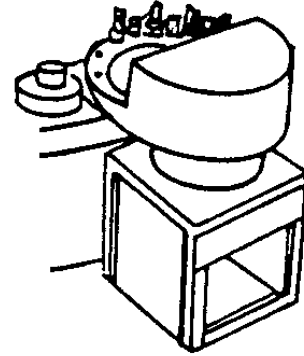
Used for feeding and orienting small identical parts, particularly in automatic assembly operations [Boothroyd]

Motion of parts in a random pile channeled so that each part automatically assumes a specified orientation, where the symmetries of a part define its possible orientations

Motion can be imparted through vibration, gravity, centrifugal force, tumbling, or air pressure

In a *vibratory bowl feeder*, the most versatile type of parts feeder, parts are dumped into a bowl and then move vibrate uphill along a track towards an outlet, where rejected parts fall off the track and are recycled

Parts feeders can be used to provide inspection capabilities with respect to the shape and weight of parts (e.g., the coin feeder of a vending machine)



7. Air film device

Used to enable precision positioning of heavy loads

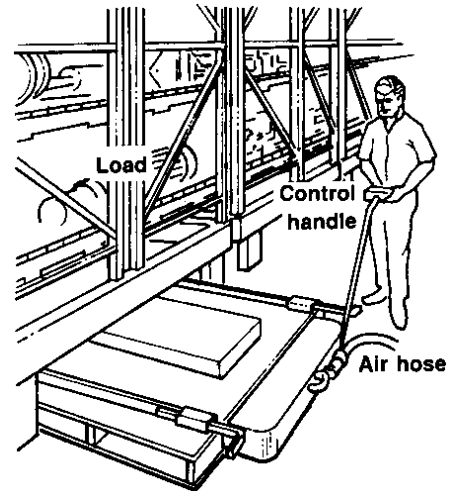
Sometimes referred to as “air pallets”

Can be used in place of cranes and hoists

Thin film of compressed (10–50 psi) air used to float loads of up to 300,000 lbs. so that a horizontal push of 1 lb. can move 1000 lb. load; floating action enables load to rotated or translated in any direction in the horizontal plane

Requires a smooth floor surface against which air streams underneath the device can push

Can be used in warehousing as the mechanism to convert stationary racks into sliding racks



8. Hoist

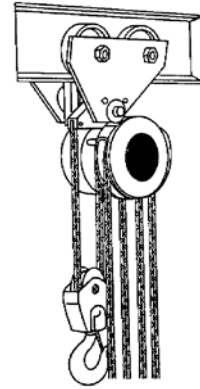
Used for vertical translation (i.e., lifting and lowering) of loads

Frequently attached to cranes and monorails to provide vertical translation capability

Can be operated manually, electrically, or pneumatically

Uses chain or wire rope as its lifting medium

Hoists are categorized into duty classes: H1—infrequent, standby duty use (1 or 2 lifts per month); H2—light duty (avg. 75 start/stops per hour); H3—medium (max. 250 start/stops per hour); H4—heavy, and H5—severe duty

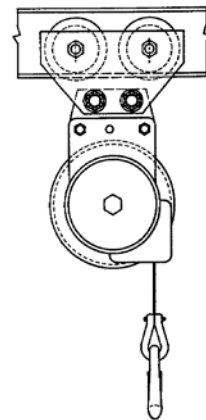


9. Balancer

Mechanism used to support and control loads so that an operator need only guide a balanced (“weightless”) load, thus providing precision positioning

Can be use to support hand tools to reduce changeover time

Can also be attached to hoists and manipulators



10. Manipulator

Used for vertical and horizontal translation and rotation of loads

Acting as “muscle multipliers,” manipulators counterbalance the weight of a load so that an operator lifts a small portion (1%) of the load’s weight

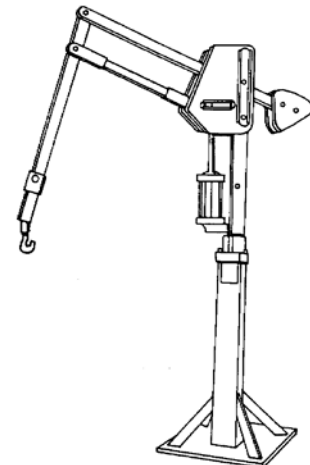
Can be powered manually, electrically, or pneumatically

Manipulator’s end-effector can be equipped with mechanical grippers, vacuum grippers, electromechanical grippers, or other tooling

Manipulators fill the gap between hoists and industrial robots: they can be used for a wider range of positioning tasks than hoists and are more flexible than industrial robots due to their use of manual control

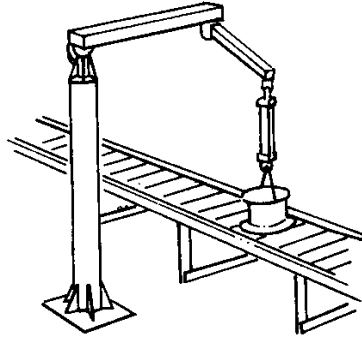
10(a) Rigid-link manipulator

Although similar in construction, a rigid-link manipulator is distinguished from an industrial robot by the use of an operator for control as opposed to automatic computer control



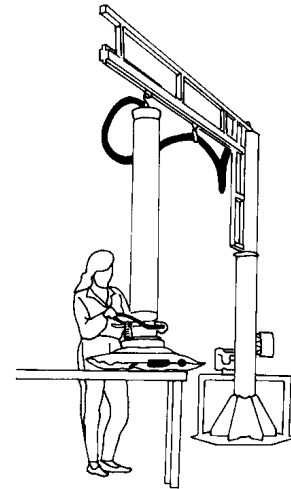
10(b) Articulated jib crane manipulator

Extends a jib crane's reaching capability in a work area through the use of additional links or "arms"



10(c) Vacuum manipulator

Provides increased flexibility because rigid links are not used (vacuum, rigid-link, and articulated jib crane manipulators can all use vacuum gripper end-effectors)



11. Industrial robot

Used in positioning to provide variable programmed motions of loads

"Intelligent" industrial robots utilize sensory information for complex control actions, as opposed to simple repetitive "pick-and-place" motions

Industrial robots also used for parts fabrication, inspection, and assembly tasks

Consists of a chain of several rigid links connected in series by revolute or prismatic joints with one end of the chain attached to a supporting base and the other end free and equipped with an end-effector

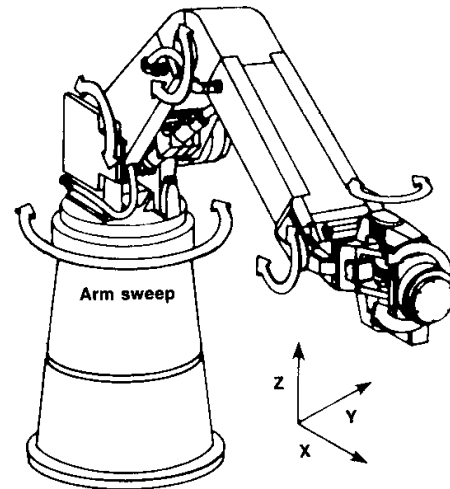
Robot's end-effector can be equipped with mechanical grippers, vacuum grippers, electromechanical grippers, welding heads, paint spray heads, or any other tooling

Although similar in construction, an industrial robot is distinguished from a manipulator by the use of programmed control logic as opposed manual control

Pick-and-place industrial robots can be used as automatic palletizers

Mobile robots similar in construction to free-ranging AGVs

Can be powered manually, electrically, or pneumatically



5. Conveyors

Conveyors are used:

- When material is to be moved frequently between specific points
- To move materials over a fixed path
- When there is a sufficient flow volume to justify the fixed conveyor investment

Conveyors can be classified in different ways:

- Type of product being handled: *unit* load or *bulk* load
- Location of the conveyor: *in-floor*, *on-floor*, or *overhead*
- Whether loads can *accumulate* on the conveyor or *no accumulation* is possible

Table 7. Conveyors

1. Chute conveyor	13. Vertical conveyor
2. Wheel conveyor	(a) Vertical lift conveyor
3. Roller conveyor	(b) Reciprocating vertical conveyor
(a) Gravity roller conveyor	14. Cart-on-track conveyor
(b) Live (powered) roller conveyor	15. Tow conveyor
4. Chain conveyor	16. Trolley conveyor
5. Slat conveyor	17. Power-and-free conveyor
6. Flat belt conveyor	18. Monorail
7. Magnetic belt conveyor	19. Sortation conveyor
8. Troughed belt conveyor	(a) Diverters
9. Bucket conveyor	(b) Pop-up devices
10. Vibrating conveyor	(c) Sliding shoe device
11. Screw conveyor	(d) Tilting device
12. Pneumatic conveyor	(e) Cross-belt transfer device
(a) Dilute-phase pneumatic conveyor	
(b) Carrier-system pneumatic conveyor	

1. Chute conveyor

Unit/Bulk + On-Floor + Accumulate

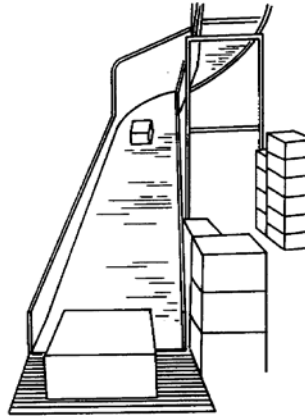
Inexpensive

Used to link two handling devices

Used to provide accumulation in shipping areas

Used to convey items between floors

Difficult to control position of the items



2. Wheel conveyor

Unit + On-Floor + Accumulate

Uses a series of skatewheels mounted on a shaft (or axle)

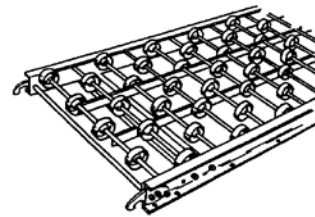
Spacing of the wheels is dependent on the load being transported

Slope for gravity movement depends on load weight

More economical than the roller conveyor

For light-duty applications

Flexible, expandable mobile versions available



3. Roller conveyor

Unit + On-Floor + Accumulate

May be powered (or live) or nonpowered (or gravity)

Materials must have a rigid riding surface

Minimum of three rollers must support smallest loads at all times

Tapered rollers on curves used to maintain load orientation

Parallel roller configuration can be used as a (roller) *pallet conveyor* (more flexible than a chain pallet conveyor because rollers can be used to accommodate are greater variation of pallet widths)

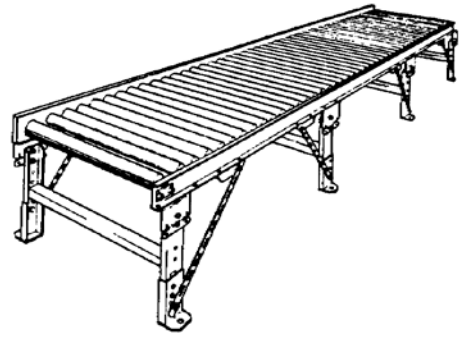
3(a) Gravity roller conveyor

Alternative to wheel conveyor

For heavy-duty applications

Slope (i.e., decline) for gravity movement depends on load weight

For accumulating loads

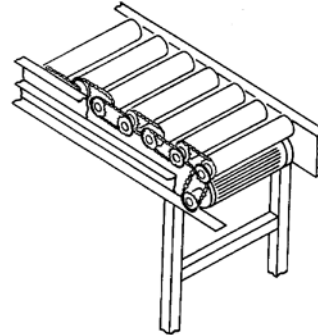
**3(b) Live (powered) roller conveyor**

Belt or chain driven

Force-sensitive transmission can be used to disengage rollers for accumulation

For accumulating loads and merging/sorting operations

Provides limited incline movement capabilities

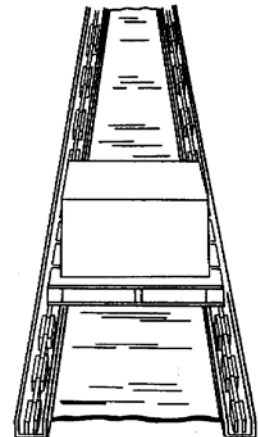
**4. Chain conveyor**

Unit + In-/On-Floor + No Accumulation

Uses one or more endless chains on which loads are carried directly

Parallel chain configuration used as (chain) *pallet conveyor* or as a pop-up device for sortation (see Sortation conveyor: Pop-up devices)

Vertical chain conveyor used for continuous high-frequency vertical transfers, where material on horizontal platforms attached to chain link (cf. vertical conveyor used for low-frequency intermittent transfers)

**5. Slat conveyor**

Unit + In-/On-Floor + No Accumulation

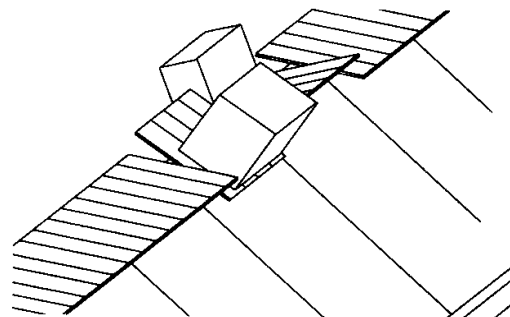
Uses discretely spaced slats connected to a chain

Unit being transported retains its position (like a belt conveyor)

Orientation and placement of the load is controlled

Used for heavy loads or loads that might damage a belt

Bottling and canning plants use flat chain or slat conveyors because of wet conditions, temperature, and cleanliness requirements



Tilt slat conveyor used for sortation

6. Flat belt conveyor

Unit + On-Floor + No Accumulation

For transporting light- and medium-weight loads between operations, departments, levels, and buildings

When an incline or decline is required

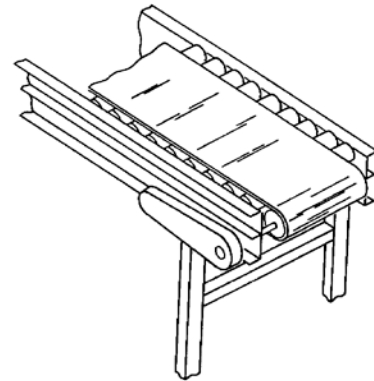
Provides considerable control over the orientation and placement of load

No smooth accumulation, merging, and sorting on the belt

The belt is roller or slider bed supported; the slider bed is used for small and irregularly shaped items

In 1957, B.F. Goodrich, Co. patented the Möbius strip for conveying hot or abrasive substances in order to have “both” sides wear equally¹³

Telescopic boom attachments are available for trailer loading and unloading, and can include ventilation to pump conditioned air into the trailer¹⁴

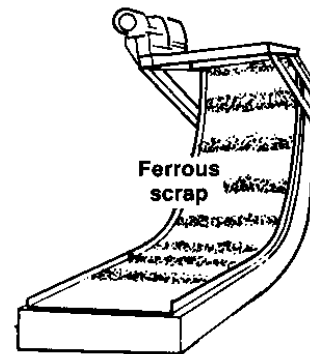


7. Magnetic belt conveyor

Bulk + On-Floor

A steel belt and either a magnetic slider bed or a magnetic pulley is used

To transport ferrous materials vertically, upside down, and around corners

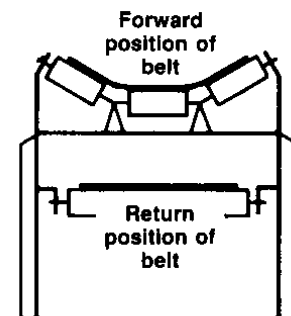


8. Troughed belt conveyor

Bulk + On-Floor

Used to transport bulk materials

When loaded, the belt conforms to the shape of the troughed rollers and idlers



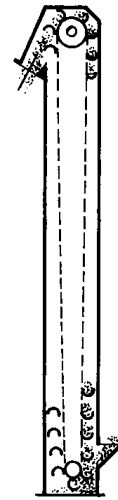
9. Bucket conveyor

Bulk + On-Floor

Used to move bulk materials in a vertical or inclined path

Buckets are attached to a cable, chain, or belt

Buckets are automatically unloaded at the end of the conveyor run



10. Vibrating conveyor

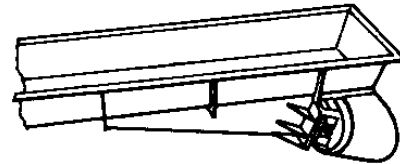
Bulk + On-Floor

Consists of a trough, bed, or tube

Vibrates at a relatively high frequency and small amplitude in order to convey individual units of products or bulk material

Can be used to convey almost all granular, free-flowing materials

An *Oscillating Conveyor* is similar in construction, but vibrates at a lower frequency and larger amplitude (not as gentle) in order to convey larger objects such as hot castings



11. Screw conveyor

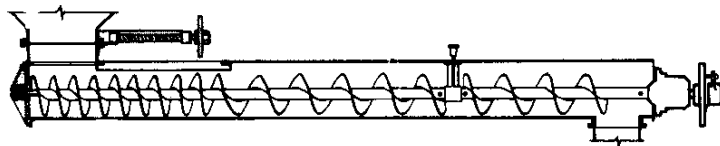
Bulk + On-Floor

Consists of a tube or U-shaped stationary trough through which a shaft-mounted helix revolves to push loose material forward in a horizontal or inclined direction

One of the most widely used conveyors in the processing industry, with many applications in agricultural and chemical processing

Straight-tube screw conveyor sometimes referred to as an “auger feed”

Water screw developed circa 250 BC by Archimedes



12. Pneumatic conveyor

Bulk/Unit + Overhead

Can be used for both bulk and unit movement of materials

Air pressure is used to convey materials through a system of vertical and horizontal tubes

Material is completely enclosed and it is easy to implement turns and vertical moves

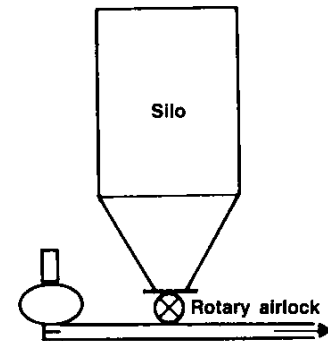
12(a) Dilute-phase pneumatic conveyor

Moves a mixture of air and solid

Push (positive pressure) systems push material from one entry point to several discharge points

Pull (negative pressure or vacuum) systems move material from several entry points to one discharge point

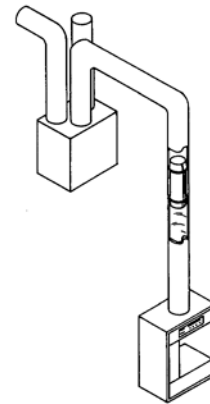
Push-pull systems are combinations with multiple entry and discharge points



12(b) Carrier-system pneumatic conveyor

Carriers are used to transport items or paperwork

Examples: transporting money to/from drive-in stalls at banks and documents between floors of a skyscraper



13. Vertical conveyor

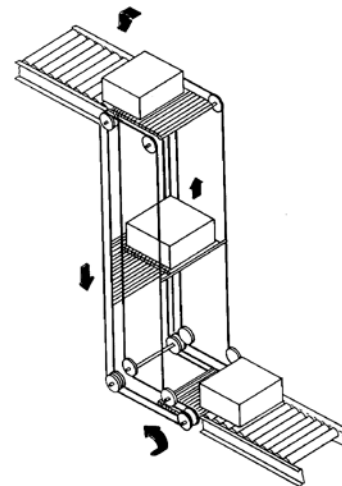
Unit + On-Floor + No Accumulation

Used for low-frequency intermittent vertical transfers a load to different floors and/or mezzanines (cf. *vertical chain conveyor* can be used for continuous high-frequency vertical transfers)

Differs from a freight elevator in that it is not designed or certified to carry people

Can be manually or automatically loaded and/or controlled and can interface with horizontal conveyors

Alternative to a chute conveyor for vertical “drops” when load is fragile and/or space is limited



13(a) Vertical lift conveyor

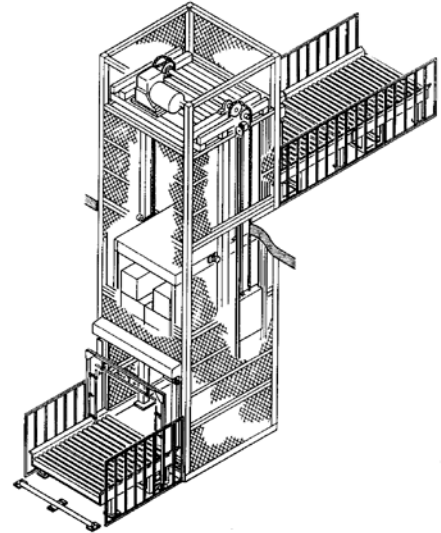
Series of flexible conveyor-carriers rotate in a loop, where empty carriers flex perpendicularly to provide access to loaded carriers moving past them in opposite direction

13(b) Reciprocating vertical conveyor

Carrier used to raise or lower load

Can be powered (hydraulic or mechanical) or non-powered

Non-powered version only be used to lower a load, where counterweight used to return empty carrier to top



14. Cart-on-track conveyor

Unit + In-Floor + Accumulate

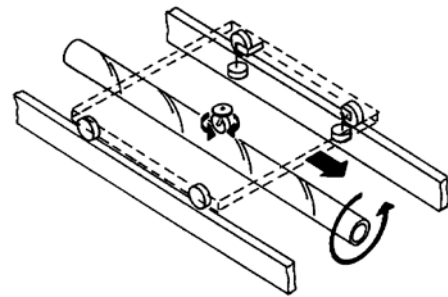
Used to transport carts along a track

Carts are transported by a rotating tube

Drive wheel connected to each cart rests on tube and is used to vary the speed of the cart (by varying angle of contact between drive wheel and the tube)

Carts are independently controlled

Accumulation can be achieved by maintaining the drive wheel parallel to the tube



15. Tow conveyor

Unit + In-Floor + Accumulate

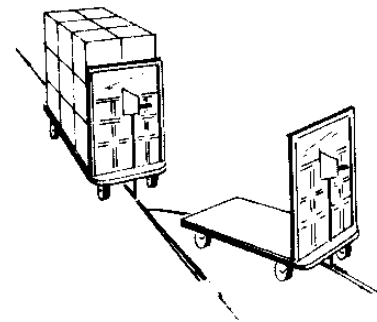
Uses towline to provide power to wheeled carriers such as trucks, dollies, or carts that move along the floor

Used for fixed-path travel of carriers (each has variable path capabilities when disengaged from towline)

Although usually in the floor, the towline can be located overhead or flush with the floor

Selector-pin or pusher-dog arrangements used to allow automatic switching (power or spur lines)

Generally used when long distance and high frequency moves are required



16. Trolley conveyor

Unit + Overhead + No Accumulation

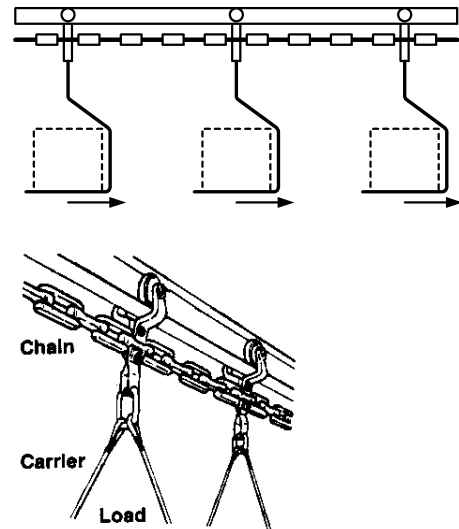
Uses a series of trolleys supported from or within an overhead track

Trolleys are equally spaced in a closed loop path and are suspended from a chain

Carriers are used to carry multiple units of product

Does not provide for accumulation

Commonly used in processing, assembly, packaging, and storage operations



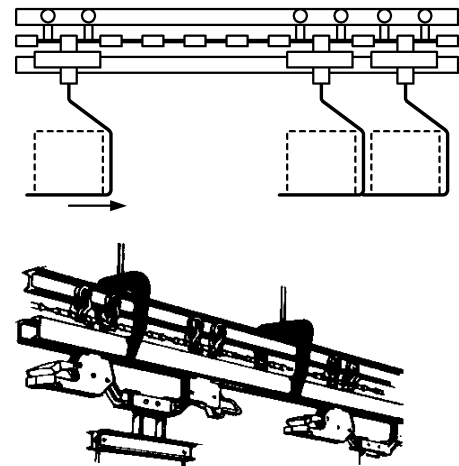
17. Power-and-free conveyor

Unit + Overhead/On-Floor + Accumulate

Similar to trolley conveyor due to use of discretely spaced carriers transported by an overhead chain; however, power-and-free conveyor uses two tracks: one powered and the other nonpowered (or free)

Carriers can be disengaged from the power chain and accumulated or switched onto spurs

Termed an *Inverted Power-and-Free Conveyor* when tracks are located on the floor



18. Monorail

Unit + Overhead + Accumulate

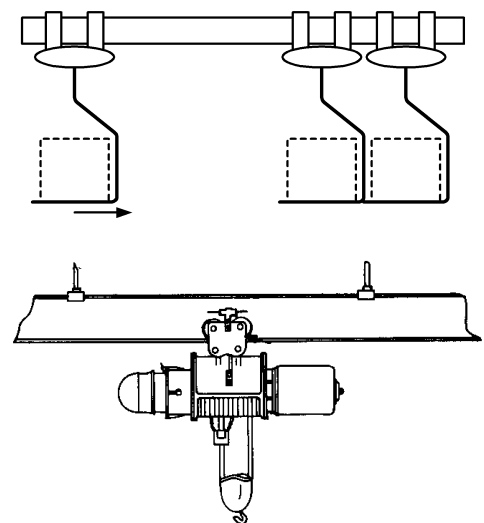
Overhead single track (i.e., mono-rail) or track network on which one or more carriers ride

Carriers: powered (electrically or pneumatically) or nonpowered

Carrier can range from a simple hook to a hoist to an intelligent-vehicle-like device

Single-carrier, single-track monorail similar to bridge or gantry crane

Multi-carrier, track network monorail similar to both a trolley conveyor, except that the carriers operate



independently and the track need not be in a closed loop, and a fixed-path automatic guided vehicle (AGV) system, except that it operates overhead

Termed an *Automated Electrified Monorail* (AEM) system when it has similar control characteristics as an AGV system

19. Sortation conveyor

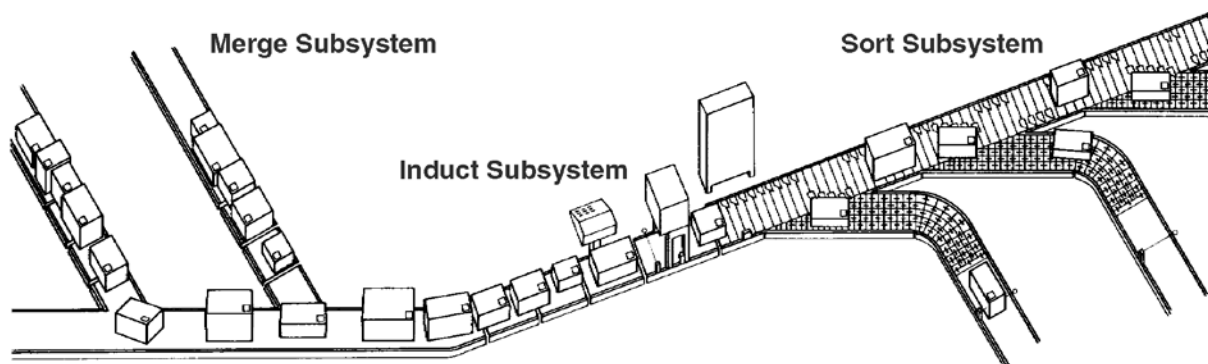
Unit + On-Floor/Overhead

Sortation conveyors are used for merging, identifying, inducting, and separating products to be conveyed to specific destinations. Sortation system throughput is expressed in cartons per minute (CPM). A sortation system is composed of three subsystems:

Merge subsystem—items transported from picking (storage) or receiving areas on conveyors and consolidated for proper presentation at the induct area.

Induct subsystem—destination of each item identified by visual inspection or automatic identification system (e.g., bar code scanner), then a proper gap between items is generated using short variable speed conveyors as they are released to the sort subsystem.

Sort subsystem—items are diverted to outbound conveyors to shipping, palletizing, staging, and/or secondary sort subsystems.



Typical sortation system

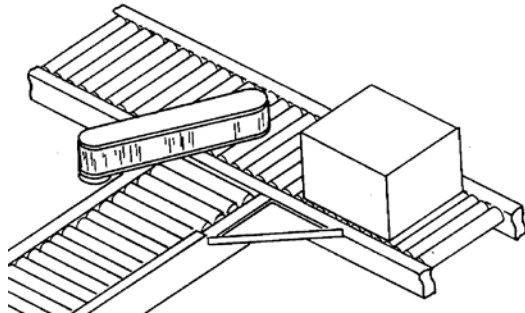
There is a trend towards more use of mixed-item loads that eliminate the need for sortation: instead of a producer sending pallet loads of a single item to a distribution center for subsequent sortation or consolidation into multi-item customer loads, single pallets can be loaded at a producer with a different mix of items for each customer. This also can enable greater use of cross docking.

19(a) Sortation conveyor: Diverters

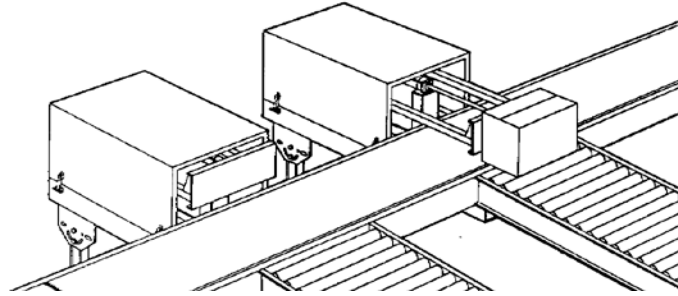
Stationary or movable arms that deflect, push, or pull a product to desired destination

Since they do not come in contact with the conveyor, they can be used with almost any flat surface conveyor

Usually hydraulically or pneumatically operated, but also can be motor driven
Simple and low cost



Deflector diverter



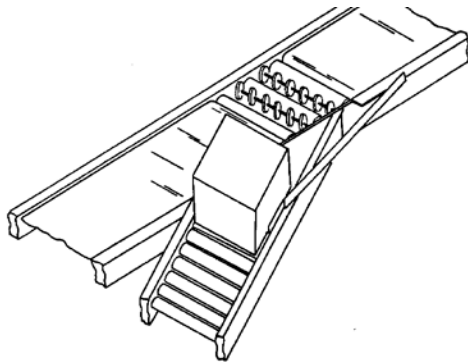
Push diverter

19(b) Sortation conveyor: Pop-up devices

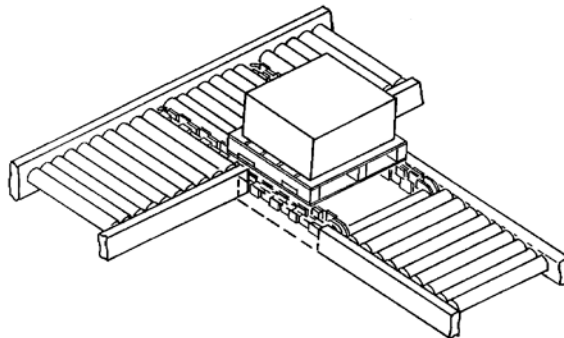
One or more rows of powered rollers or wheels or chains that pop up above surface of conveyor to lift product and guide it off conveyor at an angle; wheels are lowered when products not required to be diverted

Only capable of sorting flat-bottomed items

Pop-up rollers (not shown) are generally faster than pop-up wheels



Pop-up wheel device



Pop-up chain device

19(c) Sortation conveyor: Sliding shoe sorter

Sliding shoe sorter (a.k.a. moving slat sorter) uses series of diverter slats that slide across the horizontal surface to engage product and guide it off conveyor

Slats move from side to side as product flows in order to divert the product to either side

Gentle and gradual handling of products

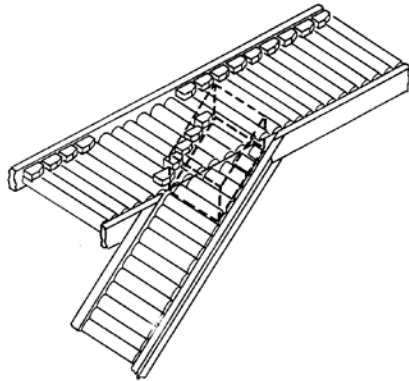
19(d) Sortation conveyor: Tilting device

Trays or slats provide combined sorting mechanism and product transporter

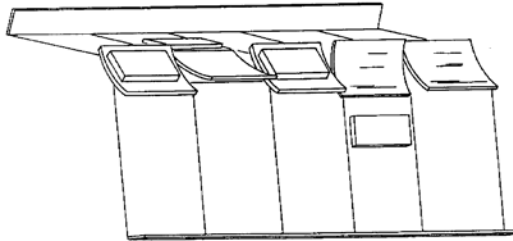
Can accommodate elevation changes

Tilt tray sorters usually designed in continuous loops with compact layout and recirculation of products not sorted first time

Tilt slat sorters carry products on flat-surface slat conveyor and can handle wider variety of products compared to tilt tray



Sliding shoe sorter



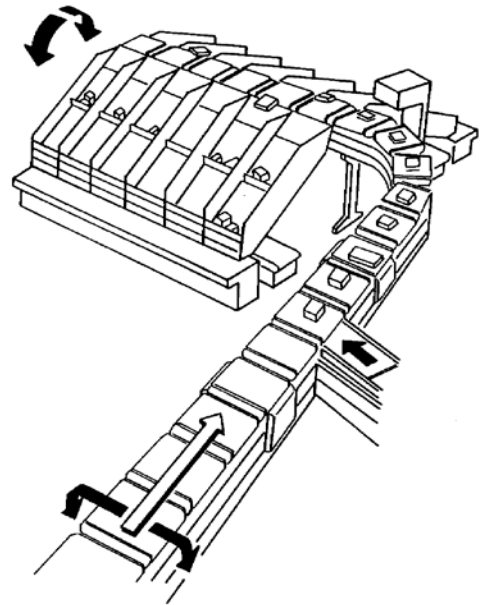
Tilt-tray device

19(e) Sortation conveyor: Cross-belt transfer device

Either continuous loop, where individual carriages are linked together to form an endless loop, or train style (asynchronous), where a small number of carriers tied together with potential for several trains running track simultaneously

Each carriage equipped with small belt conveyor, called the cell, that is mounted perpendicular to direction of travel of loop and discharges product at appropriate destination

Automatically separates single line of products into multiple in-line discharge lines



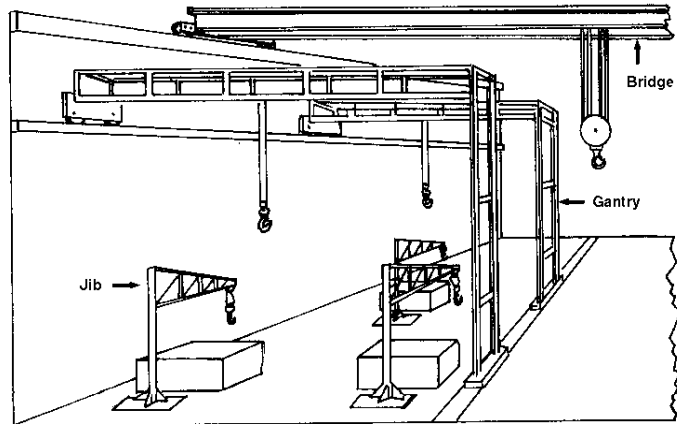
6. Cranes

General characteristics of cranes:

- Used to move loads over variable (horizontal and vertical) paths within a restricted area
- Used when there is insufficient (or intermittent) flow volume such that the use of a conveyor cannot be justified
- Provide more flexibility in movement than conveyors
- Provide less flexibility in movement than industrial trucks
- Loads handled are more varied with respect to their shape and weight than those handled by a conveyor
- Most cranes utilize hoists for vertical movement, although manipulators can be used if precise positioning of the load is required

Table 8. Cranes

1. Jib crane
2. Bridge crane
3. Gantry crane
4. Stacker crane



1. Jib crane

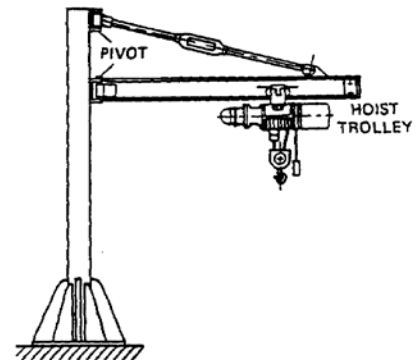
Horizontal boom (jib) supported from a stationary vertical support

Hoist can move along the jib and can be used for lifting

Operates like an arm in a work area, where it can function as a manipulator for positioning tasks

Jib can also be mounted on the wall

Arm can rotate up to 360°



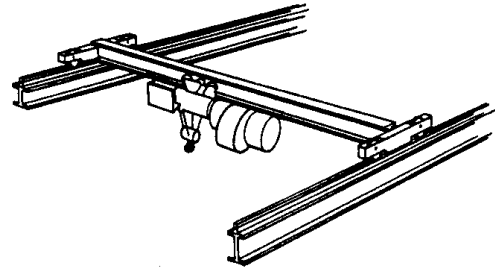
2. Bridge crane

Bridge mounted on tracks that are located on opposite walls of the facility

Enables three-dimensional handling

Top riding (heavier loads) or underhung (more versatile) versions of the crane

Underhung crane can transfer loads and interface with other MHS (e.g., monorail systems)



3. Gantry crane

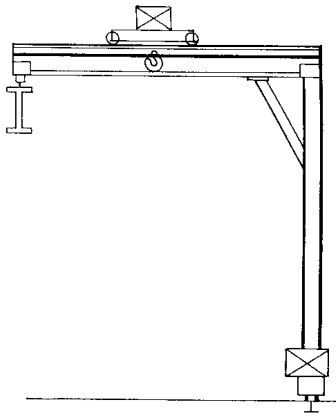
Single leg, double leg, and mobile types of gantry cranes

Similar to a bridge crane except that it is floor supported at one or both ends instead of overhead (wall) supported

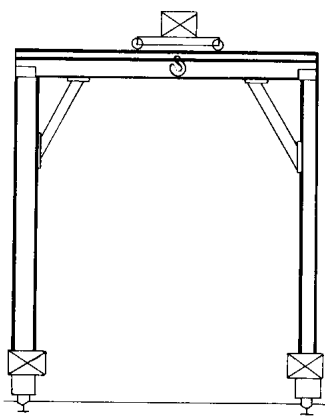
Used to span a smaller portion of the work area as compared to a bridge crane

The supports can be fixed in position or they can travel on runways

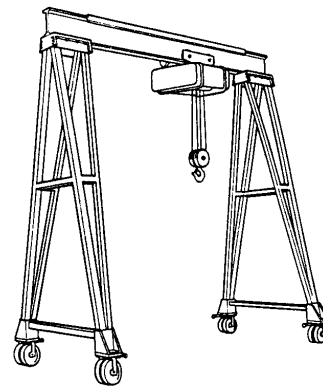
Can be used outdoors when “floor” supported at both ends



Single-leg gantry



Double-leg gantry



Mobile gantry

4. Stacker crane

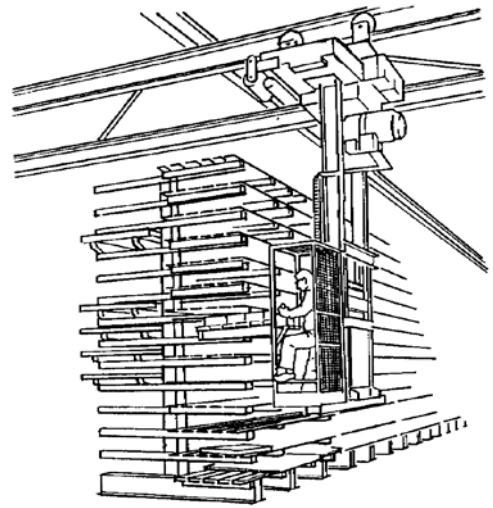
Similar to a bridge crane except that, instead of a hoist, it uses a mast with forks or a platform to handle unit loads

Considered “fork trucks on a rail”

Used for storing and retrieving unit loads in storage racks, especially in high-rise applications in which the racks are more than 50 feet high

Can be controlled remotely or by an operator in a cab on the mast

Can be rack supported



7. Industrial Trucks

Industrial trucks are trucks that are not licensed to travel on public roads—“commercial trucks” are licensed to travel on public roads. Industrial trucks are:

- Used to move materials over variable (horizontal) paths with no restrictions on the area covered (i.e., unrestricted area)
- Provide vertical movement if the truck has lifting capabilities
- Used when there is insufficient (or intermittent) flow volume such that the use of a conveyor cannot be justified
- Provide more flexibility in movement than conveyors and cranes

Characteristics:

1. *Pallet/Non-Pallet*: Does the truck have forks for handling pallets, or does the truck have a flat surface on which to place loads.

Non-Pallet ⇒ (usually) other means required to load truck

2. *Manual/Powered*: Does the truck have manual or powered vertical (lifting) and/or horizontal (travel) movement capabilities.

Manual ⇒ walk ⇒ operator provides the force needed for lifting loads and/or pushing the vehicle

Powered ⇒ on-board power source (e.g., batteries) used for lifting and/or travel

3. *Walk/Ride*: For non-automated trucks, can the operator ride on the truck (in either a standing or sitting position) or is the operator required to walk with the truck during travel.

Ride ⇒ powered ⇒ travel speed can be faster than a walking pace

Walk ⇒ manual or powered travel possible ⇒ powered travel speed limited to a normal walking pace

4. *Stack/No Stack*: Can the truck be used to lift loads for stacking purposes.

Stack ⇒ can also be used as no stack ⇒ more expensive to add stacking capability

No Stack may lift a load a few inches to clear the floor for subsequent travel (e.g., pallet jack), but the loads cannot be stacked on top of each other or on shelves

5. *Narrow Aisle*: Is the lift truck designed to have a small turning radius or does it not have to turn at all in an aisle when loading/unloading.

Narrow Aisle ⇒ greater cost and (usually) standing operator ⇒ less aisle space required

Counterbalance and/or straddle used for load support

Small turning radius \Rightarrow load support via straddle or reaching capabilities

No turning required \Rightarrow even narrower aisle \Rightarrow only one-side loading (sideloaders) or the capability to rotate the load (turret truck)

6. *Automated*: Is the truck automated so that it can transport loads without requiring an operator.

Non-Automated \Rightarrow direct labor cost of operator is by far the largest cost to operate a non-automated truck

Semi-Automated \Rightarrow operator used to control loading/unloading, but automated transport control (e.g., the S/R machine of a Man-on-board AS/RS)

Automated \Rightarrow Automated Guided Vehicle (AGV) \Rightarrow no direct labor cost, but higher equipment costs

Table 9. Industrial Trucks

1. Hand truck	7. Narrow-aisle straddle truck
(a) Two-wheeled hand truck	8. Narrow-aisle reach truck
(b) Dolly	9. Turret truck
(c) Floor hand truck	(a) Operator-down turret truck
2. Pallet jack	(b) Operator-up turret truck
(a) Manual pallet jack	10. Order picker
(b) Powered pallet jack	11. Sideloader
3. Walkie stacker	12. Tractor-trailer
(a) Manual walkie stacker	13. Personnel and burden carrier
(b) Powered walkie stacker	14. Automatic guided vehicle (AGV)
4. Pallet truck	(a) Tow AGV
5. Platform truck	(b) Unit load AGV
(a) Walkie platform truck	(c) Assembly AGV
(b) Rider platform truck	(d) Light load AGV
6. Counterbalanced lift truck	(e) Fork AGV
(a) Sit-down counterbalanced lift truck	
(b) Stand-up counterbalanced lift truck	

1. Hand truck

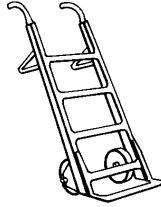
Non-Pallet + Walk + No Stack + Manual

Simplest type of industrial truck

1(a) Two-wheeled hand truck

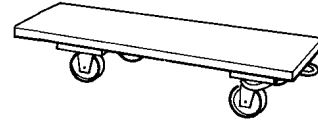
Load tilted during travel

Good for moving a load up or down stairways



1(b) Dolly

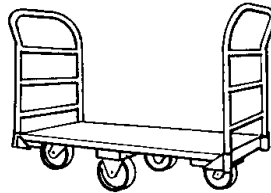
Three or more wheeled hand truck with a flat platform in which, since it has no handles, the load is used for pushing



1(c) Floor hand truck

Four or more wheeled hand truck with handles for pushing or hitches for pulling

Sometimes referred to as a “cart” or “(manual) platform truck”



Tilt floor hand truck



Order picking cart

2. Pallet jack

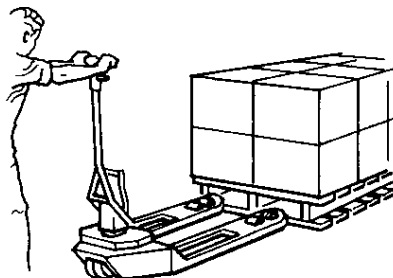
Pallet + Walk + No Stack

Front wheels are mounted inside the end of the forks and extend to the floor as the pallet is only lifted enough to clear the floor for subsequent travel

Pallet restrictions: reversible pallets cannot be used, double-faced nonreversible pallets cannot have deckboards where the front wheels extend to the floor, and enables only two-way entry into a four-way notched-stringer pallet because the forks cannot be inserted into the notches

2(a) Manual pallet jack

Pallet + Walk + No Stack + Manual
Manual lifting and/or travel

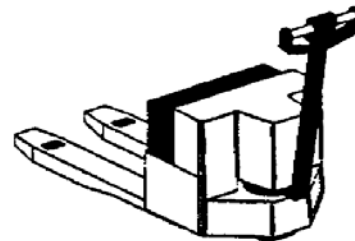


2(b) Powered pallet jack

Pallet + Walk + No Stack + Powered

Powered lifting and/or travel

Powered pallet jack is sometimes referred to as a “(walkie) pallet truck”



3. Walkie stacker

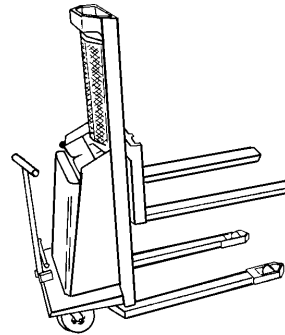
Pallet + Walk + Stack

Similar to a counterbalanced lift truck except the operator cannot ride on the truck

3(a) Manual walkie stacker

Pallet + Walk + Stack + Manual

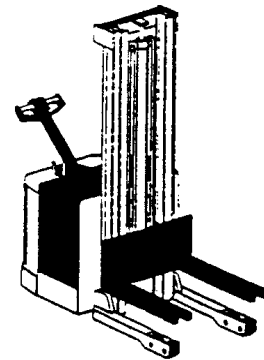
Manual lifting and/or travel (and straddle load support)



3(b) Powered walkie stacker

Pallet + Walk + Stack + Powered

Powered lifting and/or travel (and either counterbalance or straddle load support)



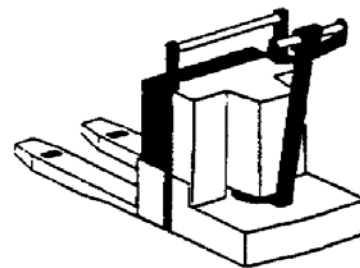
4. Pallet truck

Pallet + Ride + No Stack

Same pallet restrictions as a pallet jack

Control handle typically tilts to allow operator to walk during loading/unloading

Powered pallet jack is sometimes referred to as a “(walkie) pallet truck”



5. Platform truck

Non-Pallet + Powered + No Stack

Platform used to provide support for nonpalletized loads

Used for skid handling; platform can lift skid several inches to allow it to clear the floor

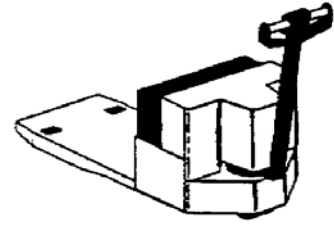
Greater lifting capacity compared to fork trucks because the platform provides a greater lifting surface to support a load

5(a) Walkie platform truck

Non-Pallet + Powered + No Stack + Walk

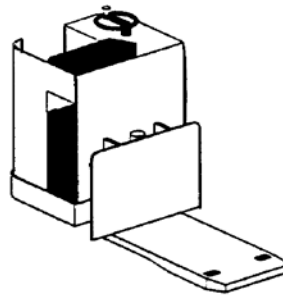
Operator walks next to truck

Floor hand truck is sometimes referred to as a “(manual) platform truck”

**5(b) Rider platform truck**

Non-Pallet + Powered + No Stack + Ride

Operator can ride on truck

**6. Counterbalanced (CB) lift truck**

Pallet + Ride + Stack

Sometimes referred to as a “fork truck” (but other attachments besides forks can be used)

Weight of vehicle (and operator) behind the front wheels of truck counterbalances weight of the load (and weight of vehicle beyond front wheels); front wheels act as fulcrum or pivot point

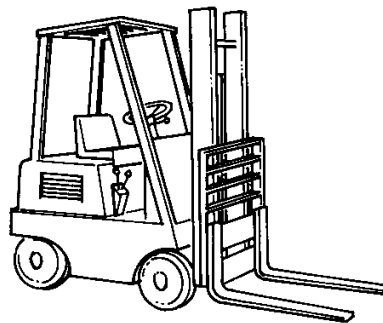
Rated capacity reduced for load centers greater than 24 in. and lift heights greater than 13 ft.

Workhorses of material handling because of their flexibility: indoor/outdoor operation over a variety of different surfaces; variety of load capacities available; and variety of attachments available—fork attachments can replace the forks (e.g., carton clamps) or enhance the capabilities of the forks (e.g., blades for slipsheets)

6(a) Sit-down counterbalanced lift truck

Operator sits down

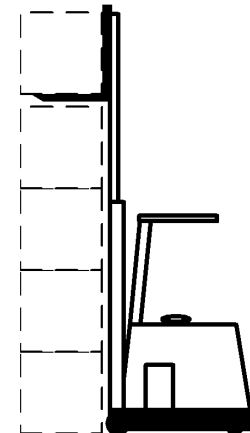
12–13 ft. minimum aisle width requirement

**6(b) Stand-up counterbalanced lift truck**

Operator stands up, giving vehicle narrow-aisle capability

9–11 ft. minimum aisle width requirement

Faster loading/unloading time compared to NA straddle and reach trucks



7. Narrow-aisle (NA) straddle truck

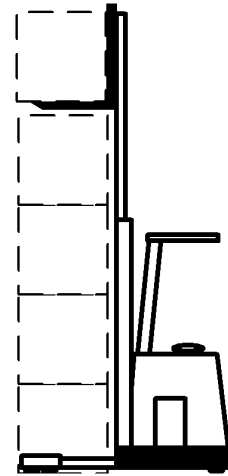
Similar to stand-up CB lift truck, except outrigger arms straddle a load and are used to support the load instead of the counterbalance of the truck

7–8 ft. minimum aisle width requirement

Less expensive than stand-up CB lift truck and NA reach truck

Since the load is straddled during stacking, clearance between loads must be provided for the outrigger arms

Arm clearance typically provided through the use of load-on-beam rack storage or single-wing pallets for load-on-floor storage



8. Narrow-aisle (NA) reach truck

Similar to both stand-up CB lift truck and NA straddle truck

8–10 ft. minimum aisle width requirement

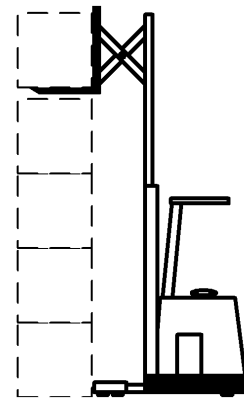
Load rests on the outrigger arms during transport, but a pantograph (scissors) mechanism is used for reaching, thereby eliminating the need to straddle the load during stacking

Reaching capability enables the use of shorter outrigger arms (arms > ½ load depth) as compared to NA straddle truck (arms = load depth)

Counterbalance of the truck used to support the load when it extends beyond the outrigger arms

Although the NA reach truck requires slightly wider aisles than a NA straddle truck since its outrigger arms do not enter a rack during storage, it does not require arm clearance between loads (arm clearance is still required when the truck must enter a storage lane when block stacking or drive-in or -through racks are used)

Extended reaching mechanisms are available to enable deep-reach storage



9. Turret truck

Greater stacking height compared to other narrow-aisle trucks (40 ft. vs. 25 ft.), but greater investment cost

Forks rotate to allow for side loading and, since truck itself does not rotate during stacking, the body of the truck can be longer to increase its counterbalance capability and to allow the operator to sit

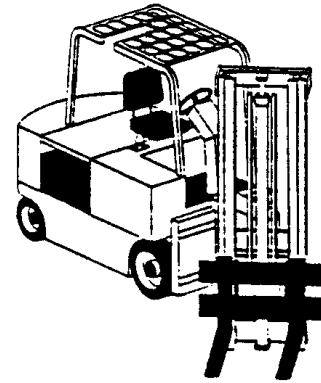
Can function like a sideloader for transporting greater-than-pallet-size load

9(a) Operator-down turret truck

Operator not lifted with the load

5–6 ft. minimum aisle width requirement

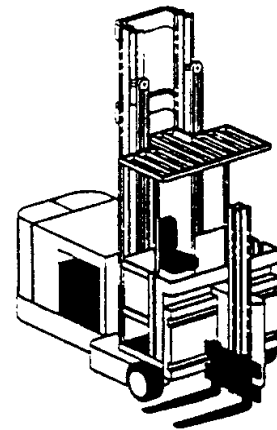
Termed a *swingmast truck* when, instead of just the forks, the entire mast rotates (thus can store on only one side of a aisle while in aisle)

**9(b) Operator-up turret truck**

Operator lifted with the load to allow precise stacking and picking

Also termed a “hybrid storage/retrieval vehicle”

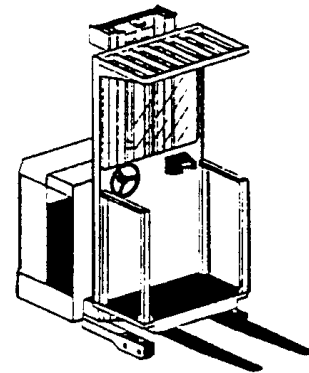
5–7 ft. minimum aisle width requirement

**10. Order picker**

Similar to NA straddle truck, except operator lifted with the load to allow for less-than-unit-load picking

Typically has forks to allow the truck to be used for pallet stacking and to support a pallet during less-than-pallet-load picking

“Belly switch” used for operator safety during picking

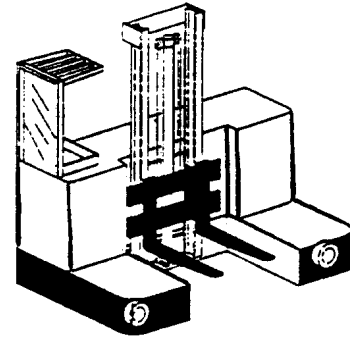


11. Sideloader

Forks mounted perpendicular to direction of travel to allow for side loading and straddle load support

5–6 ft. minimum aisle width requirement

Can be used to handle greater-than-pallet-size loads (e.g., bar stock)



12. Tractor-trailer

Non-load-carrying tractor used to pull a train of trailers (i.e., dollies or floor hand trucks)

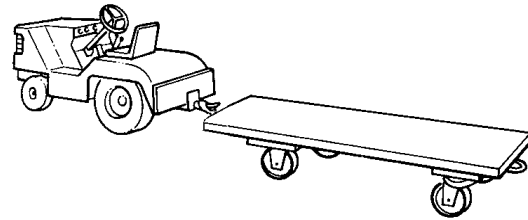
Advantage: Enables a single operator to transport multiple floor hand trucks in a single move

Disadvantage: Requires wide aisles or open spaces to operate

Tractor sometimes termed a “tugger”

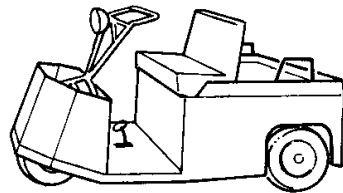
Manual version of a tow AGV

Typically used at airports for baggage handling



13. Personnel and burden carrier

Non-load-carrying vehicle used to transport personnel within a facility (e.g., golf cart, bicycle, etc.)



14. Automatic guided vehicle (AGV)

AGVs do not require an operator

Good for high labor cost, hazardous, or environmentally sensitive conditions (e.g., clean-room)

Also termed “automated guided vehicle”

AGVs good for low-to-medium volume medium-to-long distance random material flow operations (e.g., transport between work cells in a flexible manufacturing system (FMS) environment)

Two means of guidance can be used for AGV systems:

Fixed path: Physical guidepath (e.g., wire, tape, paint) on the floor used for guidance

Free-ranging: No physical guidepath, thus easier to change vehicle path (in software), but

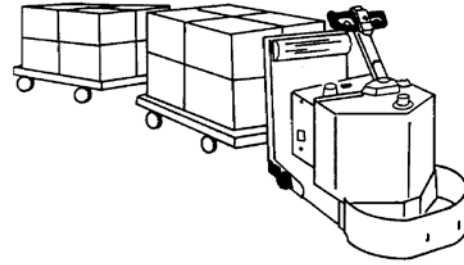
absolute position estimates (from, e.g., lasers) are needed to correct dead-reckoning error

14(a) Tow AGV

Used to pull a train of trailers

Automated version of a tractor trailer

Trailers usually loaded manually (early type of AGV, not much used today)



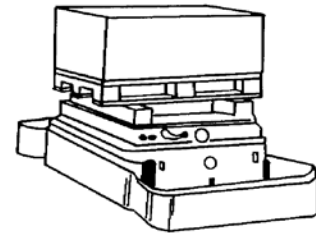
14(b) Unit load AGV

Have decks that can be loaded manually or automatically

Deck can include conveyor or lift/lower mechanism for automatic loading

Typically 4 by 4 feet and can carry 1–2,000 lb. loads

Typically less than 10 vehicles in AGV system

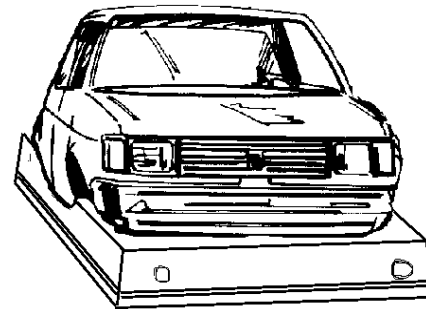


14(c) Assembly AGV

Used as assembly platforms (e.g., car chassis, engines, appliances)

Greatest development activity during the 1980s (alternative to AEMs)

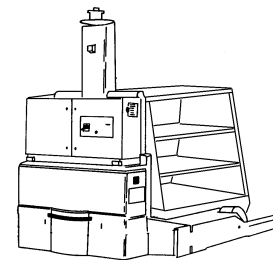
Typically 50–100 vehicles in AGV system



14(d) Light load AGV

Used for small loads (< 500 lbs.), e.g., components, tools

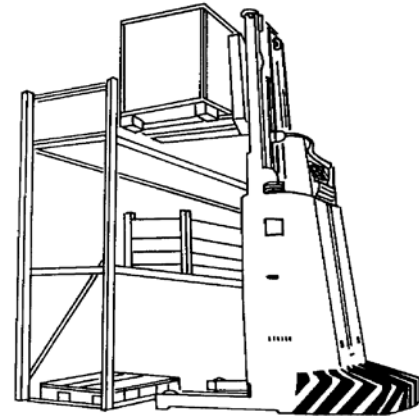
Typically used in electronics assembly and office environments (as mail and snack carriers)



14(e) Fork AGV

Counterbalanced, narrow-aisle straddle, and sideloading versions available

Typically have sensors on forks (e.g., infrared sensors) for pallet interfacing



Comparison of Standard Industrial Trucks

In Table 10, six standard, non-narrow-aisle industrial trucks are compared on the basis of four parameters.

Table 10. Industrial Truck Comparison

Industrial Truck	Technical Parameters		Economic Parameters	
	Pallet vs. No Pallet	Stacking vs. No Stacking	Manual vs. Powered	Walk vs. Ride
Hand truck	NP	NS	M	W
Platform truck	NP	NS	P	W/R
Pallet jack	P	NS	M/P	W
Walkie stacker	P	S	M/P	W
Pallet truck	P	NS	P	R
CB lift truck	P	S	P	R

Counterbalanced Lift Trucks

Counterbalanced lift trucks (a.k.a. fork trucks) are the workhorses of material handling because of their flexibility:

- Indoor/outdoor operation over a variety of different surfaces
- Variety of load capacities available
- Variety of attachments available; for example, fork attachments can replace the forks (e.g., carton clamps) or enhance the capabilities of the forks (e.g., blades for slipsheets)

Principle of Operation: the weight of the vehicle (and operator) behind the front wheels of the truck counterbalances the weight of the load (and the weight of the vehicle beyond the front wheels); the front wheels of the truck act as a fulcrum or pivot point (see Figure 5(a)).

Degrees of Freedom: a lift truck can have as many as five degrees of freedom (DOF) in its movement (see Figure 5):

1. Horizontal translation (drive wheels).
2. Horizontal rotation (turning wheels).
3. Vertical lift (forks along mast).
4. Mast tilt (forward tilt for loading/unloading and backward tilt for travel).
5. Fork translation (to handle different size loads).

Rated Load Capacity: 1,000–100,000 lbs available; a truck's rated load capacity is specified assuming a *rated load center* of 24 inches (or 500 mm) from the face of the forks of the truck and a lift height of up to 13 ft; attachments and loads with a center of gravity greater than 24 inches reduce the load capacity of the truck. Figure 6 shows the specification sheet for a 3,000 lb lift truck.

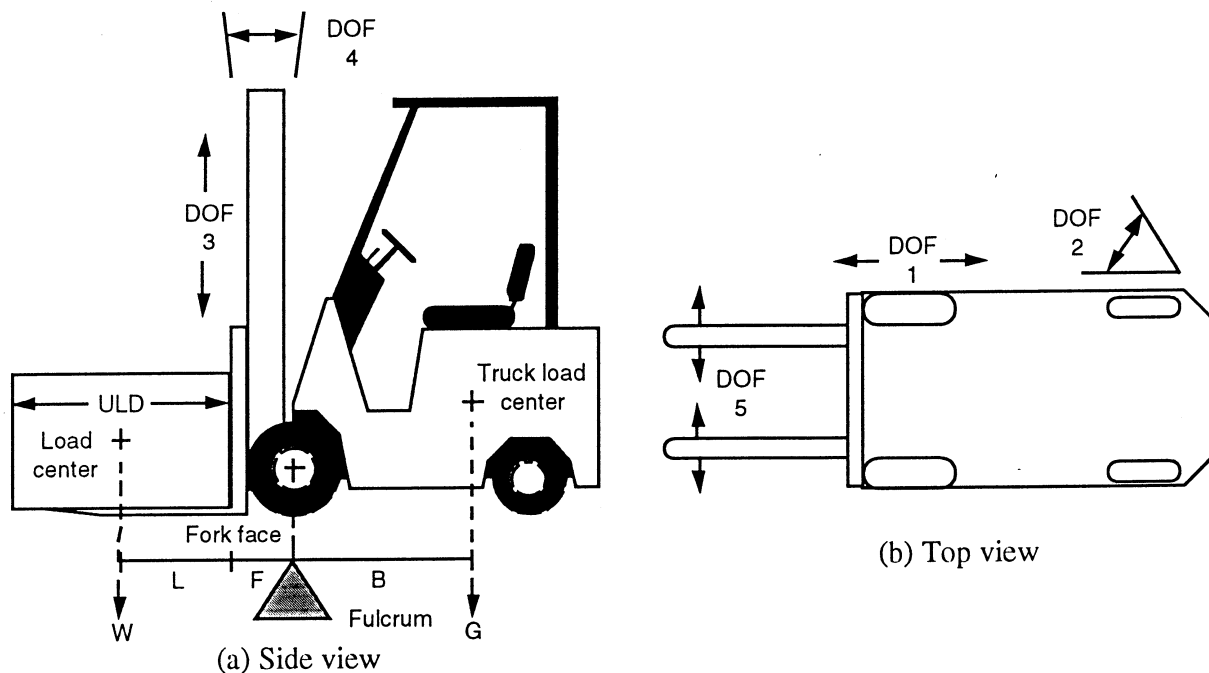


Figure 5. Sit-down counterbalanced lift truck.

Load Capacity: A truck's approximate allowable load capacity W (see Figure 5(a)) is given by

$$\text{Load capacity: } W = \frac{GB}{F+L} = \frac{M}{F+L} = \frac{W_0(F+L_0)}{F+L}, \quad (0.1)$$

where

G = empty truck weight (lbs)

B = front-axle to truck-load-center distance (in.)

F = front-axle to fork-face distance (in.)

L = actual load center, distance from fork face to load center of gravity (in.)

$$= \frac{ULD}{2} \text{ if constant-density rectangular-shaped load}$$

ULD = unit load depth

L_0 = 24 in. = rated load center

M = load moment (in·lbs)

W_0 = rated load capacity (lbs).

Although it might seem preferable, in light of (0.1), to specify a truck's load moment (M), its W_0 is specified instead because it is easier to relate to the truck's maximum allowable load weight.

Two different adjustments can be made with respect to the load capacity of the truck:

- *Derating* — ($W < W_0$) determining the maximum permissible load weight given that the load's center of gravity, L , exceeds the rated load center, $L_0 = 24$ in.
- *Rerating* — (new W_0 and $L = L_0$) modifying the truck's rated load capacity due to changes to the truck; e.g., adding extra counterbalance weight, a fork attachment, or an extended mast.

Derating Example: Assuming a constant density rectangular-shaped load, $ULD = 60$, $F = 12$, and $W_0 = 3,000$ lbs, the derated load capacity is reduced to

$$W = \frac{W_0(F + L_0)}{F + L} = \frac{3,000(12 + 24)}{12 + \frac{60}{2}} = \frac{108,000}{42} = 2,571 \text{ lbs.}$$

Rerating Example 1: Assuming $F = 12$ and $W_0 = 3,000$ lbs, if a 500 lb. counterbalance weight is attached to the back of the truck at a distance of 72 in. from the front axle, then the new rated load capacity of the truck is

$$W'_0 = \frac{M + \Delta M}{F + L_0} = \frac{W_0(F + L_0) + \Delta M}{F + L_0} = \frac{108,000 + 500 \cdot 72}{12 + 24} = \frac{144,000}{36} = 4,000 \text{ lbs.}$$

Rerating Example 2: The rated load capacity of a lift truck is 2,500 lbs and the distance from the front axle to the fork face is 12 in. The forks of the truck are to be replaced with carton clamps. The clamps and forks weigh 225 and 100 lbs, respectively, with a center of gravity relative to the front axle of 30 and 42 in., respectively. The truck's actual rated load capacity assuming the distance from the front axle to the clamp face is 15 in. is

$$W'_0 = \frac{M - \Delta M}{F + L_0} = \frac{W_0(F + L_0) - (225 \cdot 30 - 100 \cdot 42)}{15 + 24} = \frac{90,000 - 2550}{39} = 2,242 \text{ lbs.}$$

Lift Height: up to 40 feet using single-, double-, triple-, and quad-stage masts; for multiple-stage trucks, the *free lift* is the length of fork movement before the mast starts to move (important when traveling through doorways and inside trailers).

In determining a truck's approximate allowable load capacity using (0.1), its rated load moment (M_0) should be reduced by 4,800 in·lbs for every foot of lift greater than 13 ft.

Power Sources: determines where truck can operate (inside/outside) and the gradability of the truck (i.e., how steep an incline the truck can climb).

1. Internal Combustion Engine: gradability of 15%
 - (a) Gasoline—no one makes anymore
 - (b) Diesel—only for outside operation
 - (c) Liquid Petroleum Gas (LPG)—outside and ventilated inside operation (80% of trucks)
2. Electric Motor: gradability of 10%
 - (a) Battery Powered—inside operation; requires battery recharge station

Tires: determines what type of terrain the truck can operate over

1. Pneumatic—outside (rough terrain)
2. Cushion—inside and outside (smooth terrain)
3. Solid—inside

Attachments: determines the functionality of the truck

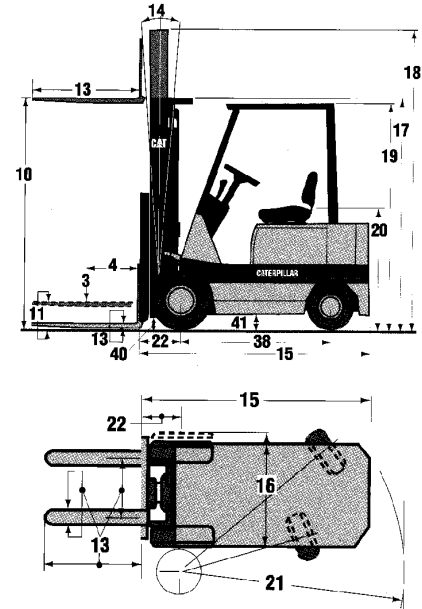
1. *Mast:* attachments to the mast of the truck
 - (a) Shelf Guides—e.g., masking tape on the mast to mark the height of shelves
2. *Carriage:* attachments to the carriage that moves on the mast
 - (a) Sideshifter—shifts the forks without repositioning the truck
 - (b) Fork Positioner (spreader)—each fork can move independently (aids load stabilization when a variety of pallet sizes are used)
 - (c) Rotators—enable dumping of a load when used with barrel clamps
 - (d) Push/Pull—grips/pushes/pulls slipsheet (used together with blades)

SPECIFICATIONS

**Specify The Model EC15 For All Your
2000-3000 lb (1000-1500 kg) Capacity Material Handling Needs**

CHARACTERISTICS							
1	Manufacturer		Caterpillar				
2	Model		EC15				
3	Capacity	rated load	lb	kg	3000	1500	
4	at load center	distance	in	mm	24	500	
5	Power	electric, diesel, gasoline, LP gas	Electric				
6	Steering control	pedestrian, stand-on, sit-down	sit-down				
7	Tires	cushion, pneumatic	cushion				
8	Wheels (x=driven)	number, front/rear	2x / 2				
DIMENSIONS							
9	Lift with standard two-stage mast	maximum fork height with rated load	in	mm	157	4000	
10		maximum fork height	in	mm	130	3300	
11		free fork height	in	mm	4.1	105	
12	Fork carriage	ITA Class	II				
13	Forks	thickness, width, length	in	mm	1.3 x 4 x 36	34x 100x 920	
		Fork spacing	out-to-out	minimum/maximum	in	mm	7.9/32.3
14	Tilt of mast	forward/back	degrees	5 / 10			
15		length to fork face	in	mm	73.2	1859	
16	Overall dimensions	width	standard tires	in	mm	37.2	
			optional	in	mm	NA	945
17		height	with lowered mast	in	mm	83	2110
18			with extended mast	in	mm	179.5	4560
19	to top of overhead guard		in	mm	83.7	2125	
20		seat height	in	mm	45.7	1160	
21	Minimum outside turning radius		in	mm	67	1700	
22	Load moment constant from center of front axle to fork face		in	mm	14.2	360	
23	Minimum aisle - 90° stack (add load length and clearance)		in	mm	80.5	2046	
PERFORMANCE							
24	Speeds	travel: loaded/empty (36 48V)	mph	km/h	6.8/8.1 9.0/10.6	11 / 13 14.5 / 17	
25		lift: loaded/empty (36 48V)	fpm	m/s	49/77 69/100	0.25/0.39 0.95/0.51	
26		lowering: loaded/empty	fpm	m/s	102 / 98	0.52 / 0.50	
27	Drawbar pull	loaded (36/48V) at 1 mph (1.6 km/h)	lb	N	1606/1771	7147/7881	
28		empty (36/48V) at 1 mph (1.6 km/h)	lb	N	1573/1749	7000/7783	
29	Gradeability	with load at 1 mph (1.6 km/h)	%	16			
30	WEIGHT						
31	Empty		lb	kg	6350	2880	
32	Axle load	with rated load front/rear	lb	kg	8490 / 1170	3850 / 530	
33		without load front/rear	lb	kg	2710 / 3640	1230 / 1650	
CHASSIS							
34	Tires	number, front/rear	no.		2 / 2		
35		size	standard tires	18 x 6 x12-1/8			
36			optional	NA			
37		rear	14 x 4-1/2 x 8				
38	Wheelbase		in	mm	45.3	1150	
39	Tread width	front	standard tires	in	mm	31.3	
			optional	in	mm	NA	795
		rear	in	mm	32.5	825	
40	Ground clearance	with load at lowest point	in	mm	2.9	75	
41		at center of wheelbase	in	mm	3.5	90	
42	Brakes	service	hydraulic				
43		parking	mechanical				
POWER TRAIN							
44	Battery	type	lead-acid				
45		36 volt	maximum capacity available	Ah	kWh	1300	44.9
		48 volt			975	44.9	
46		minimum weight	lbs	kg	1760	800	
47	Electric motors	traction output (rated at 48 V)	hp	kW	11.9	8.9	
48		lift pump output (rated at 48 V)	hp	kW	10	7.5	
49	Speed control	type	microcontroller				
		number of speeds	variable				
50	Relief pressure for attachments		psi	bar	2630	181.1	
51	Noise level	Leq	db(A)		*		

*Not available at time of printing



SAFETY Standards

These trucks are designed and manufactured to meet American National Standards Institute (ANSI) B56.1, Safety Standards for powered industrial lift trucks.

UL-Classified by Underwriters' Laboratories, Inc., as to fire and electric shock hazard only: Types E, ES and EE Industrial Trucks.

Users should be aware of, and adhere to, applicable codes and regulations regarding operator training, use, operation and maintenance of powered industrial trucks, including:

- Occupational Safety and Health Administration (OSHA) regulations that may apply.
- User's section of ANSI B56.1.
- NFPA 505, fire safety standard for powered industrial trucks - type designations, areas of use, maintenance and operation.

Contact your CAT lift truck dealer for further information including operator training programs and auxiliary visual and audible warning systems, fire extinguishers, etc., as available for specific user applications and requirements.

Figure 6. Specification sheet for the Caterpillar Model EC15 3000 lb. lift truck. ¹⁵

3. *Forks*: attachment can be either an enhancement or replacement for the forks

Enhancements:

- (a) Blades (platens)—used together with Push/Pull for slipsheet handling
- (b) Length—shorten, lengthen, or extendable

Replacements:

- (a) Blades for slipsheets—can replace forks for slipsheet handling
- (b) Clamps—carton, bale, roll, or barrel
- (c) Ram—used for coils
- (d) Shovel
- (e) Block Forks—more than two forks for handling nonpalletized loads (e.g., bricks)

6. *Trailer Hitch*

7. *Radio/RF Data Modem*—for communication with the truck operator

8. *Extra Counter Balance*—to increase the load capacity of the truck

9. *TV*—mounted between the forks

Narrow-Aisle Lift Trucks

Narrow-aisle lift trucks are designed to have a small turning radius when loading/unloading in an aisle or, in the case of turret trucks and sideloaders, not to have to turn at all. The major types of narrow-aisle trucks listed in Table 9 are the following:

- 6(a). Stand-up counterbalanced (CB) lift truck
 - 7. Narrow-aisle (NA) straddle truck
 - 8. Narrow-aisle (NA) reach truck
 - 9. Turret truck
 - 10. Order picker (less-than-unit load)
 - 11. Sideloader

Except for order pickers, all the trucks handle unit loads. Three closely related narrow-aisle trucks are compared in Figure 7.

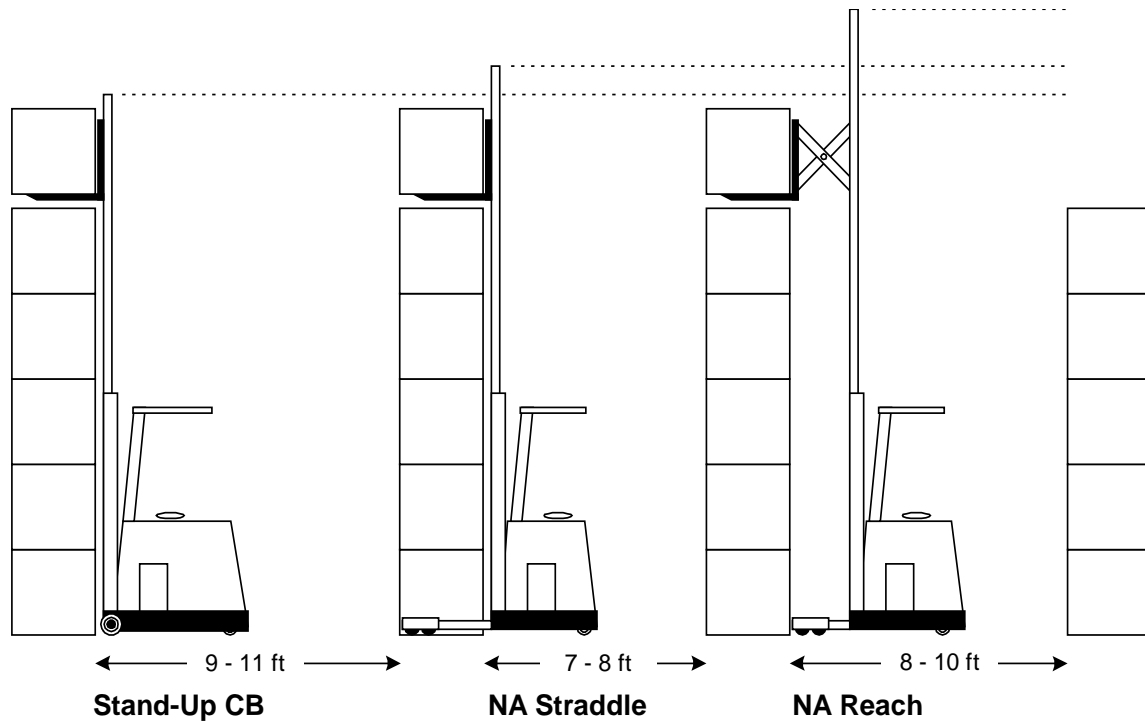


Figure 7. Narrow-aisle lift truck comparison.

Automatic (or Automated) Guided Vehicle (AGV) Systems

AGVs good for low-to-medium volume medium-to-long distance random material flow operations (e.g., transport between work cells in a flexible manufacturing system (FMS) environment).

In a FMS, AGVs usually have automatic docking and loading capabilities at each pickup and delivery (P/D) station.

First AGVs appeared in the 1950s.

Guidance

Fixed-Path

- A physical guidepath (e.g., wire, tape, paint) on the floor used for guidance
- Changing the guidepath can be expensive
- Can have congestion problems because vehicles cannot pass each other on a path (typically use one-way paths to reduce congestion)
- Can be considered “on-the-floor” version of an AEM (automated electrified monorail)

Free-Ranging

- No physical guidepath used ⇒ easier to change vehicle path (in software)
- Can maneuver to avoid congestion

- Dead-reckoning (e.g., odometers), laser, and/or optical sensors used for guidance
- Position error increases over time using just dead reckoning, so most free-ranging vehicles use some type of other sensor to obtain estimates of absolute position to correct dead-reckoning error
- RF (radio frequency) or infrared modems typically used for communication

8. Storage Equipment

Storage equipment is used for holding or buffering materials over a period of time. Some storage equipment may include the transport of materials (e.g., the S/R machines of an AS/RS, or storage carousels). If materials are block stacked directly on the floor, then no storage equipment is required. Storage racks are used to provide support to a load and/or to make the load accessible.

Table 11. Storage Equipment

1. Block stacking (no equipment)	9. Stacking frame
2. Selective pallet rack	10. Bin shelving
(a) Single-deep rack	11. Storage drawers
(b) Double-deep rack	12. Storage carousel
3. Drive-in rack	13. Vertical lift module
4. Drive-through rack	14. A-frame
5. Push-back rack	15. Automatic storage/retrieval system (AS/RS)
6. Flow-through rack	(a) Unit load AS/RS
(a) Carton-flow rack	(b) Miniload AS/RS
(b) Pallet-flow rack	(c) Man-on-board AS/RS
7. Sliding rack	(d) Deep-lane AS/RS
8. Cantilever rack	

1. Block stacking (no equipment)

Block stacking is the storage of loads on top of each other in stacks placed in lanes on the floor (a.k.a. *floor storage*)

Adv: Easy to implement and very flexible. Low investment cost since no storage medium is required.

Disadv: Honeycomb loss can be significant since, on average, half of one lane will be empty for each item. In most cases, only LIFO retrieval is possible in each lane unless there is an aisle at the back. Damage to loads might cause instable stacks.

Two to ten rows of storage typically used

Width of each lane limited by vehicle width, not load width

Storage racks are used when support and/or material accessibility is required

2. Selective pallet rack

Pallets are supported between load-supporting beams. Most popular type of storage rack. Special attachments and decking can be used to make the racks capable of supporting other types of unit loads besides pallets (e.g., coils, drums, skids)

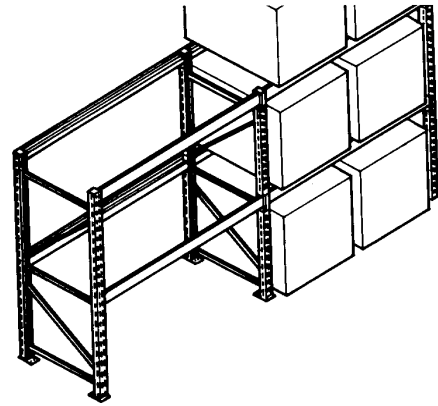
Load-on-beam racks are used to provide clearance for straddles; *load-on-floor* racks can be used when it is not necessary to use straddles.

2(a) Single-deep rack

Single position (slot) per position

Adv: Provides complete and fast accessibility to all loads with no honeycomb loss

Disadv: Can result in low cube utilization because of aisle space requirements, which can be influenced by the lift truck used (e.g., a turret truck would increase and a standard counterbalanced would decrease utilization)

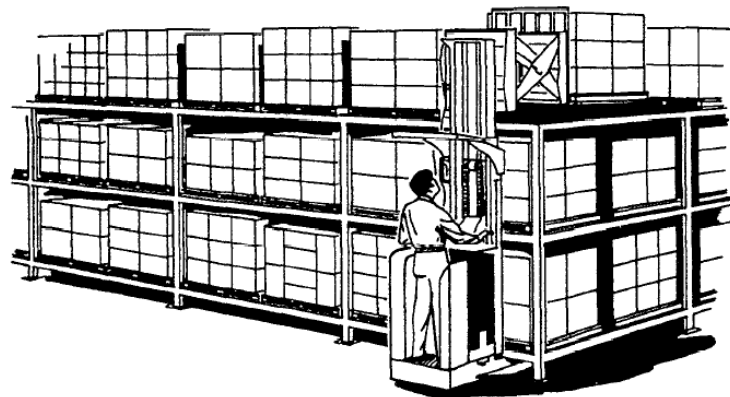


2(b) Double-deep rack

Two pallets stored per position

Adv: Provides greater cube utilization than single-deep racks because more loads can be accessed from the same side of the rack

Disadv: In order to access rear load in rack, an extended reaching mechanism is required on the lift truck



[NAVSUP Pub 529]

Typically used when the inventory level for an item is at least five or when loads are stored and picked in multiples of two pallets¹⁶

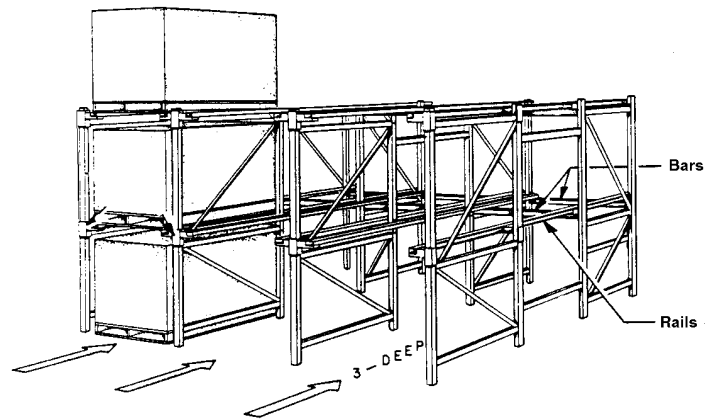
3. Drive-in rack

Loads are supported by rails attached to the upright beams. Lift trucks are driven between the upright beams.

Adv: Provides high density pallet storage.

Disadv: Requires uniform-size loads. Lengthy storage and retrieval times due to care required by driver inside of the rack.

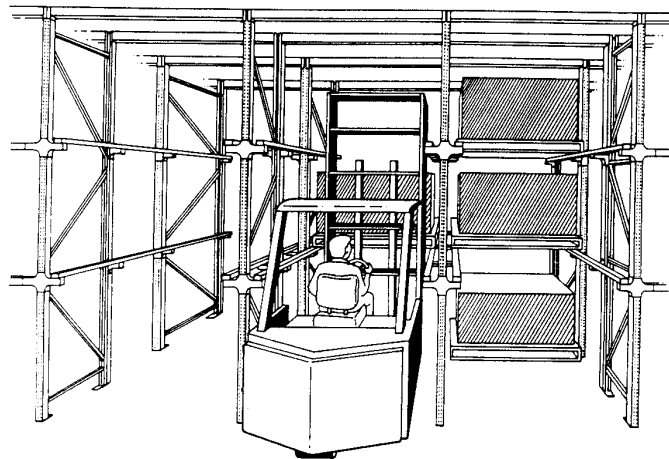
Closed at one end, allowing entry from one end (LIFO)



4. Drive-through rack

Similar to drive-in rack, except open at both ends, allowing access from both ends (FIFO)

Used for staging loads in a flow-thru fashion [Frazelle, WC WH and MH]

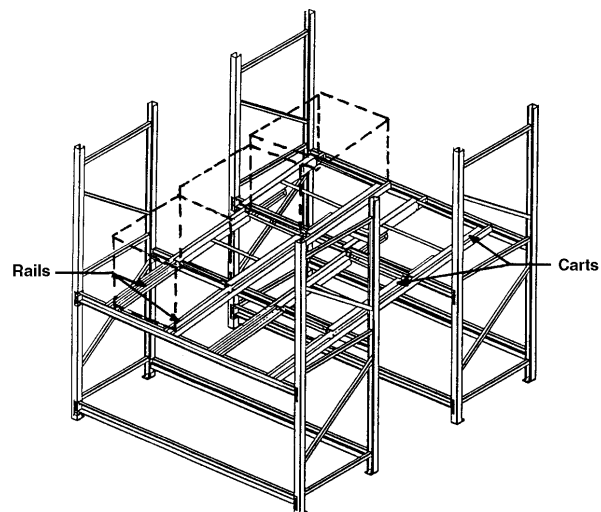


5. Push-back rack

Loads are supported on an incline to enable gravity-based movement of the loads within the rack via roller conveyor. Used to provide highly accessible pallet storage.

Provides LIFO storage in each lane: Loaded and unloaded at the lower end and closed at the higher end

Adv: Can be used to enable deep-reach storage without the need for extended reach mechanisms for loading/unloading



Disadv: Rack investment costs are greater than for double-deep racks

Maximum depth is 5 loads

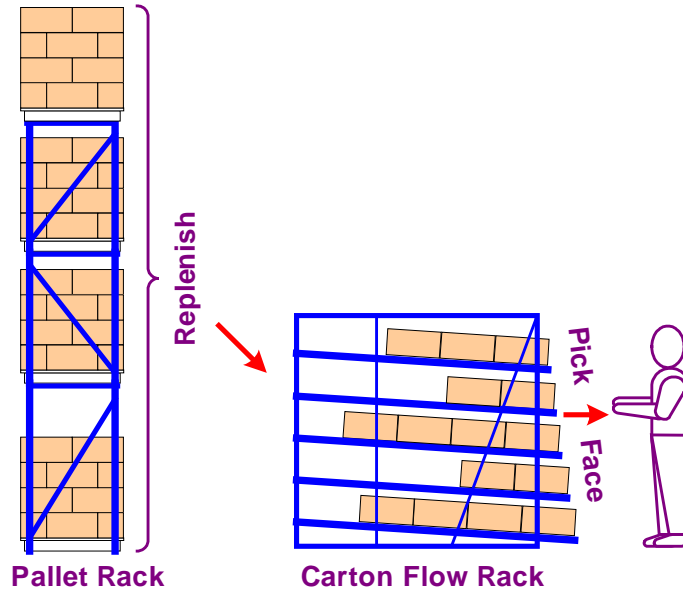
6. Flow-through rack

Similar to push-back rack in terms of storage density, except greater storage depth is possible. Rack is loaded at higher end and unloaded at lower end, providing FIFO storage in each lane.

Termed *pallet-flow rack* and *carton-flow rack* (pictured) when pallets and cartons used, respectively

6(a) Carton-flow rack

Adv: Allows a large cubic volume of product to be accessible from a small pick face area, supporting relatively high pick rates. Replenishment does not interfere with picking.



Disadv: More expensive than bin shelving.

Can have LED displays attached to shelf beam for “pick-to-light” operations (see Section **Error!** **Reference source not found.**)

6(b) Pallet-flow rack

Adv: Replenishment does not interfere with picking.

Disadv: Requires twice as much aisle space as push-back racks, but overall storage density could be higher because of greater storage depth.

Storage depth of 40 to 50 possible for pallet-flow racks

7. Sliding rack

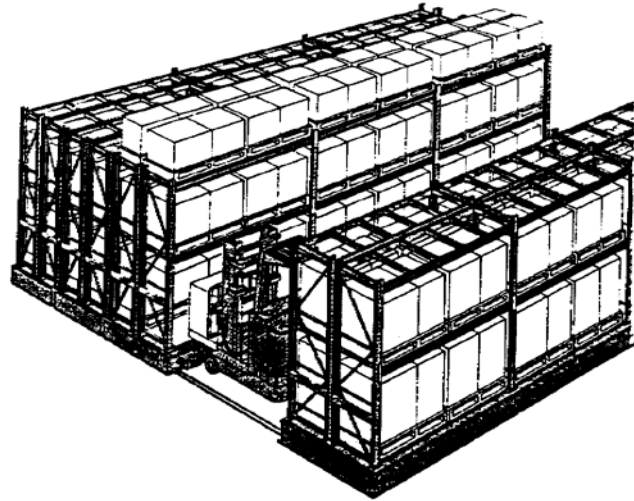
Location of the aisle is changed by sliding rows of racks along guide rails in floor (a.k.a. *mobile rack*)

Used when only single-deep storage is possible and space is very limited or expensive

Adv: High cube utilization and complete accessibility to all loads

Disadv: More expensive compared to other storage racks. Lengthy storage and retrieval times because one can only pick in one lane at a time.

Relies on having a reliable power source available.



Provides increased security for items compared to other racks

Typically found in library stacks, vaults, and climate-controlled (e.g., refrigerated) storage rooms

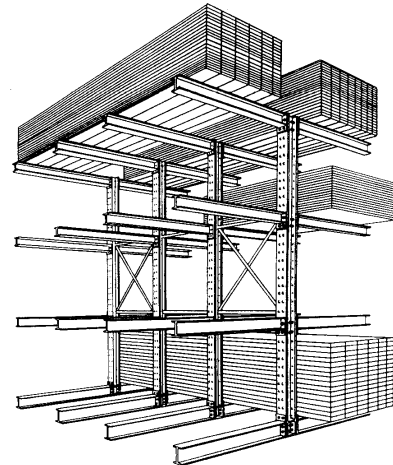
8. Cantilever rack

Loads are supported by two or more cantilevered “arms” (i.e., horizontal beams supported at only one end)

Similar to pallet racks, except the front upright and front shelf beams are eliminated

Used when there is a need for a full clear shelf that can be loaded from the front without obstruction from rack support uprights

Typically used to store long loads (e.g., bar stock, pipes, lumber)



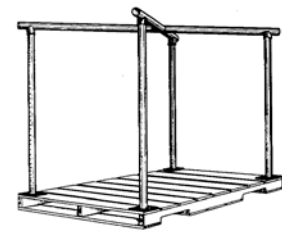
9. Stacking frame

Interlocking units that enable stacking of a load so that crushing does not occur

Can be disassembled and stored compactly when not in use

Pallet frames can be used to enable multilevel block stacking

Cost per frame: \$100–\$300 (can be leased for short-term increases in



inventory)

10. Bin shelving

Alternative to racks to store small, loose, nonpalletized items. Pieces placed either directly on shelves or in bins or cartons.

Adv: Low cost.

Disadv: Can result in excessive travel for picker. Difficult to pick from top shelf depending on the height of the picker and the weight of the unit. Replenishment can interfere with picking.

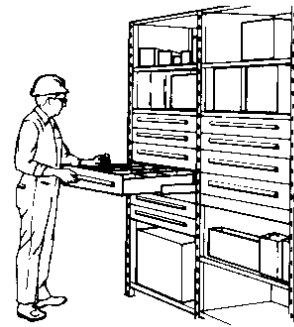
Several levels of shelves (and storage drawers) on a mezzanine can be used to allow multi-level picking (max 4 levels). A lift truck or vertical reciprocating conveyor, e.g., can be used to help with removing units from the top level.

11. Storage drawers

Drawers provide an alternative to bin shelving to store small, loose items

Adv: Drawers can provide increased security compared to bin shelving and is most important when the demand for a specific item is low and infrequent. Easy to install at point of use.

Disadv: Space is frequently underutilized unless there is an ongoing disciplined approach to managing the location and usage of the units being stored. Replenishment can interfere with picking. Cannot see inside the drawers, making labeling an important issue.



12. Storage carousel

Carousel consists of a set of horizontally (pictured) or vertically revolving storage baskets or bins.

Adv: Allows a large number of items to be picked at a high rate.

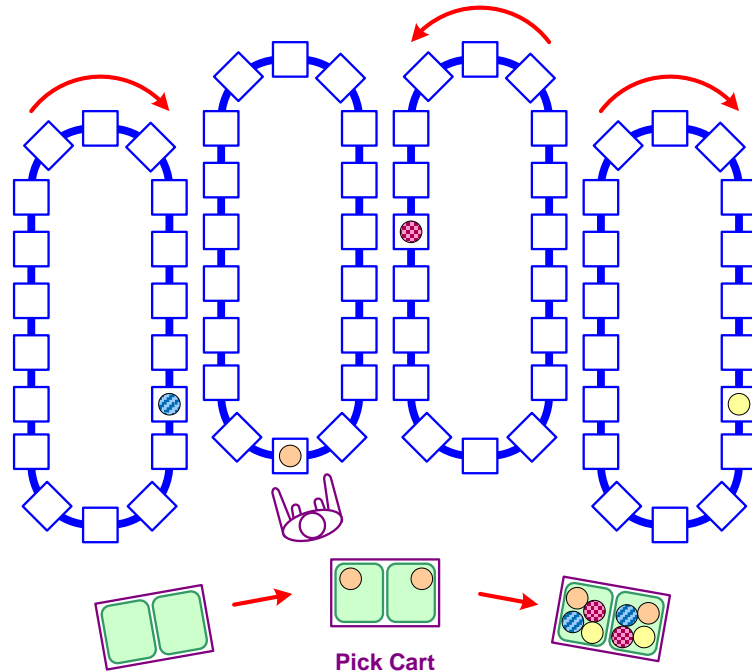
Disadv: Replenishment cannot occur during picking operations (typically, replenishment takes place during a separate shift or is interleaved between peak picking periods).



One operator picks from 2 to 4 carousels (termed a “pod”) in order to minimize waiting time while other carousels are moving.

Each level of the carousel can rotate independently in a clockwise or counter-clockwise direction

Control ranges from manually activated push buttons to automated computer controlled systems

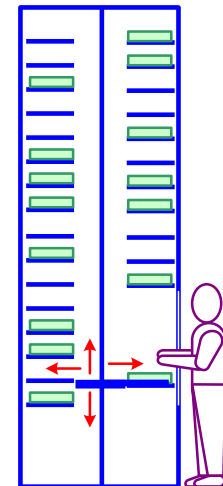


13. Vertical lift module

Pieces stored on trays inside a multi-bay enclosure that are delivered to the opening of a bay for picking by a servo-driven lift carriage.

Adv: Provides high-bay storage, and dense storage since height of trays can vary. All picking occurs at a user-adjustable waist height. Can provide even greater security compared to bin shelving when the operation of the module is often under computerized control, which can increase cost.

Disadv: High cost. Requires reliable power source.

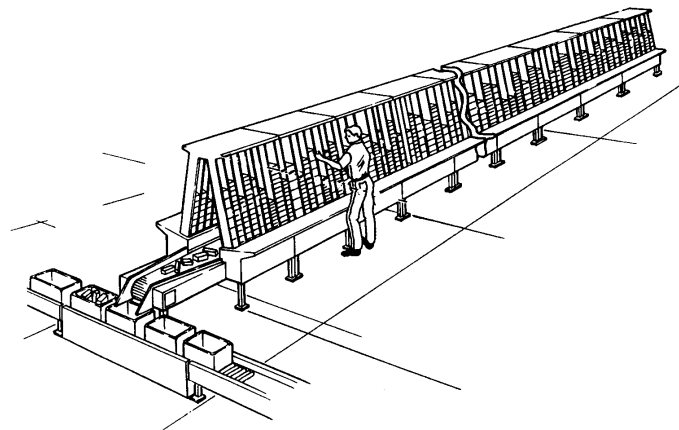


14. A-frame

Units are dispensed from parallel arrays of vertical angled channels onto a belt conveyor that carries them into a container.

Adv: Very high pick rate.

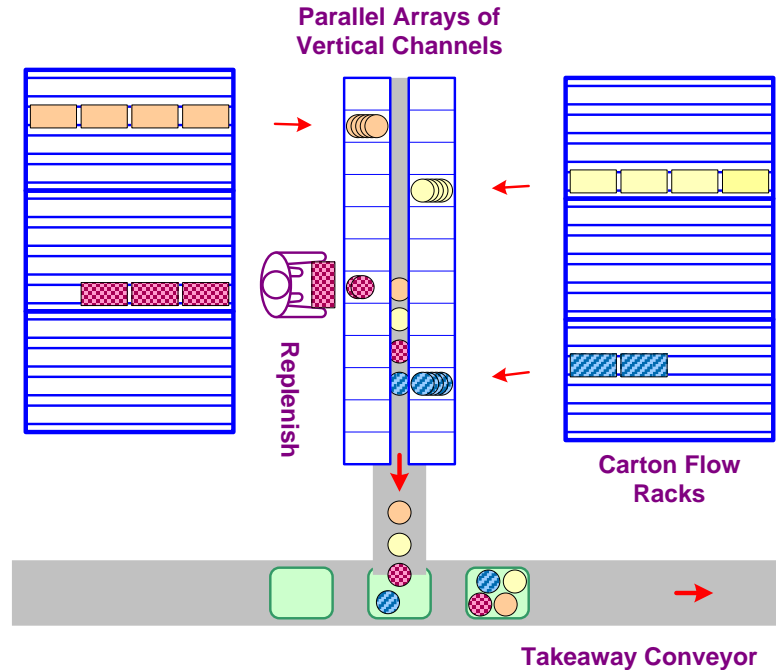
Disadv: Only feasible for small, rigid items of uniform shape that are not fragile. Requires manual replenishment..



Enables fully automated piece picking, with manual replenishment. Popular within pharmaceutical distribution centers

Inverted A-frame used for flat items

Other types of fully automated piece picking systems include robotic based systems that are similar in construction to robotic pick and place palletizers



15. Automatic storage/retrieval systems (AS/RS)

Consists of integrated computer-controlled system that combines storage medium, transport mechanism, and controls with various levels of automation for fast and accurate random storage of products and materials

Storage/retrieval (S/R) machine in an AS/RS operates in narrow aisle, serving rack slots on both sides of aisle; can travel in horizontal (along the aisle) and vertical (up and down a rack) directions at same time

Adv: Fewer material handlers, better material control (including security), and more efficient use of storage space

Disadv: Typically, high capital and maintenance costs, and more difficult to modify

Although AS/RS were originally developed for warehousing and distribution operations, they are now also being used for in-process storage as part of an automated job shop. In an automated job-shop, an AS/RS can be combined with an automatic identification system and an automatic transportation system (e.g., automatic conveyors and/or an AGV system) to provide real-time material control capabilities. The material stored in the AS/RS can include both finished goods and work in process and even production tools and jigs.

Components:

Racks: A typical AS/RS utilizes high-rise storage racks, ranging in height between 40 and 80 feet or higher, for random storage. High-rise racks require tight rack tolerances and level floors, all of which increase the cost of the racks as compared to a basic storage rack. The racks in an AS/RS can be freestanding or uses to support the building (RSS—rack-supported structure).

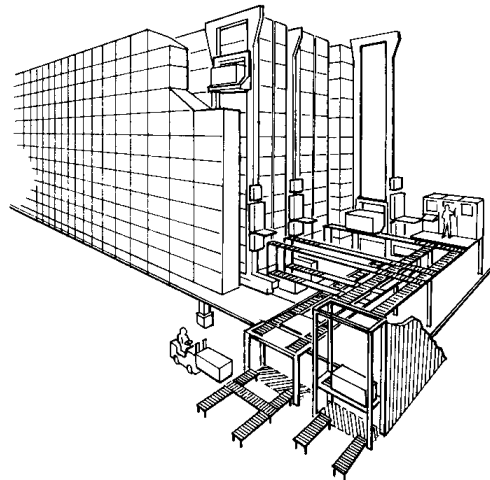
S/R Machine: An S/R machine in an AS/RS operates in a narrow aisle, serving rack slots on both sides of the aisle. The machine can travel in the horizontal (along the aisle) and vertical (up and down a rack) directions at the same time. Often the machine is captive to one aisle, although, if throughput requirements do not justify dedicating a machine to each aisle, a transfer car can be provided to move the machine from the end of one aisle to another, thus enabling the machine to operate in more than one aisle. The machine is a structural single- or multiple-mast frame that rides on one or two floor-mounted wheel rails. A carriage carrying a load-supporting mechanism (or shuttle) operates within the frame. The shuttle is used to store/retrieve loads at the racks and, at the end of the aisle, to transfer loads onto or away from conveyors, vehicles, or pick-up and delivery (P/D) stations or transfer stations. Deep-reach “mole” S/R machines can detach and run into a lane.

Control: The operation of an AS/RS can be controlled by an operator working from a console, but in many cases, the control system is under complete computer control. Typically, distributed control, where each S/R machine is controlled by a dedicated computer with interfaces with a central computer, is used to increase system reliability.

15(a) Unit load AS/RS

Used to store/retrieve loads that are palletized or unitized and weigh over 500 lbs.

Stacking heights up to 130 ft. high, with most ranging from 60 to 85 ft. high; 5 to 6 ft. wide aisles; single- or double-deep storage racks



15(b) Miniload AS/RS

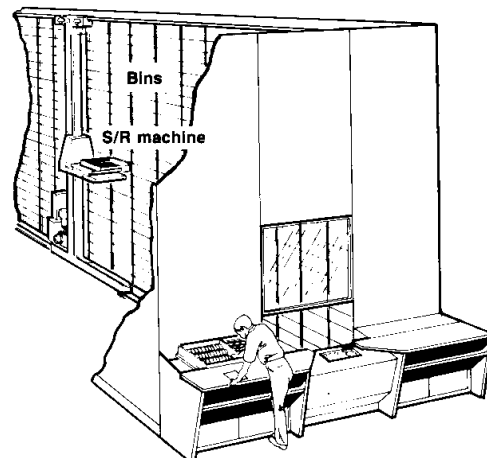
Used to store/retrieve small parts and tools that can be stored in a storage bin or drawer

End-of-aisle picking and replenishment

Stacking heights range from 12 to 20 ft.; bin capacities range from 100 to 750 lbs.

Not typically used for order picking because of long cycle times and high cost

Termed a “microload AS/RS” when capacity is less than 100 lbs (used in assembly, kitting, and testing operations to deliver small containers of parts to individual workstations)



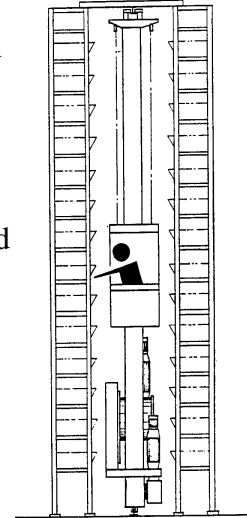
Workstations are typically located on the sides of a pair of racks and the S/R machine operates between the racks to move containers to openings in the racks (storage lanes) located next to each station

15(c) Man-on-board AS/RS

Used for in-aisle picking; operator picks from shelves, bins, or drawers within the storage structure

Manual or automatic control

S/R machine is similar to an order picker or turret truck and can sometimes operate as an industrial truck when outside an aisle, except the S/R is guided along a rail when operating in an aisle



15(d) Deep-lane AS/RS

Similar to unit load AS/RS, except loads can be stored to greater depths in the storage rack

A rack-entry vehicle is used to carry loads into the racks from the S/R machine, and is controlled by the S/R machine

Termed an “automated item retrieval system” when used to automatically retrieve individual items or cases, with replenishment (storage) taking place manually from the rear of a flow-through storage lane and items are pushed forward with a rear-mounted pusher bar for automatic picking from the front of the storage lane

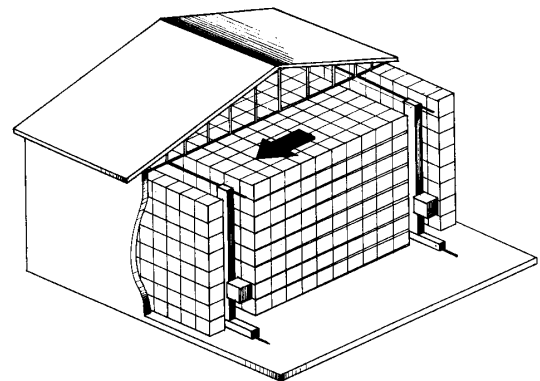


Table 12 provides a comparison of the different type of storage equipment that can be used for pallet picking. Note that there are approximately two lanes of storage per item:

$$\text{Lanes per item} = \frac{\text{Inventory level per item}}{\text{Storage depth per lane}} \approx 2$$

Table 12. Pallet Storage Comparison

Type of Rack	Block Stacking	Single Deep	Double Deep	Drive In	Drive Through	Push Back	Pallet Flow	Sliding Racks
Investment cost per position*	–	1	1.1	1.4	1.4	3	5	7
Storage depth per lane	2–10	1	2	5–10	5–10	2–5	2–5	1
Inventory level per SKU	≥ 5	< 3	≥ 5	≥ 20	≥ 20	3–10	3–10	< 3
All loads accessible	No	Yes	No	No	No	No	No	Yes
S/R throughput	Good	Good	Average	Average	Average	Good	Excellent	Poor
FIFO retrieval possible	Yes	Yes	No	No	Yes	No	Yes	Yes
Vertical honeycomb loss	Yes	No	No	Yes	Yes	No	No	No

* Ratio relative to Single Deep cost (see Gross & Associates’ “Rules of Thumb” for current cost estimates).

9. MH Equipment Selection

Given the material flow requirements for one or moves, MHS alternatives can be determined by selecting appropriate MH equipment that, in some way, “satisfies” the requirements.

An important issue is the classification level from which the MH equipment is selected:

- High Level—categories of equipment, e.g., conveyors, cranes, industrial trucks, positioning equipment
- Intermediate Level—equipment types within categories, e.g., chute or roller conveyors, pallet jack or pallet truck industrial trucks
- Low Level—equipment models within an equipment type, e.g., an Acme Model X diesel-powered counterbalanced lift truck with a rated lift capacity of 5,000 lbs.

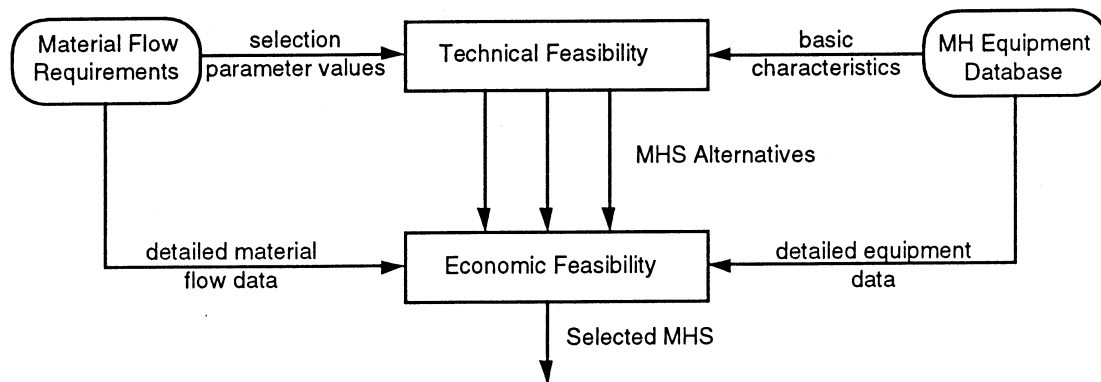


Figure 8. MHE selection.

Selection Problem: Starting from a low level can result in too many possible choices, while starting from a high level does not narrow the number of possible choices enough; starting from the intermediate level reduces the selection problem to choosing from 15–50 possible types of MH equipment.

The process of MH equipment selection can be decomposed into two stages (see Figure 8):

1. Determine Technical Feasibility—select MH equipment types that can satisfy the material flow requirements from a technological perspective;
e.g., a pallet jack is not technically feasible for stacking pallets onto storage racks
2. Determine Economic Feasibility—from among the technically feasible equipment types, select the equipment type that is most cost effective given the material handling requirements;
e.g., while both a pallet jack and pallet truck are technically feasible for long-distance moves, the pallet truck, while costing more initially, would be more cost effective because it can travel faster due the operator’s ability to ride on the truck

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⁴ Fig. 2-3 in Kulwiec, R.A., 1981, *Basics of Material Handling*, Material Handling Institute.

⁵ Fig. 7-6 in Kulwiec, R.A., 1983, *Advanced Material Handling*, Material Handling Institute.

⁶ Adapted from Table 1 of Chu, H.K., Egbelu, P.J., and Wu, C.T., 1995, "ADVISOR: A computer-aided material handling equipment selection system," *Int. J. Prod. Res.*, 33(12):3311–3329.

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¹⁰ Fig. 17.2 in Hanna, S.R., and Konz, S., 2004, *Facility Design and Engineering*, 3rd Ed., Scottsdale, AZ: Holcomb Hathaway.

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¹² Feare, T., 1993, "Work positioners—making them work for You," *Modern Materials Handling*, Sept., pp. 44–45.

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¹⁵ Caterpillar, 1993, Document No. CECB0162 1/93.

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