An Introduction to Material Handling Equipment Selection[1]

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Introduction

This document provides an overview of different material handling equipment. It is intended to familiarize readers with the various material handling technologies and provide some general guidelines for selecting a particular technology for a particular application. Thus, its role is primarily informational or educational and not as a mechanism for detailed design of a specific system for a particular application.

General Considerations

When deciding what material handling equipment to use, it is important to take into account the general characteristics of the equipment types available in the market. Then, the decision maker should determine which equipment matches better to the required application. In this sense, Dunning [84] provided the following general guide for some big equipment categories that can be helpful in this decision process.

	Conveyors	***Cranes and hoists***	***Industrial trucks***
General application	Moving uniform loads continuously from point over fixed paths where primary function is transporting.	Moving varying loads intermittently to any point within a fixed area.	Moving mixed or uniform loads intermittently over various path with suitable surfaces where primary function is maneuvering.
Material Volume	High	Low, medium	Low, medium, relatively high
Type	Individual item, unit load, bulk	Individual item, unit load, variety	Individual item, unit load, variety
Shape	regular, uniform, irregular	Irregular	regular, uniform
Size	Uniform	Mixed, variable	Mixed, or uniform
Weight	Low, medium, heavy, uniform	Heavy	Medium, heavy
Move Distance	Any, relatively unlimited	Moderate, within area	Moderate, 250- 300 ft
Rate, speed	Uniform, variable	Variable, irregular	Variable
Frequency	Continuous	Intermittent, irregular	Intermittent
Origin, Destination	Fixed	May vary	May vary
Area covered	Point to point	Confined to area within rails	Variable
Sequence	Fixed	May vary	May vary
Path	Mechanical, fixed point to fixed point	May vary	May vary
Route	Fixed, area to area	Variable, no path	Variable, over defined path
Location	Indoors, outdoors	Indoors, outdoors	Indoors, outdoors
Cross Traffic	Problems in by-passing	Can be by-pass, no affect	Can be by-pass, maneuver, no affect
Primary function	Transport, process /store in move	Lift & carry, position	Stack, maneuver, carry, load, unload
% Transport in	Should be high	Should be low	Should be low

	Conveyors	Cranes and hoists	Industrial trucks
operation			
Method Load support	None, or in containers	Suspension, pallet, skid, none	From beneath; pallet, skid, container
Load/unload characteristics	Automatic, manual, designated points	Manual, self, any point	Self, any point on available package
Operator accompany load	No	May not, usually does	Usually does, may be remote
Building characteristics Cost of floor space	Low, medium	High	Medium, high
Clear height	If enough, conveyor can go overhead	High	Low, medium, high
Floor load capacity	Depends on the type of conveyor and material	Depends on activity	Medium, high
Running surfaces	Not applicable	Not applicable	Must be suitable
Aisles	Not applicable	Not applicable	Must be sufficient
Congested areas	Fair	Good	Poor

Static Storage Systems

Static storage systems include storage racks, block stacking systems, mezzanines and shelf and drawer storage. The common feature of static storage systems is that loads remain stationary or "static" in their storage locations until removed from the system. Static storage systems are more likely to be associated with low turnover inventories where manual storage and retrieval is a cost effective mode of operation. In this section, only selection guidelines for storage racks, mezzanines, shelf and drawer storage are discussed since block stacking does not require mechanical structures. Block stacking generally deals with lane storage of pallets or other unit loads stacked directly on top of each other in high volume, low turnover applications. Generally, block stacking provides a low cost, high density storage alternative when loads are stackable and not susceptible to crushing. In some cases, pallet stacking frames can be used for block stacking of unstable or fragile loads. Pallet stacking frames are discussed in more detail in a later section.

Industrial Steel Storage Racks

Several characteristics influence the type of unit load storage rack appropriate in a given application. These include unit load specifications, selectivity requirements, throughput requirements, the material handling equipment used, and the building configuration. Unit load specifications refer to the load dimensions, the weight, and the type, condition and volume of pallets stored. Selectivity requirements refer to the number of stock picking locations that must be immediately available. This factor directly influences the depth of storage lanes as well as the picking speed. Throughput requirements refer to the number of storage positions maintained, the time frame of load movement through the system, inventory control policies and load dispatching rules. Material handling equipment directly influences the type of rack selected since factors such as turning radius, aisle width, lifting capacities, and reach capabilities determine the ability of handling equipment to interface with a given rack system. Building configuration refers to ceiling height, floor condition, structural features and other facility characteristics that influence the selection of a rack system. Pallet rack design alternatives include standard selective pallet rack, double deep rack, bridge across rack, drive in and drive through racks, gravity flow racks, push back racks, and cantilever racks. Standard selective pallet rack is the most common alternative which allows 100% selectivity for high picking efficiency. Double deep racks are similar to standard selective pallet racks but add a second row of storage to increase storage density with somewhat reduced selectivity. With bridge across racks, lower beams are removed to create an aisle. Material is then stored over the passageway. Drive in racks allow vehicles to enter the storage area for pallet replacement in a back to front approach while drive through racks provide two access aisles within this configuration. Gravity flow racks use one aisle for pallet deposit and a second for retrieval with racks inclined and loads placed on skate wheels or roller conveyors which move loads by gravity to forward (picking) positions. Push back racks refer to another type of gravity system that uses a single aisle. Cantilever racks are designed for storing long, bulky awkward items such as piping, lumber or paper rolls. The first table in this section summarizes application guidelines for the major types of rack systems as well as block stacking and pallet stacking frames.

	Block storage	Tier Rack & stacking frames	Standard Pallet (selective)	Double Deep
Installed cost/unit load	--	--	150	150
Footprint			Large	Medium
Storage density	High	High	Low	Medium
Throughput	High	Medium	High	Medium
Effectiveness of space use	Very good	Very good	Fair	Good
Load accessibility	Poor	Poor	Excellent	Fair
Rotation of loads	LIFO	LIFO	FIFO	LIFO
Number of aisles	Few	Few	Many	Medium
Unit loads deep/opening	8-10	8-10	1	2
Maximum unit loads deep/opening			1	2
Stacking height, ft	20-25	20-25	20-40	20-40
Maximum stacking height, ft			40	40
Equipment	W,N	W,N	W,N,VNA	N
Selectivity, %			100	50
Utilization factor , %	60	60	85	80
Probability of damage	High	Low	Low	Low
Sprinker requirement	Ceiling	Ceiling	Ceiling, in rack	Ceiling, in rack
Security	Poor	Poor	Good	Good
SKU opening/aisle	1	1	2	2
Number of unit loads/sku	High	High	Variable	2 or more
Pick positions	1 high	1-2 high	1-2 high	1-2 high
Type of pallets	All	captive	All	All

W= wide aisle, N= narrow aisle, VNA= very narrow aisle.

	Bridge across	Drive in	Drive trough	Movable
Installed cost/unit load	50	200	225	300
Footprint	None	Small	Small	Small
Storage density	Varies	High	High	High
Throughput	Medium	Medium	Medium	Low
Effectiveness of space use	Good	Very good	Very good	Excellent
Load accesibility	Excellent	Poor	Poor	Good
Rotation of loads	FIFO	FIFO	Either	FIFO

Number of aisles	None	Few	Few	Few
Unit loads deep/opening	1	8-10	8-10	1
Maximum unit loads deep/opening	1	15	10	1
Stacking height, ft	20-25	20-30	20-30	20-30
Maximum stacking height, ft	25	30	30	30
Equipment	W,N	W,N	W,N	W,N
Selectivity, %	50 or 100	20	30	100
Utilization factor , %	85	66	66	66
Probability of damage	Low	Medium	Medium	Low
Sprinker requirement	Ceiling	Ceiling, in rack	Ceiling, in rack	Ceiling
Security	Good	Good	Good	Good
SKU opening/aisle	2	1/vertical	1/vertical	2
Number of unit loads/sku	2/opening	High	High	Varies
Pick positions	Not feasible	1 high	1 high	1-2 high
Type of pallets	All	Varies	Varies	Varies

W= wide aisle, N= narrow aisle, VNA= very narrow aisle.

	Gravity flow	Push back	Car-in-Lane	Cantilever
Installed cost/unit load	250	225	300	200
Footprint	Small	Medium		Large
Storage density	High	Medium	High	Low
Throughput	High	Medium	Low	Medium
Effectiveness of space use	Excellent	Good	Excellent	Fair
Load accessibility	Fair	Fair	Poor	Excellent
Rotation of loads	FIFO	LIFO	FIFO(1aisle) LIFO(2 aisles)	FIFO
Number of aisles	Few	Few	Few	Many
Unit loads deep/opening	3-20	3	10-20	1
Maximum unit loads deep/opening	15	5		1
Stacking height, ft	20-30	20-30	40-80	20-40
Maximum stacking height, ft	30	30		20
Equipment	W,N	W,N	VNA	VNA
Selectivity, %	20	40		100
Utilization factor , %	90	66	66	85
Probability of damage	Low	Medium	Low	Low
Sprinker requirement	Ceiling, in rack	Ceiling, in rack	Ceiling, in rack	Ceiling, in rack
Security	Good	Good	Excellent	Good
SKU opening/aisle	1/lane	1/lane	1/lane opening	1-3
Number of unit loads/sku	High	2 or more	High	Varies
Pick positions	1 high	1 high	Not feasible	1-2 high
Type of pallets	Captive	Captive	Captive	None

W= wide aisle, N= narrow aisle, VNA= very narrow aisle.

Shelving and Drawer Storage

The major factors driving the design of a shelving and drawer storage system include the types of products stored, the type of storage equipment used, the material handling system involved, the characteristics of the facility and the applicable government regulations and building codes. The design process involves analysis of the dimensions and weight of stored items and the determination of how each item is to be stocked, e.g., individual items, packages, cartons, pallets, rolls, drums, etc. Inventory levels, the form of material issues, transactions throughput, and the number of stock keeping units must then be determined. This is followed by creation of a drawing of the front elevation of the storage units and notation of the specific items to be stored in each. Typically, this involves the development of several alternative storage layouts. Consideration of seismic requirements and government regulations may also influence the design of a shelf and drawer storage unit. These considerations may impose the need for such features as side and rack sway braces, heavier gauge steel members, handrails, floor anchor clips, etc. Some general guidelines for selection of shelving and drawer storage are presented in the second table of this section.

	Description	Approximate cost
Shelving	They are organized of storage parts and packages. Steel sections commonly used with adjustable shelves. Hand loaded. Accessories include shelf boxes, doors, inserts, dividers.	\$50-\$150 for standard 3 x 1.5 x 7 ft section. Variables include number of shelves, load capacity, open or closed configuration. Accessories are additional.
Modular drawers Cabinets	Organized, disciplined, high density storage of parts and tools. Modular drawers of varying heights fit into stackable cabinets. High-rise configurations can be provided.	\$800-\$1,000 per cabinet, or about \$150-\$200 per sq. ft. of storage.
Modular drawers Shelving	Combines high-density parts storage with conventional shelving storage.	\$100-\$150 per drawer, depending on divider arrangement.

Mezzanines

Mezzanines involve the construction of an extra floor and storage space between the ground floor and ceiling of a facility. They can be constructed in a large variety of ways to create additional floor space at relatively low cost. Typical reasons for construction of mezzanines include increasing storage space or production areas, centralization or consolidation of operations, creation of convenient but isolated office and/or restricted access space, separating storage and manufacturing functions, clearances for better ground level traffic flow, better cubic space utilization, and reduction of energy and maintenance costs. Although mezzanines are not appropriate when other floor space is available, when long spans are required to clear ground floor equipment, when less than fourteen feet of headroom is available, or when floor loading capacity is inadequate, they can often provide floor space in the location where it is needed the most. The two major types of mezzanines include free standing and full mat (floor over) mezzanines. Free standing mezzanines are pre-engineered and can be custom designed or pre-specified. They can be ordered in modular sizes and a variety of capacities to fit specific applications. Full mat (floor over) mezzanines use the shelving or racks that are already installed at floor level. They can be built between free standing racks or with shelving over them permitting rearrangement of second or third levels. There are numerous codes and regulations applicable to mezzanines that vary from state to state and community to community with large, older cities having the most red tape. The third table in this section summarizes some important features about the two major types of mezzanines in use today.

Free-standing mezzanine	Full mat (or floor over) mezzanine
Custom design or Pre-engineered. Standard spans are of 16 ft between columns. But, custom span can go up to 30 ft.	Can use the shelving or racks that the user already had at floor level.

In-Plant Industrial Trucks

In this section, in-plant industrial trucks and dock equipment are discussed. This category includes electric rider trucks, electric narrow aisle trucks, electric hand pallet trucks, cushion tire internal combustion trucks, and pneumatic tire internal combustion trucks. These trucks are used for moving either mixed or uniform loads intermittently over various paths. While these paths can be somewhat random at the discretion of the driver, the paths are restricted to suitable indoor or outdoor surfaces. Industrial trucks provide not only a means of transporting materials, but also provide a means of accurate lifting and stacking. Appropriate tooling for the truck permits users to lift not only pallets, but a wide array of specialized loads. For example, rolls of carpet are easily moved via industrial truck by replacing standard forks with a single tube. The dock equipment discussed in this section includes dock levelers and truck restraining devices. Both of these equipment types support the use of industrial trucks for loading/unloading.

Powered Trucks

Industrial electric motor trucks can be found in almost any manufacturing plant, loading dock, or warehouse. Although they are made by a variety of manufacturers for diverse purposes, including some highly specialized applications, they can be classified into five general groups using Industrial Truck Association guidelines: electric rider trucks, electric narrow aisle trucks, electric hand pallet trucks, cushion tire internal combustion trucks, and pneumatic tire internal combustion trucks. Electric rider trucks are general purpose trucks and are used primarily indoors. These trucks can lift up to 6 tons and up to 18 feet in height. Electric narrow aisle trucks are used in narrow aisle applications. These trucks are used primarily for storage/retrieval in applications similar to AS/RS functions. They can easily lift loads from 2,000 to 4,500 pounds to heights of 40 feet. Narrow aisle trucks can be further subdivided into standard trucks, high lift straddle trucks, side loaders, swing mast trucks, and convertible turret/stock pickers. The names of these devices are indicative of their function. Electric hand pallet trucks are generally used for indoor applications and can handle loads up to 4 tons. These trucks are perfect for situations in which material is to be moved from one location to another without the need for lifting more than a few inches. For example, this type of truck is commonly used in grocery stores to move pallet loads of cans or boxes to a display location within the store. An added convenience is that the operator can move among customers in the store safely and without obstructed views. Internal combustion trucks add the advantage of outdoor use. They can lift 2,000 to 15,000 pounds with some specialty trucks lifting up to 50 tons. They can lift up to 20 feet in height and can operate on gasoline, LP-gas, or diesel fuel.

Non-Powered Trucks

In this section, non-powered hand trucks and non-powered pallet trucks are discussed. These trucks provide low cost material handling alternatives for some applications. They are best suited for moving lightweight loads over relatively short distances.

Non-powered hand trucks

Non-powered hand trucks are used in many situations. They are inexpensively manufactured for diverse and specific applications. Common construction materials include aluminum/magnesium, steel, and wood. Because these trucks are so inexpensive, it makes sense to design them for specific material handling functions. In this way, it is possible to increase the cube utilization within the truck for material handling optimization. Aluminum or magnesium trucks generally carry 300-500 pounds of material, while steel or wooden trucks can be used to carry approximately 1000 pounds to 2000 pounds, respectively. The trucks range in weight from as little as 20 pounds for aluminum trucks to as much as 125 pounds for wooden trucks.

Non-powered hand pallet trucks

These trucks are designed to carry unit loads on pallets from one location to another, generally in indoor settings. Because unit loads can be quite heavy, the distances transported using this type of equipment is generally short. In many settings, hand pallet trucks are used to supplement motorized truck fleets. They are extremely efficient for transporting unit loads short distances when high lifting is not required. They can be used to position materials very precisely. Generally speaking, non-powered hand trucks cannot be used to lift more than 8,000-10,000 pounds and cannot lift a unit load to a height more than 8 inches. For heavy duty applications, steel wheels are required while lighter duty applications require only nylon or polyurethane construction. These trucks can range in weight from 200 to 400 pounds.

Dock Equipment

In this section, dock leveling equipment and truck restraining devices are discussed. Both are necessary components to ensure safe and efficient use of industrial trucks.

Dock Levelers

In this section, devices that equalize the height of the rear of a trailer to the dock’s height are discussed. Powered applications make use of electric or LP-gas motors and can have a load capacity from 2,000 to 30,000 pounds. Non-powered dock levelers can be used when the difference between dock and trailer height is less severe. If the difference between the dock and the trailer is less than approximately four inches, non-powered dock levelers can be used with a wide variety of industrial truck types, including hand pallet jacks. Even so, the length of the leveler would likely need to be approximately 12 feet in length to produce an acceptable grade for hand trucks. Using gas or electric lift trucks, a leveler of less than 3 feet would be acceptable. Electric pallet jacks are feasible for height differentials up to 10 inches, electric lift trucks are feasible for height differentials up to 12 inches, and gas lift trucks are feasible for differentials up to 18 inches, provided that the leveler is of sufficient length, say 12 feet.

Height differentials are not the only factors to be considered when selecting a leveler. Other less obvious considerations include truck tailgate differences, the degree of loading/unloading activity, the speed of operation required, and various personnel factors. Also of interest are environmental factors such as heat & cold retention and the corrosiveness of the applications. Certainly, designers should also decide about the level of desirable investment given the status of the building in terms of leasing versus owning the property.

Dock levelers are further subdivided into four types in order of decreasing loading rating: released, vertical, edge-of-dock, and front-of-dock. Released levelers can handle up to 40 tons while front-of-dock levelers generally handle 15,000-20,000 pounds. Front-of-dock levelers are generally hard to remove and are therefore not recommended for buildings with a short duration lease.

Truck Restraining Devices

Truck restraining devices include wheel chocks, trailer constraints, and automatic chock devices. Their function is to prevent the trailer from moving during loading or unloading, or to prevent the truck from leaving the dock until authorized to do so from a safety viewpoint. Wheel chocks are very inexpensive and very effective and they are OSHA approved safety devices. They are used in applications from warehousing to airports. In fact, wheel chocking is one of the first activities performed when an airplane arrives at a terminal building. Even for huge aircraft, chocking is a cost effective way to achieve passenger safety. Chocks are generally made of laminated or molded rubber or wood and are wedged under tires. Although cost effective, chocks can have some disadvantages. For example, they are easily forgotten or lost, they require labor for correct placement, they reduce productivity of dock attendants by adding an extra step to vehicle arrivals and departures, and they can be ineffective in bad weather or on some surfaces.

Trailer restraints are permanent fixtures holding the trailer at the dock using the ICC (Interstate Commerce Commission) bar. Designs range from manual and low cost to automatic and high cost. Automatic chock devices perform the same function as trailer restraints, but do not rely on the trailer's ICC bar to secure the trailer to the dock. These devices are stored in the driveway and raise to hold the wheels in place. Both are extremely effective in terms of ensuring that the vehicle remains in place until unsecured. Factors to consider when selecting any restraining device include the following. They should have clearly visible hooking devices. They should provide constant engagement. They should support clear communications and should be durable. Components should be designed for their environment in terms of rust and corrosion and should be sealed against dirt. Furthermore, they should be easy to maintain and should allow for integration opportunities with other systems such as alarm systems or production/shipment supervisory programs.

Fixed Path Conveying

Fixed path conveyances are advantageous for periodic and continuous transport of material between locations in warehouses and factories. They are also used to accumulate goods, store packages, change elevations, and provide a continuous work surface on which progressive assembly or processing can be performed [25]. Consider the factors below when developing conveying systems:

Conveying Systems Planning Criteria
1. Product size and weight (or container characteristics if used)
2. Distance
3. Control requirements
4. Flow rates
5. Obstructions and facility limitations
6. Human factors, including noise
7. Environment

Gravity Conveyors

These conveyors are the simplest and usually least expensive. They are useful where material is moved for short distances and movement requirements are simple. Three common types are chutes, skate wheels, and rollers. They are often used in conjunction with powered systems. Pros and cons are listed below [27].

Gravity Conveyors	
Advantages	***Disadvantages***
1. Excellent for elevation drops 2. Low initial and operating cost 3. Quieter operation than powered conveyors 4. Low maintenance 5. Low profile 6. Easier to manually move products 7. Unlimited configurations allow use for wide range of product weight	1. Less control of products on long runs, including failure to move once stopped. 2. Impractical for fragile products that are damaged by bumping or crashing. 3. Singulation and non-contact difficult. 4. Tend to increase the work in progress. 5. High pitch requirements 6. May require manual assistance

The literature yielded the following selection criteria[2] for roller conveyors [34]

Selection Criteria for Non-powered Roller Conveyors
More costly than skate wheel conveyors.
Load capacities ranges from 1 to 1600 lb/ft

[2] Selection criteria were not found for: chute, skate wheel, and ball or wheel transfer tables.

Selection Criteria for Non-powered Roller Conveyors
Roller width ranges from 12 to 50 in.
Section length varies from 5 to 10 ft.

Horizontal Powered Conveyors

These are used to move material over moderate to long distances.

Live Roller

This type of conveyor is used for a variety of applications, loads, and environments [34]; but they are typically used for 30-50 lb.ft loads in warehouses. They can provide brief periods of product accumulation or dwell points [27]. Live rollers can handle up to 10,000 lbs and can carry irregular shaped containers. Live rollers are classified by their drive method, listed below. Some disadvantages are:

1. Higher cost due to construction materials.
2. Product slippage on rollers requires frequent tracking updates and diverter timing.
3. Products cannot negotiate inclines over 7 degrees without manual assistance.
4. Power surges when accumulating on driving rollers; disrupting product spacing.

Below are selection guidelines from the literature for powered roller conveyors [34]:

	Powered Roller Conveyor Type				
Criteria	***Flat Belt***	***V-Belt***	***Cable***	***Line Shaft***	***Chain***
Load Capacity (lb/ft)	up to 2000	up to 100	10 to 60	10 to 50	up to 10,000
Roller Widths (in.)	10 to 39	18-36	18 to 36	13 to 51	27 to 64
Typical Speed (fpm)	65 (200 lb/ft)	up to 150	45 to 150	30 to 250	10 to 40 (100-2000 lb/ft)
Duty type	All type	Light-Med	Light-Med	Light-Med	Heavy

Live Roller Accumulation Conveyors[3]

These conveyors are used to regulate the flow of products into downstream operations by providing a temporary buffer for excess products. Selection criteria depends on specific applications. Proper product alignment is required when using accumulation conveyors. Various releases are available, depending on conveyor speed. Three types of powered accumulation conveyors are [29]:

1. Zero-pressure. The line pressure (horizontal pressure between products) is eliminated.
2. Non-contact. Products are always separated from each other.
3. Minimum pressure. Some line pressure is allowed (2 to 3% of total net load).

Slider Bed/Roller Bed Conveyors[4]

The slider bed consists of a moving belt operated across a steel support bed. The roller bed is a belt supported by rollers. The slider bed is the least expensive powered conveyor, but handles less loading than the roller bed. Roller beds require more power than live rollers. Belt conveyors offer stable support, are used for heavy loads, and can be operated at high speeds. The belt conveyors maintain product spacing to allow excellent material tracking. These conveyors are also used for inclines and declines of up to 30 degrees (and can be combined in a single conveyor). Belt conveyors are not used to accumulate

[3] General selection criteria were not found for accumulation conveyors.

[4] Selection criteria were not found for slider bed or belt on roller conveyors.

products, but they can start and stop and they can be used to meter products at the exit of an accumulator conveyor.

Roller Curves and Belt Turn Conveyors[5]

Curves and turns are used to change the direction of material flow. Roller curves are less expensive than belt curves and they are the most common. They can be self powered or slave driven. Belt curves are used to maintain product orientation and spacing. The flat surface also allows handling of smaller, irregular sized products.

Sortation Conveyors

Sortation conveyors are used to identify packages, present packages to sortation equipment, or sort packages to multiple locations [132].

Below are selection guidelines from the literature for sortation conveyors [132,133]:

Type of Sortation Equipment	***Maximum Sorts per Minute***	***Typical Load Range***	***Minimum Distance Between Spurs***	***Impact on Load***	***Relative Initial Cost***	***Typical Repair Cost***	***Package Orientation Maintained***
Manual	15-25	1-75	Pkg. Width + 3 in	Gentle	Lowest	Lowest	Yes
Deflector	20-40*	1-50	3-5 ft	Medium to Rough	Low	Low	No
Pusher/Puller	30-70	1-150	Pkg. Width + 6 in	Medium	Low to Medium	Low to Medium	No
Wheel Transfer	5-10	10-150	1 ft	Gentle to Medium	Low to Medium	Low	No
Roller Transfer	15-20	10-300	1 ft	Gentle to Medium	Medium	Low to Medium	No
V-Belt Transfer (Belt & Chain Transfer)	15-20	1-200	2-3 ft	Gentle to Medium	Medium to High	Medium to High	No
Roller Diverter	50-120	10-500	4-5 ft	Gentle	Medium to High	Medium	Yes
Wheel Diverter	65-150	3-300	4-5 ft	Gentle	Medium	Medium	Yes
V-Belt Diverter	65-120	1-250	4-5 ft	Gentle	Medium to High	Medium to High	Yes
Tilt-Tray Sorter	65-200	1-250	1 ft	Medium to Rough	High	Medium to High	No
Tilt-Slat Sorter	65-200	1-300	12 ft	Gentle to Medium	High	High	Yes
Slat Diverter	50-150	1-200	4-5 ft	Gentle	High	Medium to High	Yes
Diverter	20-70	1-150	Carton length + 6 in	Medium	Low to Medium	Low to Medium	No
Pop-up Belt & Chain	30-120	1-250	1 ft	Medium to Rough	High	Medium to High	No

[5] Selection criteria were not found for curves or turns.

Type of Sortation Equipment	*Maximum Sorts per Minute*	*Typical Load Range*	*Minimum Distance Between Spurs*	*Impact on Load*	*Relative Initial Cost*	*Typical Repair Cost*	*Package Orientation Maintained*
Pop-up Roller	50-150	10-500	4-5 ft	Gentle	Medium to High	Medium	Yes
Pop-up Wheel	60-150	3-300	4-5 ft	Gentle	Medium	Medium	Yes
Sliding-Shoe Slat Sorter	50-200	1-200	4-5 ft	Gentle	High	Medium to High	Yes

* more recently 20-60

Powered Overhead Conveyors

Powered overhead conveyors are used when system flexibility is desired or floor space is congested [24] because material flow paths are easily established and altered and obstructions are minimized, enhancing freedom of movement. Additionally, drives and other equipment are offered some protection from the environment on the floor.

Below are selection guidelines from the literature for powered overhead conveyors [24]:

Criteria	*Powered Overhead Type*[6]			
	Endless Chain with Exposed Trolleys	*Endless Chain with Enclosed Track*	*Powered Monorail with Commercial Rail*	*Powered Monorail with Integral Motorized Trolley*
Maintenance	8	8	5	6
Cost	9	10	5	6
Noise	6	7	9	9
Speed	7	7	10	10
Capacity	7	4	10	7
Easy in Changing Layout	9	10	8	8
Surge Capacity	0	0	8	8
Change of Elevation	9	9	4	4
Follow Alternate Paths	0	0	10	10
Interface with Robots	6	6	10	10
Change Load Centers	0	0	6	6
Minimum Radius Horizontal Turns	9	10	6	8

Vertical Conveyors[7]

Vertical conveyors are used to lift or lower heavy loads between various levels in intermittent-flow operations and where horizontal space is limited. Of the two vertical types, the reciprocating is simpler, but the continuous supports a higher flow rate.

The literature yielded the following guidelines for vertical reciprocating conveyors [25]:

Criteria	*Description*
Speed (fpm)	30 to 60 typical; up to 150 (heavy duty)

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[6] Table scale from 0 to 10

[7] Selection criteria were not found for vertical conveyors.

Criteria	*Description*
Load Capacity (lb.)	200 to 500 typical; up to 10,000 (heavy duty)
Operation (manual or automatic)	Either push-button or automatic
Requires safety interlocks	Either electrical or mechanical
Maximum dimension of load	Is an important decision factor

Variable Path Conveying

This group of material handling devices is used to transport material over a variety of routes through a facility. Typically, a system consists of a number of discrete carriers which are capable of independent movement. Two main types of systems will be considered: automated guided vehicles and monorails. A third type of delivery mechanism, pneumatic tube system, will be described for specialized applications, such as moving bulk solids.

Automatic Guided Vehicles (AGV)

Automatic guided vehicle is a vehicle equipped with automatic guidance equipment that is capable of following prescribed guidepaths, either physical or residing in software, to transport material between various points in a system. Some advantages of these systems include[3]:

1. Most AGVs load and unload automatically.
2. They can transport materials of many different sizes and shapes.
3. They efficiently interface with other equipment, thereby, providing physical integration.
4. They are well suited to operate under computer control, allowing the control system to know the location of all materials at all times.

There are several different ways to classify vehicles. The following two tables show a summary of the different types of vehicles and the different options for the main vehicle characteristics.

AGV Vehicle Type
Tractor/Tow Vehicle
Unit Load Carrier
Fork Lift
Light-Load Carrier

Characteristic	*Common Options*
Guidance Used	Inductive Wire Guidance Optical Guidance Chemical Guidance Dead Reckoning Vision Systems Laser Triangulation Inertial Guidance
Communication System	Inductive Wire Floor Devices RF Transmission Optical Infrared
Battery Type	Lead Acid Nickel Cad Gell Cell PH Acid 24 V DC

	48 V DC
Host Communication Protocol	Real Time TCP/IP RS-232 Serial ACS II Ethernet

Monorails

Monorails are self-powered vehicles riding on an overhead track. These systems provide flexible transport of material without using valuable floor space. They are being used increasingly in the automation of fabrication, finishing, and assembly operations; but usually these systems are used in batch operations[72]. Some advantages associated with this type of equipment are ([72] and [100]):

1. They are capable of higher speeds than other transportation options (up to 500 fpm on straight runs). Therefore, they can be used to make deliveries on demand.
2. High speed and low cost tracks compared to overhead conveyors.
3. Queuing capability.
4. Could have bi-directional carriers.
5. Easy interfacing with other equipment.
6. They provide quiet running and clean carriers that are individually powered and controlled.
7. They also provide greater flexibility for expansion and layout changes.

Pneumatic Tube Systems

They provide a versatile approach to moving bulk solids [32]. If necessary, they can cover great distances, both vertically and horizontally.

Dynamic Storage Systems

High-Density Dynamic Storage Systems

These systems provide high-density storage for a variety of product types. They are often referred to as flow delivery systems or flow racks because of the way products are stored and retrieved from the systems. These systems can be broadly classified into three different types.

1. High-rise, served by a guide truck

   Stacking heights to 40 feet. Narrow aisle, high-lift, or turret truck can be used under rail or wire guidance. Somewhat tighter tolerances that on conventional selective pallet racks.
2. Storage/retrieval (S/R) machine

   High degree of inventory control in large-volume, high-throughput applications. Operations frequently automated under computer control. Exacting tolerances on racks and floors. Storage heights can reach 75 feet or more.
3. High density

   Loads confined to specific lanes under automated control. Traveling carrier or retrieval mechanism removes loads on first-in, first-out basis. High-rise configurations can be used.

Horizontal and Vertical Carousels

Horizontal and vertical carousels are usually incorporated into automated material handling operations [76]. These systems have movable racks or shelves that hold parts. The entire set of racks/shelves is rotated to bring the needed item to a pick position for retrieval (or a empty slot to the pick position for storage). Picking and placing is done manually or automatically. The manual weight limit is 35 to 40 lb. Typically, automatic extraction weight limit ranges from light loads to about 100 lb. The storage systems can be used for many applications, including maintenance parts, tooling, dies, WIP, buffer storage, warehousing, and distribution.

The advantages associated in the use of carousels are [76]:
1. They are low cost, stand-alone, and modular storage systems.
2. Both versions are available in a wide assortment of heights, lengths, and capacities.
3. Automated or manual extraction methods are available for adding or removing stored products.

Automated Storage and Retrieval System (AS/RS)

AS/RS are commonly applied in two types of operations [76]: warehousing or distribution and plant automation. These systems are typically high-rise systems capable of storing pallets, totes, drums, or other similar types of unit loads. The systems may be single aisle or large, multi-aisle systems. The storage/retrieval machine is automated and capable of moving at high speeds within the captive aisle. Occasionally, multiple aisles will be equipped with a transfer mechanism so that one S/R machine can serve multiple aisles. These systems provide good inventory control as well as protection from damage and pilferege. These systems are typically used in conjunction with other automated material handling devices, such as automated guided vehicles. Some of the system advantages typically cited for AS/R systems are:
1. The equipment enables reduced inventory levels through tightened control measures [76].
2. Space requirements are reduced with high-rise, high-density storage techniques [76].
3. Their ability to operate almost unattended [10]. If the load or products can be identified automatically by their size or shape or by a code that can be read automatically, then the storage system can operate unattended.
4. Capability to interface automatically with a number of different types of conveyors and other transportation equipment [10].

Lifting, Leveling, and Work Positioning Systems

In this section, lifting, leveling and work positioning systems are discussed. This category of equipment includes stationary systems, overhead mobile cranes, gantry cranes, stacker cranes, hoists, and balancers. The focus of this section will be primarily on cranes and hoists because they are the most widely used equipment for lifting, leveling, and work positioning. Stationary systems include fixed devices such as the jib crane which is a fixed crane with a cantilevered bridge supported from a stationary vertical support. Overhead mobile cranes are traveling cranes with a movable bridge running on the top surface of rails of an overhead fixed runway structure. They carry a movable or fixed hoisting mechanism. Gantry cranes are traveling cranes similar to the overhead mobile crane, except that the bridge carrying the hoisting mechanism is rigidly supported on two or more legs running on fixed rails or other runways. A stacker crane is a crane adapted to piling or stacking bulk materials. It could include a fixed or pivotally mounted boom. A hoist can be defined broadly as any mechanism for lifting or lowering loads.

Cranes

In this section, five different types of cranes are discussed: single girder bridge cranes, double girder bridge cranes, single girder gantry cranes, jib cranes, and overhead stacker cranes. The discussion includes characteristics of these crane types in terms of maximum span, maximum lifting capacity, maximum height, maximum bridge, trolley and hoist speeds, and the type of use for which they are suitable.

Single girder bridge cranes generally have a maximum span between 20 and 50 feet with a maximum lift of 15-50 feet. They can handle 1-15 tons with bridge speeds approaching a maximum of 200 feet per minute (fpm), trolley speeds of approximately 100 fpm, and hoist speeds ranging from 10-60 fpm. They are candidates for light to moderate service and are cost effective for use as a standby (infrequently used) crane.

Double girder bridge cranes increase the permissible span by a factor of two to 100 feet. The lift height is approximately the same as for the single girder bridge crane. Double girder cranes are faster, with maximum bridge speeds, trolley speeds and hoist speeds approaching 350 fpm, 150 fpm, and 60 fpm, respectively. They are the fastest of the five crane types considered herein. They are useful cranes for a variety of usage levels ranging from infrequent, intermittent use to continuous severe service. They can lift up to 100 tons.

Gantry (single girder) cranes represent a usage compromise between single girder and double girder bridge cranes with uses that range from light service to heavy service. Their maximum span range is from 30-80 feet. The maximum lift height is approximately 40 feet with up to 100 tons in lifting capacity. Bridge, trolley, and hoist speeds are as much as 250 fpm, 150 fpm, and 60 fpm, respectively.

Jib cranes are not strong candidates for heavy or severe use. They are best suited for light to moderate service. Their maximum span is only 20 feet or so with a lifting height of about 25 feet and a capacity reaching to 10 tons. The jib crane is not bridge mounted, but trolley and hoist speeds approach 90 fpm and 30 fpm, respectively.

Finally, the overhead stacker crane is a candidate for light through heavy service, like the gantry crane. This type of crane offers bridge speeds of 150-300 feet, trolley speeds of 75-150 feet, and hoist speeds of 15-30 feet. The maximum load capacity is 5-30 tons for most commercially available systems and the maximum lift height is generally 20-40 feet. The maximum span is comparable to that of the double girder bridge crane, reaching 30-100 feet.

In terms of cost, jib and single girder bridge cranes are most economical but are not suitable for heavy or severe operations. Double girder bridge and single girder gantry cranes are in the mid-price range with increased usage capability (the double girder bridge crane offers the greatest usage flexibility). Finally, the overhead stacker crane is generally the most expensive of the five options discussed herein.

Electric Hoists

Industrial hoists are widely used for lifting. They are generally inexpensive and reliable. They increase the safety associated with lifting and enable the movement of much larger unit loads than would be possible with many other economical lifting options. An electric hoist can be defined as a suspended machinery unit using wire rope or chain for vertical lifting or lowering of freely suspended unguided loads. Because the primary reason cited for hoist failure is the failure to consider the duty environment of the hoist, it is useful to consider duty factors in the hoist selection process.

Let us consider five duty cycle classes that include infrequent or standby use, light use, standard use, heavy use, and severe use. Infrequent or standby use can be defined as a system that is busy 12-25% of the time with 75-100 starts per hour. Light use can be defined similarly but with different usage types. For example, power houses and utilities with infrequent handling could be considered infrequent, while light machine shops and fabricating industries could be considered light usage. Standard usage could be defined as a hoist that is busy 25-50% of the time with 150-200 starts per hour. General machine shops, fabrication shops, assembly, storage and warehousing all could make use of standard hoists. Heavy usage hoists are likely busy approximately 50% of the time with up to 300 starts per hour. High volume handling in steel warehousing is an example as are some machine shops, fabricating plants, mills and foundries. Finally, a hoist can be considered severe in its use if it is used close to 100% of the time with up to 600 starts per hour. This type of hoist could be useful in bulk handling of material in combination with buckets, magnets, or other heavy attachments.

Unitizing Systems

Unitizing systems refer to systems for the creation of the unit handling load. Usually, unitizing systems must be carefully considered in the shipping, receiving, in-process handling, and storage activities associated with manufacturing and/or distributions systems. The type of unitizing system that is appropriate for a given application depends on the form of the unit load, e.g., pallets, containers, etc., as well as the physical characteristics of the material being handled. Palletizers are systems for consolidating unit loads onto pallets. These systems are often used in conjunction with systems for stabilizing palletized unit loads such as stretch wrappers, strappers or shrink wrapping systems. In this section, issues directly related to unitizing systems are discussed with results presented from recent literature which provide guidelines for the application of various elements of unitizing systems including pallets, industrial metal and plastic containers, palletizers and load stabilizing systems.

Pallets

Pallets are probably the most common platform for moving unit loads. Perhaps the most obvious area of concern associated with the use of pallets today involves cost and quality tradeoffs. Poor quality pallets annually cost industry billions of dollars in the form of product damage, lost productivity, and damaged handling. A key decision affecting the overall life cycle cost of pallets is the materials used in their manufacture which can include wood, pressed wood fiber, corrugated fiberboard, plastic or metal. More wooden pallets are sold each year than any other type due to the versatility, low cost, biodegradability and recyclability of this material. Pressed wood fiber is a combination of wood fibers and organic resins which eliminates the need for nails and enables the molding of pallets into more space efficient designs. Disposable, corrugated fiberboard pallets can be made of recycled paper materials and provide a light weight, low cost alternative for one way shipping when loads do not need to be stored outdoors. Durable plastic and metal pallets may provide the low cost alternative over the full pallet life cycle despite their high initial cost. Both of these materials are recyclable, can be sanitized for clean applications, and can be used in the most demanding applications. The table in this section summarizes some of the tradeoffs associated with different materials used for the manufacture of pallets and the typical applications associated with each.

Material	*Durability*	*Repairable*	*Environmental Impact*	*Typical Application*
Wood	Medium	Yes	Material is biodegradable and recyclable	Grocery Automotive Durable goods Hardware
Pressed Wood Fiber	Medium	Yes	Material is recyclable and can be burned without leaving fuel residues.	Printing Metal stampings Plumbing fixtures Building materials
Corrugated fiberboard	Low	No	Material is biodegradable and recyclable	One-way shipping applications in: Grocery lightweight-paper Paper products Industrial parts
Plastic	High	No	Material is recyclable	Captive or closed loop FDA, USDA applications Automotive
Metal	High	No	Material is recyclable	Captive or closed loop systems FDA, USDA applications Military

Industrial Metal Containers and Plastic Containers

Selecting a container is an integral part of the design and planning of any parts handling and storage system. The key attribute of importance to system designers is the degree of protection afforded from environmental hazards such as rough handling, moisture, temperature variation and other influences. Additional important features include accessibility for manual or automated part retrieval, stackability/nestability, and the difficulty associated with handling the container itself. These factors drive the design of the container with common variations which include pans, hopper front storage bins, modular containers, tote boxes, wire containers, corrugated metal containers, wood boxes and wirebound boxes. Pans provide shallow, open storage space that is ideal for odd shaped, durable parts which can be transferred through simple dumping. Hopper front storage bins are ideal for organizing and storing small to medium sized parts where easy access is important. Modular containers, particularly useful for sorting and organizing small parts, are typically used in conjunction with standard racks or shelving. Tote boxes provide an efficient container alternative when strength for heavier loads and stackability are important. Wire and corrugated metal containers provide stackability and selectivity in unit loads that are usually compatible with standard handling equipment and pallet racks. Collapsible wire containers provide the additional advantage of efficiency in storage and shipping when empty. Application notes and design factors applicable to these types of containers are summarized in the first table in this section. The selection of the material to use in making containers is also an important consideration. Possibilities include plastic, metal, wood, corrugated, fiberboard and various combinations of these materials. The costs and benefits of these various materials for the manufacture of containers are summarized in the second table included in this section.

Type of container	*Design, size, or configuration factors*	*Application notes*	*Approx. cost*
Metal shop pans	Hopper front and rear, usually with carrying angles. Variety of sizes.	For handling heavy small parts. Extended-metal or perforated metal designs available for dipping or draining applications.	10-50
Hopper-front storage bins	4 to 20 in. long; 4 to 10 in. wide. 2 to 10 in. high.	Organizing and storing small to medium-sized items, maintenance parts. Can be mounted on floors, shelves, or racks.	01 - 5.0 (plastic)
Modular containers (Plastic)	In modular sizes to stack with each other and fit standard racks and carts.	Handling small parts, assemblies, and components. Good for organizing into families or groupings.	2-40 (5-15 typical)
Tote boxes	Often fiberglass; static load capabilities to 3,000 lb. Around 25 in. lengths.	Industrial grade box for small casting, stampings, large quantities of small parts with high total weight.	7-14 (typical)
Wire containers: Collapsible	High strength to weight ratio. Hinged gates for product access.	Can contain large, heavy, or irregularly shaped items that are awkward to handle, such as foundry castings. High product visibility. Compact storage. Maximum stack of 3 or 4 high.	To 100
Wire	Equipped with	Heavy duty units for high	140-175

containers: Rigid	corner posts such as 3 x 3 in. angle for rigidity.	stacking, use with order- picking vehicles. Loads to 6,000 lb.	
Corrugated steel containers	Variety of solid and perforated designs with lids, stacking legs, and other special attachments. Basic unit is two-piece box welded to platform base or corrugated bottom.	Heavy-duty handling of castings, forgings, stampings, fasteners, and other items. Can be used with tilting stands or dumping attachments.	Basic 33 x 48 x 24 in., 0.105 in. thick steel container cost about $100. Depending on duty, standard units range from $75 to $300.
Wood boxes	All wood construction; can be equipped with lids, pallet or skid bases.	Commonly used for textiles or soft goods, or when high impact resistance of wood is desirable for parts handling. Readily repaired.	$25-$65 for standard units. A 48 x 30 x 30 in. skid container is $60.
Wirebound boxes	Wooden slats attached to wood, plastic, or metal base, bound with wire.	Handling and shipping of compo-nents, assemblies, and implements. Can be readily built or repaired in the field.	N/A

Material	*Features*						*Notes*
	Weight	*Strength*	*Average service life*	*Relative initial cost*	*Repairable*	*Washable*	
Corrugated paper	Very light	Very weak	Very short	Very low	No	No	For single or limited use.
Fiberboard	Light	Weak to moderate	Short	Low	Yes	No	Will distort; not recommended for exact positioning.
Wood: Wood & fasteners only	Heavy	Weak to moderate	Short	Low	Yes	Yes	Fasteners and type of wood are factors in strength rating.
Wood: wire bound	Medium to Heavy	Moderate	Short to moderate	Low to moderate	Yes	Yes	Provides versatility not available in wood with fasters only.
Steel	Very heavy	Very strong	Long	High	Yes, with difficulty	Yes	Service life is extended by regular maintenance.
Aluminum	Medium	Strong	Long	Very high	Yes, with difficulty	Yes	Compares favorably with plastics in most respects. May corrode in chemical-laden environment.
Wire	Medium to Heavy	Strong	Moderate to long	Moderate	No	Yes	---
Plastic:	Light to	Moderate	Moderate	Low to	No	Yes	May deform with

traditional thermoplastics	medium			moderate			use at high temperatures.
Plastic: engineering thermoplastics	Medium	Strong	Long	High	Yes	Yes	Less distortion than with most thermoplastics. Excellent for precise positioning.
Plastic: fiberglass reinforced	Light	Strong	Long	Moderate		Yes	More durable alternative to thermoplastics.

Palletizers

Palletizing involves the consolidation of individual products into unit loads. It usually takes the form of stacking layers of cartons, cases or bags onto pallets in a predetermined pattern. Factors to consider in selecting a palletizing system include product characteristics, pallet specifications, location information, upstream sources of products being palletized and throughput requirements. Examples of product characteristics include the physical envelope, weight, special features and handling requirements of the product. Examples of pallet specifications include the design of the pallet and the mix of pallet sizes and quality levels included in the application. Location information refers to the available floor space, headroom, and proximity to other operations. There are three major types of palletizers which include vacuum head, row stripping and robotic palletizers. Vacuum head palletizers use pneumatically powered suction cups to grip layers of products and place them on pallets. Row stripping palletizers first form a row of products. After this, a pusher transfers the row to the machine's makeup area in order to fill another row of a layer of products. When the layer is complete, the machine deposits it onto a pallet or another layer. Robotic palletizers can use a cartesian, articulated arm or gantry design. Cartesian palletizers feature a mast and a cross arm which maneuver products through four axis movement. Articulated arm models also offer four axis movement but use an arm with waist, shoulder, elbow and wrist joints instead of a cartesian table. Gantry palletizers mate a robotic arm to a gantry. The table in this section compares the key application attributes of the three major types of palletizers.

	Speed (CPM)	*Capacity*	*Stacking Height (ft)*	*Flexibility*	*Application Comments*
Manual	<10	<40 lb/canton	5.5	High	Requires attention to ergonomics
Manual w/assistance (e.g manipulator)	<10	<400 lb/carton	5.5	High	Makes work easier, not necessary faster.
Automated: Vacuum head	10-25	100 lb/carton	6-7.5	Medium	Usually for loads with flat, rigid tops
Automated: Row stripping (sequential)	20-120	250 lb/carton 800 lb/layer 6,000 lb/load	5.5-10	Medium	Both floor level and high level available
Robotic: cartesian	10-30	200 lb/carton	7-10	High	Provides most flexibility with some speed penalty
Robotic: articulated arm	"	50 lb/carton	6	"	"
Robotic: gantry	"	400 lb/carton	9.5	"	"

Load Stabilizing Systems

Load stabilizing systems are used to prevent hazardous conditions and/or product damage that can occur as a result on unstable unit loads. In most applications, stretching, strapping and shrink wrapping systems are the alternative load stabilizing technologies. Stretch wrap is an economical and versatile alternative that forms a barrier to dirt and moisture as well as keeping loads stable. Stretch wrap can be dispensed either manually from hand held rolls or through high speed automated systems. In both cases, it requires a force to be exerted on the film as it is wrapped around the four sides of a load. With heavy duty transport and outdoor storage, shrink wrap can provide a more effective option for load protection and stabilization. Shrink wrap uses heat to form the film tightly around the load for better five sided load protection. For heavy, tough applications requiring high strength, strapping provides a practical, low cost alternative. The first table in this section provides guidelines for matching these three load stabilizing alternatives with applications.

Application	*Stretch*	*Shrink*	*Strapping*
When protecting heat sensitive loads	X		
When unit loads need to be protected as well as secured	X	X	
When 4 or 5-sided protection is required	X	X	
When outdoor storage occurs	X	X	
When securing light, crushable loads	X	X	
When unit loads have extremely sharp or protruding edges			X
When very high load compression is required			X
When holding loads to the pallet			X
When securing very heavy, bulky or shifting loads			X

Stretching

Stretch wrap is normally used to stabilize loads on pallets or slip sheets by providing a tight wrap of plastic film around four sides of a load. Introduced in the early seventies, the popularity of stretch wrap systems has grown steadily over the past 25 years. The major decision in selection of a stretch wrap system is the type of equipment. This decision determines the amount of film used, the labor required and the maintenance required. There are eight types of stretch wrappers which are summarized in the second table in this section. Hand held wrappers are ideal for small volume users. Walk around wrappers dispense wrap from a wheeled stand with either an operator or a self propelled robot circling the load to apply the wrap. Semi-automatic rotary wrappers require an operator to tuck film under a load and then the load wraps itself by rotating on a platform. Automatic rotary wrappers allow a lift truck driver to set a load down on a platform and then activate a wrapping cycle without leaving the vehicle. Straddle wrappers pass loads underneath a wrapper mounted on a conveyor or AGV. Pass through stretch wrappers wrap loads with a wide web of film as they pass through on a conveyor. Stretch bundlers are used to wrap small items instead of placing them in a corrugated box. The second table in this section describes the throughput, load capacities, options and film heights associated with the alternative types of stretch wrappers. Recent developments in the area of stretch wrap systems have emphasized reduction in film consumption and the use of films with increased strength and reduced weight. A broader taxonomy of stretch wrapping systems can be based on the eight variations described above to include rotary turntable and overhead spiral stretching machines. Critical application features of these two systems are summarized in the third table included in this section.

	Load/hr	*Load capacity (lb.)*	*Options*	*Film height (in.)*
Hand held	6-10	No limit	Available in throwaway models, with grippers, or with metal handles.	12-18

Walk-around	10-15	No limit	Available with 3 or 4 wheels; robot models operate semi-automatically.	20-70
Manual rotary	12-15	2,000-3,000	Can be converted to semi-automatic rotary.	20-70
Semi-automatic rotary	20-60	2,000-4,000	Available in platform and conveyorized models with high or low profile platform, pre-stretch devices, conveyorized turntables, dual turntable, top platen, powered or non-powered conveyor.	20-70
Automatic rotary	30-80	4,000-6,000	Available in platform and conveyorized models with high or low profile platform, pre-stretch devices, automatic fill roll changer, electronic scale.	20-70
Straddle wrapper	30-70	8,000	Automatic top-sheet dispenser, pre-stretch, gravity and powered conveyors.	20-30
Pass-trough	90-120	500-4,000	AGV interface.	20-110
Stretch bundlers	20-60	50-2,000	Automatic and semiautomatic film cutting, conveyor interface.	10-40

	Rotary turntable stretching machine	Overhead spiral stretching machine
Cost range	$4,250-$75,000+	$8,000-$80,000+
Speed (RPM)	6-12	12-20
Load stability	Low when load<500 lb.; medium otherwise	High
Footprint required (in2)	3,000-56,000	7,224-22,500
Weight capacity (lb.)	6,000	Unlimited
Ideal application	When wrapping very low to moderate volumes; stable loads; where floor space/ceiling space is at premium.	When wrapping tall, unstable, or unusually heavy loads (greater than 6,000 lb.); high volumes; environments in which the floor gets wet or dirty or wash down is required.

Strapping

Strapping is a fundamental unitization method used for sealing packages, securing loads to pallets, or simply tying bundles, coils, drums or other containers and/or products. It is usually a simple, low cost and reliable alternative for load stabilization that can make use of hand held or automatic dispensing systems that use either steel or plastic strapping. The type of strap used by a system provides one way to classify strappers since no system can use both metal and plastic strapping. The development of strong polyesters has made plastic strapping competitive with metal strapping in many traditional applications where straps need to stretch with a load. Steel strapping is still preferred in many applications where thinner strapping is required. Another approach to classification of strapping systems is by the level of automation. Apart from simple manual strapping, strapping machines follow a near continuum of automation levels ranging from semi-automatic, automatic and operatorless systems. Strapping machines are also frequently integrated within larger material handling systems. Semi-automatic strappers tension and strap the load after the operator has looped the strapping over it and fed the end of the strap into a return chute. Automatic strapping machines require only that the operator place each load against a strapping head which feeds the strapping around the load. Operatorless systems strap automatically when a sensor indicates that a load is in position. The fourth table in this section summarizes important application features for the three different types of strapping systems.

Criteria	*Semi-automatic*	*Automatic*	*Operatorless*
Straps per minute	Up to 15-20	Up to 35	Up to 50
Load weight (lb)	up to 100	up to 400	up to 250
Price	\$2,000-\$3,500	Up to \$9,000	Up to \$100,00+
How they work	Usually requires operator to position load and feed strapping.	Usually operator just pushes a button after positioning loads.	No operator required. Machine automatically positions and straps loads.

Shrinking

Shrink wrapping systems provide total load encapsulation to provide maximum product protection. The two primary modes of shrink wrap unitizing are manual and automatic. Manual systems involve the use of a portable heat gun which can use an LP gas cylinder or a gas line. Operators must exercise caution in controlling dwell times to avoid melting a hole in the film. This method usually requires about five minutes to wrap a standard sized pallet load. Automatic systems can use either heat frames, heat closets or heat tunnels. Heat frames, sometimes called shrink rings, can use gas or electric power. These systems are usually mounted on a pedestal, dolly or conveyor base. Heat closets and heat tunnels may be gas, electric or infrared powered and can also be mounted on conveyors, platforms, or dollies. The fifth table in this section summarizes selection guidelines associated with manual and automatic shrink wrapping systems.

Criteria	Hand-held gun	System with pedestal, dolly, or conveyor base
Application	Small loads, low volumes	Heavy or large loads, irregular configurations. Range of throughput rates available.
Approximate cost	\$900-\$1,000	From about \$10,000-\$35,000 and goes up.

Pallet Stacking Frames

Pallet stacking frames are used when block stacking of pallets is desirable, but unit loads lack the necessary stability or strength. Stacking frames are portable fixtures that normally rest directly on the edges of the pallet. They can be manufactured from steel or wood. Typically, they have rigid frames that reach up the sides and across the top of the load. This enables the stacking of pallets directly on top of each other without putting direct pressure on the load. Stacking frames can also be self contained steel units made up of decks and posts which can be stored in a minimum of space when not in use. The sixth table of this section summarizes selection guidelines for choosing between steel and wood pallet stacking frames.

Criteria	Steel pallet	Wood pallet
Application	Heavy-duty applications. Can be used as part of	Same function as steel pallet system, typically for lighter-duty

	distribution system, as well as storage.	jobs.
Approximate cost	$95-$115	$30-$40

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25	Conveyor	Kulwiec, Ray	AConveyors. A basic review of equipment types, applications, engineering data, cost factors, and suppliers@	Plant Engineering	V35 no. 18, Sept. 1981, p 86-99.

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28	Conveyor	Whitlock, Robert	AHeavy-duty scrap handling conveyors@	Plant Engineering	V43 no13, Aug. 17 1989, p80-83
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31	Conveyor (Chain)	Colijn, H.	ASelecting and applying chain conveyors for bulk materials@	Plant Engineering	V38 no13, June 14 1984, p79-81
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33	Conveyor (Power & free)	Beck, Larry	AProven equipment for today=s handling needs@	Modern Materials Handling	V44 no2, Feb. 1989, p78-81
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36	Conveyor (Strap)	Fitzpatrick, Daniel	ASelecting scrap metal handling conveyors@	Plant Engineering	V37 no21, Oct. 13 1983, p76-79
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46	Dock	Loring, R. P.	ASelecting and applying lift tables for loading -dock and inplant handling@	Plant Engineering	V35 no. 5, Mar. 1981, p 73-75.
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89	Hoist	Gould, Les	APick the right hoist for the job@	Modern Materials Handling	V48 no9, Aug. 1993, p44-45
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91	Hoist + Elevators	Colijn, H.	ASelecting bucket elevators and skip hoists@	Plant Engineering	V38 no26, Nov. 8 1984, p79-81
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93	Hoist (Package)	Torok, Douglas B.	AChoose a package hoist for safety and productivity@	Material Handling Engineering	V46 no12, Dec. 1991, p57-59
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106	Packaging / Palletizing	Beck, Larry	ADon=t leave palletizing methods to chance@	Modern Materials Handling	V43 no13, Nov. 1988, p78-80
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150	Storage (Rack)	Mulcahy, David E.	AComparing full unit load storage systems@	Plant Engineering	V42 no19, Dec. 15 1988, p52-56
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