CHAPTER 38
MATERIAL HANDLING

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38.1 INTRODUCTION

Material handling is defined by the Materials Handling Institute (MHI) as the movement, storage, control, and protection of materials and products throughout the process of their manufacture, distribution, consumption, and disposal. The five commonly recognized aspects of material handling are:

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1. Motion. Parts, materials, and finished products that must be moved from one location to another should be moved in an efficient manner and at minimum cost.
2. Time. Materials must be where they are needed at the moment they are needed.
3. Place. Materials must be in the proper location and positioned for use.
4. Quantity. The rate of demand varies between the steps of processing operations. Materials must be continually delivered to, or removed from, operations in the correct weights, volumes, or numbers of items required.
5. Space. Storage space, and its efficient utilization, is a key factor in the overall cost of an operation or process.

The science and engineering of material handling is generally classified into two categories, depending upon the form of the material handled. *Bulk solids handling* involves the movement and storage of solids that are flowable, such as fine, free-flowing materials (e.g., wheat flour or sand), pelletized materials (e.g., soybeans or soap flakes), or lumpy materials (e.g., coal or wood bark). *Unit handling* refers to the movement and storage of items that have been formed into unit loads. A *unit load* is a single item, a number of items, or bulk material that is arranged or restrained so that the load can be stored, picked up, and moved between two locations as a single mass. The handling of liquids and gases is usually considered to be in the domain of fluid mechanics, whereas the movement and storage of containers of liquid or gaseous material properly comes within the domain of unit material handling.

38.2 BULK MATERIAL HANDLING

The handling of bulk solids involves four main areas: (1) conveying, (2) storage, (3) packaging, and (4) transportation.

38.2.1 Conveying of Bulk Solids

The selection of the proper equipment for conveying bulk solids depends on a number of interrelated factors. First, alternative types of conveyors must be evaluated and the correct model and size must be chosen. Because standardized equipment designs and complete engineering data are available for many types of conveyors, their performance can be accurately predicted when they are used with materials having well-known conveying characteristics. Some of the primary factors involved in conveyor equipment selection are as follows:

1. *Capacity requirement.* The rate at which material must be transported (e.g., tons per hour). For instance, belt conveyors can be manufactured in relatively large sizes, operate at high speeds, and deliver large weights and volumes of material economically. On the other hand, screw conveyors can become very cumbersome in large sizes, and cannot be operated at high speeds without severe abrasion problems.
2. *Length of travel.* The distance material must be moved from origin to destination. For instance, belt conveyors can span miles, whereas pneumatic and vibrating conveyors are limited to hundreds of feet.
3. *Lift.* The vertical distance material must be transported. Vertical bucket elevators are commonly applied in those cases in which the angle of inclination exceeds 30°.
4. *Material characteristics.* The chemical and physical properties of the bulk solids to be transported, particularly flowability.
5. *Processing requirements.* The treatment material incurs during transport, such as heating, mixing, and drying.
6. *Life expectancy.* The period of performance before equipment must be replaced; typically, the economic life of the equipment.
7. *Comparative costs.* The installed first cost and annual operating costs of competing conveyor systems must be evaluated in order to select the most cost-effective configuration.

Table 38.1 lists various types of conveyor equipment for certain common industrial functions. Table 38.2 provides information on the various types of conveyor equipment used with materials having certain characteristics.

The choice of the conveyor itself is not the only task involved in selecting a conveyor system. Conveyor drives, motors, and auxiliary equipment must also be chosen. Conveyor drives comprise from 10%–30% of the total cost of the conveyor system. Fixed-speed drives and adjustable speed drives are available, depending on whether changes in conveyor speed are needed during the course of normal operation. Motors for conveyor drives are generally three-phase, 60-cycle, 220-V units; 220/440-V units; 550-V units; or four-wire, 208-V units. Also available are 240-V and 480-V ratings.

Table 38.1 Types of Conveyor Equipment and Their Functions

Function	Conveyor Type
Conveying materials horizontally	Apron, belt, continuous flow, drag flight, screw, vibrating, bucket, pivoted bucket, air
Conveying materials up or down an incline	Apron, belt, continuous flow, flight, screw, skip hoist, air
Elevating materials	Bucket elevator, continuous flow, skip hoist, air
Handling materials over a combination horizontal and vertical path	Continuous flow, gravity-discharge bucket, pivoted bucket, air
Distributing materials to or collecting materials from bins, bunkers, etc.	Belt, flight, screw, continuous flow, gravity-discharge bucket, pivoted bucket, air
Removing materials from railcars, trucks, etc.	Car dumper, grain-car unloader, car shaker, power shovel, air

Auxiliary equipment includes such items as braking or arresting devices on vertical elevators to prevent reversal of travel, torque-limiting devices or electrical controls to limit power to the drive motor, and cleaners on belt conveyors.

38.2.2 Screw Conveyors

A screw conveyor consists of a helical shaft mount within a pipe or trough. Power may be transmitted through the helix, or in the case of a fully enclosed pipe conveyor through the pipe itself. Material is forced through the channel formed between the helix and the pipe or trough. Screw conveyors are generally limited to rates of flow of about 10,000 ft^3/hr. Figure 38.1 shows a chute-fed screw conveyor, one of several types in common use. Table 38.3 gives capacities and loading conditions for screw conveyors on the basis of material classifications.

38.2.3 Belt Conveyors

Belt conveyors are widely used in industry. They can traverse distances up to several miles at speeds up to 1000 ft/min and can handle thousands of tons of material per hour. Belt conveyors are generally placed horizontally or at slopes ranging from 10°–20°, with a maximum incline of 30°. Direction changes can occur readily in the vertical plane of the belt path, but horizontal direction changes must be managed through such devices as connecting chutes and slides between different sections of belt conveyor.

Belt-conveyor design depends largely on the nature of the material to be handled. Particle-size distribution and chemical composition of the material dictate selection of the width of the belt and the type of belt. For instance, oily substances generally rule out the use of natural rubber belts. Conveyor-belt capacity requirements are based on peak load rather than average load. Operating conditions that affect belt-conveyor design include climate, surroundings, and period of continuous service. For instance, continuous service operation will require higher-quality components than will intermittent service, which allows more frequent maintenance. Belt width and speed depend on the bulk density of the material and lump size. The horsepower to drive the belt is a function of the following factors:

1. Power to drive an empty belt

Table 38.2 Material Characteristics and Feeder Type

Material Characteristics	Feeder Type
Fine, free-flowing materials	Bar flight, belt, oscillating or vibrating, rotary vane, screw
Nonabrasive and granular materials, materials with some lumps	Apron, bar flight, belt, oscillating or vibrating, reciprocating, rotary plate, screw
Materials difficult to handle because of being hot, abrasive, lumpy, or stringy	Apron, bar flight, belt, oscillating or vibrating, reciprocating
Heavy, lumpy, or abrasive materials similar to pit-run stone and ore	Apron, oscillating or vibrating, reciprocating

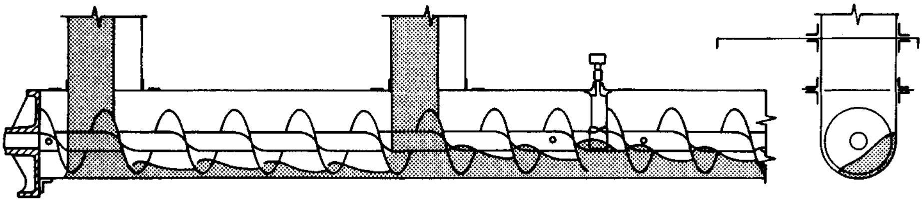


Fig. 38.1 Chute-fed screw conveyor.

2. Power to move the load against the friction of the rotating parts
3. Power to elevate and lower the load
4. Power to overcome inertia in placing material in motion
5. Power to operate a belt-driven tripper

Table 38.4 provides typical data for estimating belt-conveyor and design requirements. Figure 38.2 illustrates a typical belt-conveyor loading arrangement.

38.2.4 Bucket Elevators

Bucket elevators are used for vertical transport of bulk solid materials. They are available in a wide range of capacities and may operate in the open or totally enclosed. They tend to be acquired in highly standardized units, although specifically engineered equipment can be obtained for use with special materials, unusual operating conditions, or high capacities. Figure 38.3 shows a common type of bucket elevator, the spaced-bucket centrifugal-discharge elevator. Other types include spaced-bucket positive-discharge elevators, V-bucket elevators, continuous-bucket elevators, and super-capacity continuous-bucket elevators. The latter handle high tonnages and are usually operated at an incline to improve loading and discharge conditions.

Bucket elevator horsepower requirements can be calculated for space-bucket elevators by multiplying the desired capacity (tons per hour) by the lift and dividing by 500. Table 38.5 gives bucket elevator specifications for spaced-bucket, centrifugal-discharge elevators.

38.2.5 Vibrating or Oscillating Conveyors

Vibrating conveyors are usually directional-throw devices that consist of a spring-supported horizontal pan or trough vibrated by an attached arm or rotating weight. The motion imparted to the material particles abruptly tosses them upward and forward so that the material travels in the desired direction. The conveyor returns to a reference position, which gives rise to the term *oscillating conveyor*. The capacity of the vibrating conveyor is determined by the magnitude and frequency of trough displacement, angle of throw, and slope of the trough, and the ability of the material to receive and transmit through its mass the directional "throw" of the trough. Classifications of vibrating conveyors include (1) mechanical, (2) electrical, and (3) pneumatic and hydraulic vibrating conveyors. Capacities of vibrating conveyors are very broad, ranging from a few ounces or grams for laboratory-scale equipment to thousands of tons for heavy industrial applications. Figure 38.4 depicts a leaf-spring mechanical vibrating conveyor, and provides a selection chart for this conveyor.

38.2.6 Continuous-Flow Conveyors

The continuous-flow conveyor is a totally enclosed unit that operates on the principle of pulling a surface transversely through a mass of bulk solids material, such that it pulls along with it a cross section of material that is greater than the surface of the material itself. Figure 38.5 illustrates a typical configuration for a continuous-flow conveyor. Three common types of continuous flow conveyors are (1) closed-belt conveyors, (2) flight conveyors, and (3) apron conveyors. These conveyors employ a chain-supported transport device, which drags through a totally enclosed boxlike tunnel.

38.2.7 Pneumatic Conveyors

Pneumatic conveyors operate on the principle of transporting bulk solids suspended in a stream of air over vertical and horizontal distances ranging from a few inches or centimeters to hundreds of feet or meters. Materials in the form of fine powders are especially suited to this means of conveyance, although particle sizes up to a centimeter in diameter can be effectively transported pneumatically. Materials with bulk densities from one to more than 100 lb/ft^3 can be transported through pneumatic conveyors.

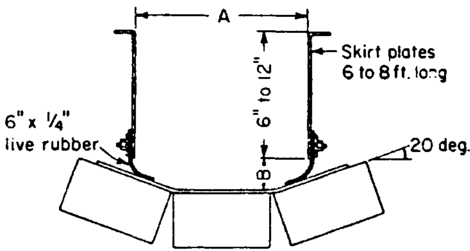
The capacity of a pneumatic conveying system depends on such factors as the bulk density of the product, energy within the conveying system, and the length and diameter of the conveyor.

Table 38.3 Capacity and Loading Conditions for Screw Conveyors

Capacity		Diam. of Flights	Diam. of Pipe	Diam. of Shafts	Hanger Centers	Max. Size Lumps			Speed	Max. Torque Capacity	Feed Section Diam.	Hp at Motor					Max. Hp. Capacity at Speed Listed
tons/hr	ft³/hr	(in.)	(in.)	(in.)	(ft)	All Lumps	Lumps 20–25%	Lumps 10% or Less	(rpm)	(in.-lb)	(in.)	15 ft Max. Length	30 ft Max. Length	45 ft Max. Length	60 ft Max. Length	75 ft Max. Length	
5	200	9	2½	2	10	¾	1½	2¼	40	7,600	6	0.43	0.85	1.27	1.69	2.11	4.8
10	400	10	2½	2	10	¾	1½	2½	55	7,600	9	0.85	1.69	2.25	3.00	3.75	6.6
15	600	10	2½	2	10	¾	1½	2½	80	7,600	9	1.27	2.25	3.38	3.94	4.93	9.6
		12	2½	2	12	1	2	3	45	7,600	10	1.27	2.25	3.38	3.94	4.93	5.4
		12	3½	3						16,400		1.27	2.25	3.38	3.94	4.93	11.7
20	800	12	2½	2	12	1	2	3	60	7,600	10	1.69	3.00	3.94	4.87	5.63	7.2
			3½	3						16,400		1.69	3.00	3.94	4.87	5.63	15.6
25	1000	12	2½	2	12	1	2	3	75	7,600	10	2.12	3.75	4.93	5.63	6.55	9.0
			3½	3						16,400		2.12	3.75	4.93	5.63	6.55	19.5
		14	3½	3		1¼	2½	3½	45	16,400	12	2.12	3.75	4.93	5.63	6.55	11.7
30	1200	14	3½	3	12	1¼	2½	3½	55	16,400	12	2.25	3.94	5.05	6.75	7.50	14.3
35	1400	14	3½	3	12	1¼	2½	3½	65	16,400	12	2.62	4.58	5.90	7.00	8.75	16.9
40	1600	16	3½	3	12	1½	3	4	50	16,400	14	3.00	4.50	6.75	8.00	10.00	13.0

Table 38.4 Data for Estimating Belt Conveyor Design Requirements

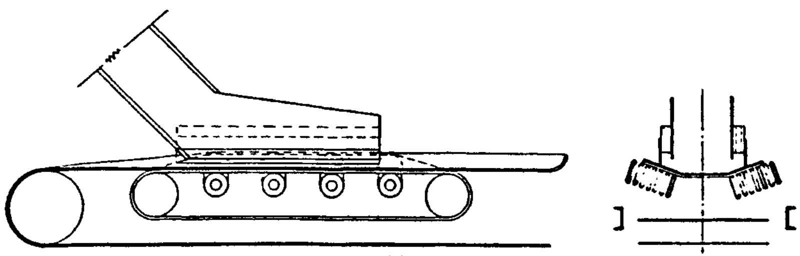
Belt Width (in.)	Cross-Sectional Area of Load (ft^2)	Belt Speed: Normal Operating Speed (ft/min)	Belt Speed: Max. Advisable Speed (ft/min)	Belt Plies: Min.	Belt Plies: Max.	Max. Size Lump (in.): Sized Material 80% Under	Max. Size Lump (in.): Unsized Material Not Over 20%	Belt Speed (ft/min)	50 lb/ft^3 Material: Capacity (tons/hr)	50 lb/ft^3 Material: hp 10-ft Lift	50 lb/ft^3 Material: hp 100-ft Centers	100 lb/ft^3 Material: Capacity (tons/hr)	100 lb/ft^3 Material: hp 10-ft Lift	100 lb/ft^3 Material: hp 100-ft Centers	Add hp for Tripper
14	0.11	200	300	3	5	2	3	100	16	0.17	0.22	32	0.34	0.44	1.00
								200	32	0.34	0.44	64	0.68	0.88	
								300	48	0.52	0.66	96	1.04	1.32	
16	0.14	200	300	3	5	2½	4	100	22	0.23	0.28	44	0.46	0.56	1.25
								200	44	0.45	0.56	88	0.90	1.12	
								300	66	0.68	0.84	132	1.36	1.68	
18	0.18	250	350	4	6	3	5	100	27	0.29	0.35	54	0.58	0.7	1.50
								250	67	0.71	0.88	134	1.42	1.76	
								350	95	1.00	1.21	190	2.00	2.42	
20	0.22	250	350	4	6	3½	6	100	33	0.35	0.42	66	0.70	0.84	1.60
								250	82	0.86	1.03	164	1.72	2.06	
								350	115	1.22	1.45	230	2.44	2.9	
24	0.33	300	400	4	7	4½	8	100	49	0.51	0.51	98	1.02	1.02	1.75
								300	147	1.53	1.52	294	3.06	3.04	
								400	196	2.04	2.02	392	4.08	4.04	
30	0.53	300	450	4	8	7	12	100	79	0.80	0.75	158	1.60	1.5	2.50
								300	237	2.40	2.25	474	4.80	4.5	
								450	355	3.60	3.37	710	7.20	6.74	
36	0.78	400	600	4	9	8	15	100	115	1.22	0.80	230	2.44	1.59	3.53
								400	460	4.87	3.18	920	9.74	6.36	
								600	690	7.30	4.76	1380	14.6	9.52	
42	1.09	400	600	4	10	10	18	100	165	1.75	1.14	330	3.50	2.28	4.79
								400	660	7.00	4.56	1320	14.0	9.12	
								600	990	11.6	6.84	1980	23.2	13.68	
48	1.46	400	600	4	12	12	21	100	220	2.33	1.52	440	4.66	3.04	6.42
								400	880	9.35	6.07	1760	18.7	12.14	
								600	1320	14.0	9.10	2640	28.0	18.2	
54	1.90	450	600	6	12	14	24	100	285	3.02	1.97	570	6.04	3.94	10.56
								450	1282	13.6	8.85	2564	27.2	17.7	
								600	1710	18.1	11.82	3420	36.2	23.6	
60	2.40	450	600	6	13	16	28	100	360	3.82	2.49	720	7.64	4.98	
								450	1620	17.2	11.20	3240	34.4	22.4	
								600	2160	22.9	14.95	4320	45.8	29.9	



Side elevation

Belt width, in.	14	16	18	20	24	30	36	42	48	54	60
A	9	11	12	13	16	20	24	28	32	36	40
B-roller bearing	2	2¼	2¼	2⅞	2⅞	3⅛	3⅝	4	4⅜	4¾	5¼
B-ball bearing	2½	2½	2⅜	2⅞	2⅞	3¼	3⅝				

(*a*)



(*b*)

Fig. 38.2 A typical belt conveyor loading arrangement.

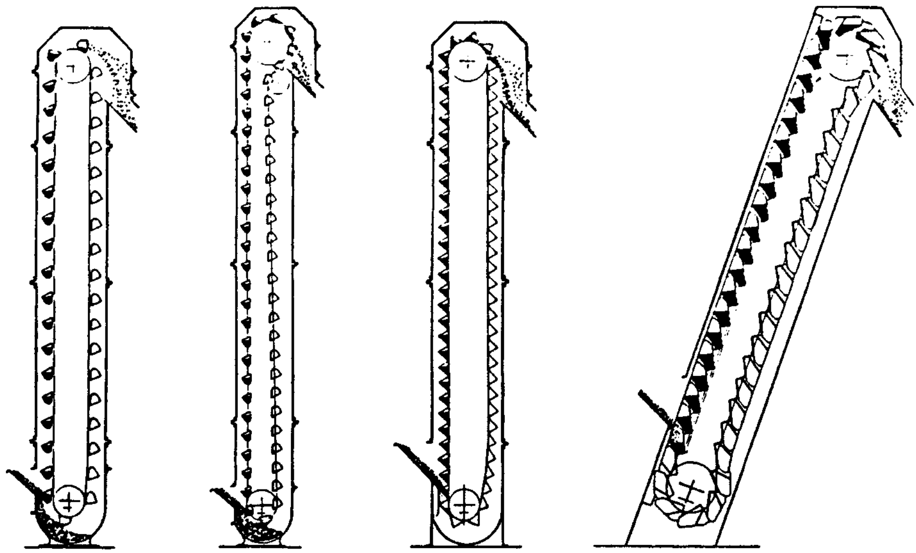


Fig. 38.3 Bucket elevators.

There are four basic types of pneumatic conveyor systems: (1) pressure, (2) vacuum, (3) combination pressure and vacuum, and (4) fluidizing. In pressure systems, the bulk solids material is charged into an air stream operated at higher-than-atmospheric pressures, such that the velocity of the air stream maintains the solid particles in suspension until it reaches the separating vessel, usually an air filter or cyclone separator. Vacuum systems operate in much the same way, except that the pressure of the system is kept lower than atmospheric pressure. Pressure–vacuum systems combine the best features of these two techniques, with a separator and a positive-displacement blower placed between the vacuum "charge" side of the system and the pressure "discharge" side. One of the most common applications of pressure–vacuum systems is with the combined bulk vehicle (e.g., hopper car) unloading and transporting to bulk storage. Fluidizing systems operate on the principle of passing air through a porous membrane, which forms the bottom of the conveyor, thus giving finely divided, non-free-flowing bulk solids the characteristics of free-flowing material. This technique, commonly employed in transporting bulk solids over short distances (e.g., from a storage bin to the charge point to a pneumatic conveyor), has the advantage of reducing the volume of conveying air needed, thereby reducing power requirements. Figure 38.6 illustrates these four types of pneumatic conveyor systems.

38.3 BULK MATERIALS STORAGE

38.3.1 Storage Piles

Open-yard storage is a commonplace approach to the storage of bulk solids. Belt conveyors are most often used to transport to and from such a storage area. Cranes, front-end loaders, and draglines are commonly used at the storage site. Enclosed storage piles are employed where the bulk solids materials can erode or dissolve in rainwater, as in the case of salt for use on icy roads. The necessary equipment for one such application, the circular storage facility, is (1) feed conveyor, (2) central support column, (3) stacker, (4) reclaimer, (5) reclaim conveyor, and (6) the building or dome cover.

38.3.2 Storage Bins, Silos, and Hoppers

A typical storage vessel for bulk solids materials consists of two components—a bin and a hopper. The bin is the upper section of the vessel and has vertical sides. The hopper is the lower part of the vessel, connecting the bin and the outlet, and must have at least one sloping side. The hopper serves as the means by which the stored material flows to the outlet channel. Flow is induced by opening the outlet port and using a feeder device to move the material, which drops through the outlet port.

If all material stored in the bin moves whenever material is removed from the outlet port, *mass flow* is said to prevail. However, if only a portion of the material moves, the condition is called *funnel flow*. Figure 38.7 illustrates these two conditions.

Many flow problems in storage bins can be reduced by taking the physical characteristics of the bulk material into account. Particle size, moisture content, temperature, age, and oil content of the

Table 38.5 Bucket Elevator Specifications

Size of Bucket (in.)[a]	Elevator Centers (ft)	Capacity (tons/hr) Material Weighing 100 lb/ft[b]	Size Lumps Handled (in.)[c]	Bucket Speed (ft/min)	rpm Head Shaft	Horsepower[b] Required at Head Shaft	Additional Horsepower[b] per Foot for Intermediate Lengths	Bucket Spacing (in.)	Shaft Diameter (in.) Head	Shaft Diameter (in.) Tail	Diameter of Pulleys (in.) Head	Diameter of Pulleys (in.) Tail	Belt Width (in.)
	25	14	$\frac{3}{4}$	225	43	1.0	0.02	12	$1\frac{15}{16}$	$1\frac{11}{16}$	20	14	7
	50	14	$\frac{3}{4}$	225	43	1.6	0.02	12	$1\frac{15}{16}$	$1\frac{11}{16}$	20	14	7
$6 \times 4 \times 4\frac{1}{4}$	75	14	$\frac{3}{4}$	225	43	2.1	0.02	12	$1\frac{15}{16}$	$1\frac{11}{16}$	20	14	7
	25	27	1	225	43	1.6	0.04	14	$1\frac{15}{16}$	$1\frac{11}{16}$	20	14	9
	50	30	1	260	41	3.5	0.05	14	$1\frac{15}{16}$	$1\frac{11}{16}$	24	14	9
$8 \times 5 \times 5\frac{1}{2}$	75	30	1	260	41	4.8	0.05	14	$2\frac{7}{16}$	$1\frac{11}{16}$	24	14	9
	25	45	$1\frac{1}{4}$	225	43	3.0	0.063	16	$1\frac{15}{16}$	$1\frac{15}{16}$	20	16	11
	50	52	$1\frac{1}{4}$	260	41	5.2	0.07	16	$2\frac{7}{16}$	$1\frac{15}{16}$	24	16	11
$10 \times 6 \times 6\frac{1}{4}$	75	52	$1\frac{1}{4}$	260	41	7.2	0.07	16	$2\frac{15}{16}$	$1\frac{15}{16}$	24	16	11
	25	75	$1\frac{1}{2}$	260	41	4.7	0.1	18	$2\frac{7}{16}$	$1\frac{15}{16}$	24	18	13
	50	84	$1\frac{1}{2}$	300	38	8.9	0.115	18	$2\frac{15}{16}$	$1\frac{15}{16}$	30	18	13
$12 \times 7 \times 7\frac{1}{4}$	75	84	$1\frac{1}{2}$	300	38	11.7	0.115	18	$3\frac{7}{16}$	$2\frac{7}{16}$	30	18	13
	25	100	$1\frac{3}{4}$	300	38	7.3	0.14	18	$2\frac{15}{16}$	$2\frac{7}{16}$	30	18	15
	50	100	$1\frac{3}{4}$	300	38	11.0	0.14	18	$3\frac{7}{16}$	$2\frac{7}{16}$	30	18	15
$14 \times 7 \times 7\frac{1}{4}$	75	100	$1\frac{3}{4}$	300	38	14.3	0.14	18	$3\frac{7}{16}$	$2\frac{7}{16}$	30	18	15
	25	150	2	300	38	8.5	0.165	18	$2\frac{15}{16}$	$2\frac{7}{16}$	30	20	18
	50	150	2	300	38	12.6	0.165	18	$3\frac{7}{16}$	$2\frac{7}{16}$	30	20	18
$16 \times 8 \times 8\frac{1}{2}$	75	150	2	300	38	16.7	0.165	18	$3\frac{15}{16}$	$2\frac{7}{16}$	30	20	18

[a] Size of buckets given: width × projection × depth.

[b] Capacities and horsepowers given for materials weighing 100 lb/ft^3. For materials of other weights, capacity and horsepower will vary in direct proportion. For example, an elevator handling coal weighing 50 lb/ft^3 will have half the capacity and will require approximately half the horsepower listed above.

[c] If volume of lumps averages less than 15% of total volume, lumps of twice size listed may be handled.

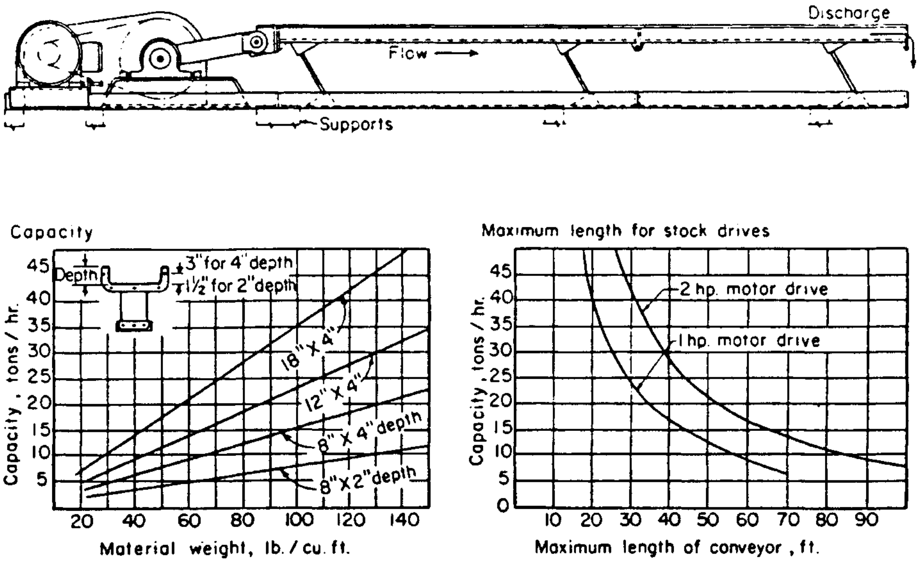


Fig. 38.4 Leaf-spring mechanical vibrating conveyor.

stored material affect flowability. Flow-assisting devices and feeders are usually needed to overcome flow problems in storage bins.

38.3.3 Flow-Assisting Devices and Feeders

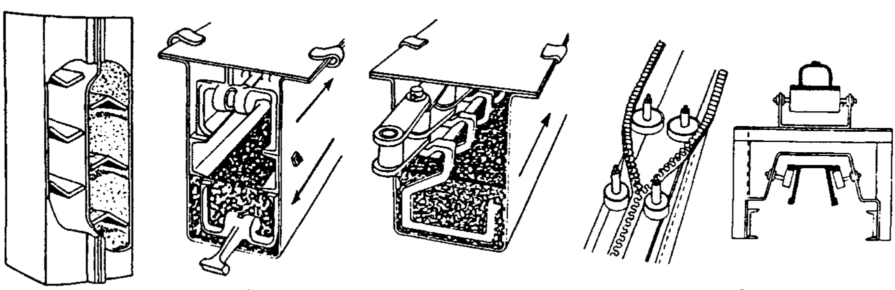
To handle those situations in which bin design alone does not produce the desired flow characteristics, flow-assisting devices are available. Vibrating hoppers are one of the most important types of flow-assisting devices. These devices fall into two categories: *gyrating devices,* in which vibration is applied perpendicular to the flow channel; and *whirlpool devices,* which apply a twisting motion and a lifting motion to the material, thereby disrupting any bridges that might tend to form. Screw feeders are used to assist in bin unloading by removing material from the hopper opening.

38.3.4 Packaging of Bulk Materials

Bulk materials are often transported and marketed in containers, such as bags, boxes, and drums. Packaged solids lend themselves to material handling by means of unit material handling.

Bags

Paper, plastic, and cloth bags are common types of containers for bulk solids materials. Multiwall paper bags are made from several plies of kraft paper. Bag designs include valve and open-mouth designs. Valve-type bags are stitched or glued at both ends prior to filling, and are filled through a



(a) (b) (c) (d)

Fig. 38.5 Continuous-flow conveyor.

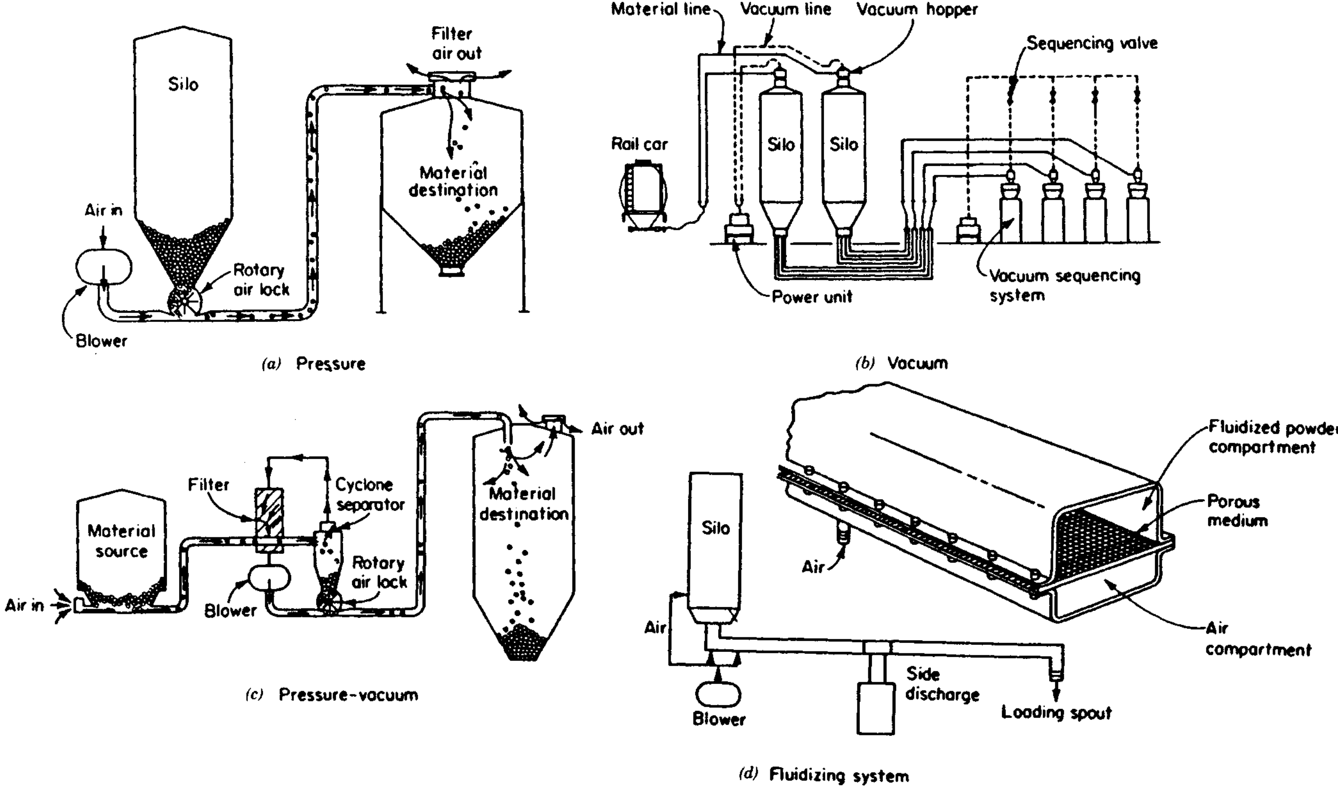


Fig. 38.6 Four types of pneumatic conveyor systems.

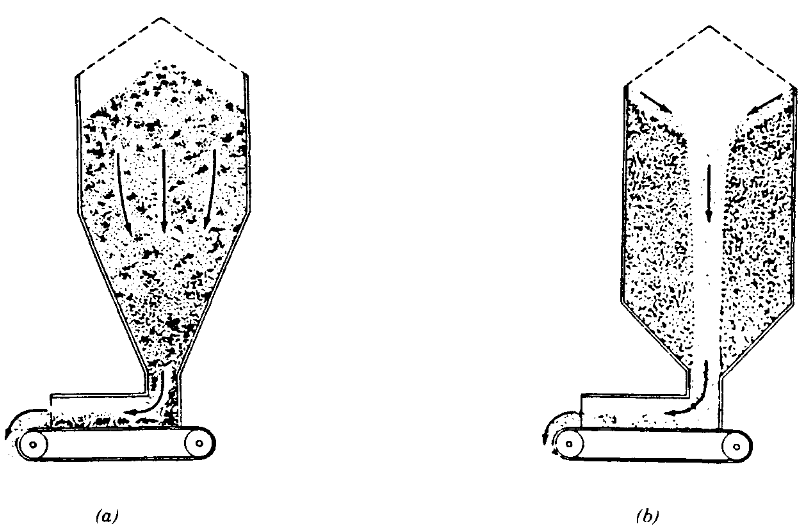


Fig. 38.7 Mass-flow (*a*) and funnel-flow (*b*) in storage bins.

valve opening at one corner of the bag. Open-mouth bags are sealed at one end during manufacture, and at the open end after filling. Valve bags more readily lend themselves to automated filling than open-mouth bags, yielding higher packing rates.

Bag size is determined by the weight or volume of material to be packed and its bulk density. Three sets of dimensions must be established in bag sizing:

1. Tube–outside length and width of the bag tube before closures are fabricated
2. Finished face-length, width, and thickness of the bag after fabrication
3. Filled face-length, width, and thickness of the bag after filling and closure

Figure 38.8 shows the important dimensions of multiwall paper bags, and Table 38.6 gives their relationships to tube, finished face, and filled face dimensions.

Boxes

Bulk boxes are fabricated from corrugated kraft paper. They are used to store and ship bulk solid materials in quantities ranging from 50 lb to several hundred pounds. A single-wall corrugated kraft board consists of an outside liner, a corrugated medium, and an inside liner. A double-wall board has two corrugated mediums sandwiched between three liners. The specifications for bulk boxes depend on the service requirements; 600 lb/in.^{2} is common for loads up to 1000 lb, and 200 lb/in.^{2} for 100-lb loads. Bulk boxes have the advantages of reclosing and of efficient use of storage and shipping space, called *cube*. Disadvantages include the space needed for storage of unfilled boxes and limited reusability. Figure 38.9 shows important characteristics of bulk boxes.

Folding cartons are used for shipping bulk solids contained in individual bottles, bags, or folding boxes. Cartons are of less sturdy construction than bulk boxes, because the contents can assist in supporting vertically imposed loads.

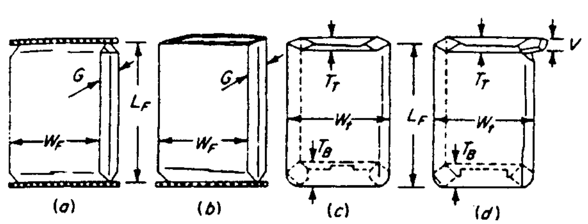


Fig. 38.8 Dimensions of multiwall paper bags.

Table 38.6 Dimensions of Multiwall Paper Bags

Bag Type	Tube Dimensions	Finished-Face Dimensions	Filled-Face Dimensions	Valve Dimensions
Sewn open-mouth	Width = $W_t = W_f + G_f$ Length = $L_t = L_f$	Width = $W_f = W_t - G_f$ Length = $L_f = L_t$ Gusset = G_f	Width = $W_F = W_f + \frac{1}{2}$ in. Length = $L_F = L_f - 0.67G_f$ Thickness = $G_F = G_f + \frac{1}{2}$ in.	
Sewn valve	Width = $W_t = W_f + G_f$ Length = $L_t = L_f$	Width = $W_f = W_t - G_f$ Length = $L_f = L_t$ Gusset = G_f	Width = $W_F = W_f + 1$ in. Length = $L_F = L_f - 0.67G_f$ Thickness = $G_F = G_f + 1$ in.	Width = $V = G_f \pm \frac{1}{2}$ in.
Pasted valve	Width = $W_t = W_f$ Length = L_t	Width = $W_f = W_t$ Length = $L_f = L_t - (T_T + T_B)/2 - 1$ Thickness at top = T_T Thickness at bottom = T_B	Width = $W_F = W_f - T_T + 1$ in. Length= $L_F = L_f - T_T + 1$ in. Thickness = $T_F = T_T + \frac{1}{2}$ in.	Width = $V = T_T \begin{cases} +0 \text{ in.} \\ -1 \text{ in.} \end{cases}$

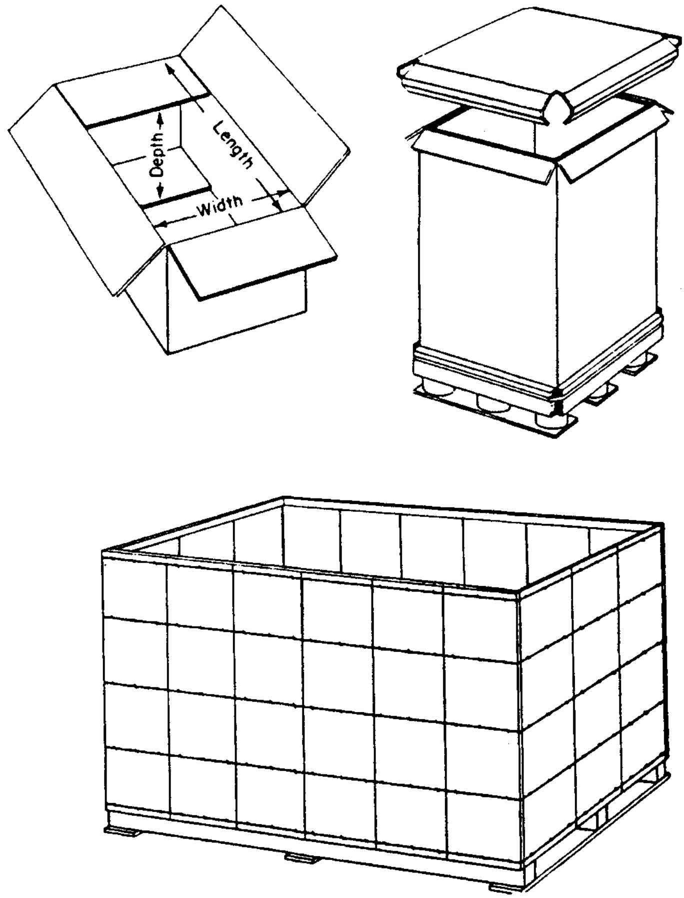


Fig. 38.9 Bulk boxes and cartons.

38.3.5 Transportation of Bulk Materials

The term *transportation of bulk materials* refers to the movement of raw materials, fuels, and bulk products by land, sea, and air. A useful definition of a bulk shipment is any unit greater than 4000 lb or 40 ft^3. The most common bulk carriers are railroad hopper cars, highway hopper trucks, portable bulk bins, barges, and ships. Factors affecting the choice of transportation include the characteristics of material size of shipment, available transportation routes from source to destination (e.g., highway, rail, water), and the time available for shipment.

Railroad Hopper Cars

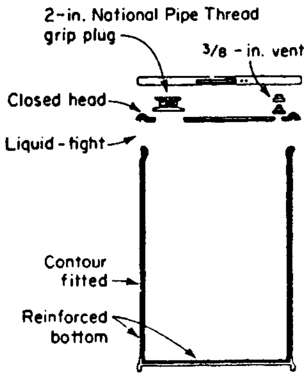
Railroad hopper cars are of three basic designs:

1. Covered, with bottom-unloading ports
2. Open, with bottom-unloading ports
3. Open, without unloading ports

Gravity, pressure differential, and fluidizing unloading systems are available with railroad hopper cars. Loading of hopper cars can be done with most types of conveyors: belt, screw, pneumatic, and so on. Unloading of bottom-unloading hopper cars can be managed by constructing a special dumping pit beneath the tracks with screw or belt takeaway conveyors.

Hopper Trucks

Hopper trucks are used for highway transportation of bulk solids materials. The most common types include (1) closed type with a pneumatic conveyor unloading system and (2) the open dump truck.



Drum type	Outside dimensions	
	Dia., in.	Height, in.
55-gal. lever top	21	40 3/4
55-gal. lever top	23 1/2	30 3/4
55-gal. lever top	22	34 3/4
41-gal. lever top	20 1/2	30 1/4
30-gal. lever top	19	26 1/4
6.28-cu.ft. rectangular	17 5/8*	37 1/2
55-gal. liquid	22	37 1/2
30-gal. liquid	19	28
55-gal. fiber	20 3/8	40 3/4
30-gal. fiber	17 3/8	30 3/4

* Side dimension, square

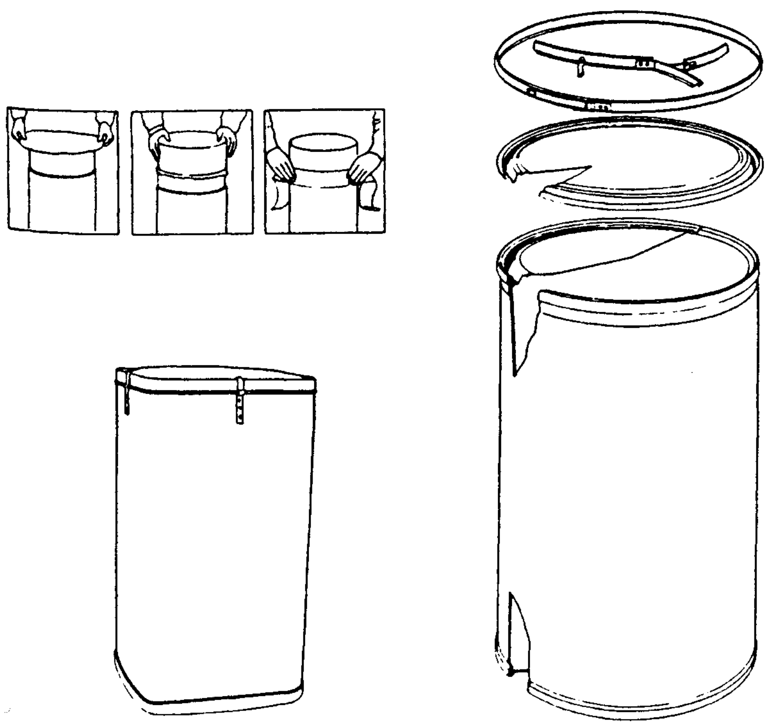


Fig. 38.10 Storage drums.

With the first type, a truck can discharge its cargo directly into a storage silo. The shipment weights carried by trucks depend on state highway load limits, usually from 75,000–125,000 lb.

38.4 UNIT MATERIAL HANDLING

38.4.1 Introduction

Unit material handling involves the movement and storage of unit loads, as defined in Section 38.1. Examples include automobile body components, engine blocks, bottles, cans, bags, pallets of boxes, bins of loose parts, and so on. As the previous definition implies, the word *unit* refers to the single entity that is handled. That entity can consist of a single item or numerous items that have been unitized for purposes of movement and storage.

This section discusses some of the procedures employed in material-handling system design, and describes various categories, with examples, of material-handling equipment used in handling unit loads.

38.4.2 Analysis of Systems for Material Handling

Material handling is an indispensable element in most production and distribution systems. Yet, while material handling is generally considered to add nothing to the value of the materials and products that flow through the system, it does add to their cost. In fact, it has been estimated that 30%–60% of the end-price of a product is related to the cost of material handling. Therefore, it is essential that material handling systems be designed and operated as efficiently and cost-effectively as possible.

The following steps can be used in analyzing production systems and solving the inherent material-handling problems:

1. Identify and define the problem(s).
2. Collect relevant data.
3. Develop a plan.
4. Implement the solution.

Unfortunately, when most engineers perceive that a material-handling problem exists, they skip directly to step 4; that is, they begin looking for material-handling equipment that will address the symptoms of the problem without looking for the underlying root causes of the problem, which may be uncovered by execution of all four steps listed above.

Thus, the following sections explain how to organize a study and provide some tools to use in an analysis of a material-handling system according to this four-step procedure.

38.4.3 Identifying and Defining the Problem

For a new facility, the best way to begin the process of identifying and defining the problems is to become thoroughly familiar with all of the products to be produced by the facility, their design and component parts, and whether the component parts are to be made in the facility or purchased from vendors. Then, one must be thoroughly knowledgeable about the processes required to produce each part and product to be made in the facility. One must also be cognizant of the production schedules for each part and product to be produced; that is, parts or products produced per shift, day, week, month, year, and so on. Finally, one must be intimately familiar with the layout of the facility in which production will take place; not just the area layout, but the volume (or cubic space) available for handling materials throughout the facility.

Ideally, the persons or teams responsible for the design of material-handling systems for a new facility will be included and involved from the initial product design stage through process design, schedule design, and layout design. Such involvement in a truly concurrent engineering approach will contribute greatly to the efficient and effective handling of materials when the facility becomes operational.

In an existing facility, the best way to begin the process of identifying and defining the problems is to tour the facility, looking for material-handling aspects of the various processes observed. It is a good idea to take along a checklist, such as that shown in Fig. 38.11. Another useful guide is the Material Handling Institute (MHI) list of "The Twenty Principles of Material Handling," as given in Fig. 38.12.

Once the problem has been identified, its scope must be defined. For example, if most of the difficulties are found in one area of the plant, such as shipping and receiving, the study can be focused there. Are the difficulties due to lack of space? Or is part of the problem due to poor training of personnel in shipping and receiving? In defining the problem, it is necessary to answer the basic questions normally asked by journalists: Who? what? when? where? why?

38.4.4 Collecting Data

In attempting to answer the journalistic questions above, all relevant data must be collected and analyzed. At a minimum, the data collection and analysis must be concerned with the products to be produced in the facility, the processes (fabrication, assembly, and so on) used to produce each product, the schedule to be met in producing the products, and the facility layout (three-dimensional space allocation) supporting the production processes.

Some useful data can be obtained by interviewing management, supervisors, operators, vendors, and competitors, by consulting available technical and sales literature, and through personal observation. However, most useful data are acquired by systematically charting the flows of materials and the movements that take place within the plant. Various graphical techniques are used to record and analyze this information.

An assembly chart, shown in Fig. 38.13, is used to illustrate the composition of the product, the relationship among its component parts, and the sequence in which components are assembled.

Material Handling Checklist

- ☐ Is the material handling equipment more than 10 years old?
- ☐ Do you use a wide variety of makes and models which require a high spare parts inventory?
- ☐ Are equipment breakdowns the result of poor preventive maintenance?
- ☐ Do the lift trucks go too far for servicing?
- ☐ Are there excessive employee accidents due to manual handling of materials?
- ☐ Are materials weighing more than 50 pounds handled manually?
- ☐ Are there many handling tasks that require 2 or more employees?
- ☐ Are skilled employees wasting time handling materials?
- ☐ Does material become congested at any point?
- ☐ Is production work delayed due to poorly scheduled delivery and removal of materials?
- ☐ Is high storage space being wasted?
- ☐ Are high demurrage charges experienced?
- ☐ Is material being damaged during handling?
- ☐ Do shop trucks operate empty more than 20% of the time?
- ☐ Does the plant have an excessive number of rehandling points?
- ☐ Is power equipment used on jobs that could be handled by gravity?
- ☐ Are too many pieces of equipment being used, because their scope of activity is confined?
- ☐ Are many handling operations unnecessary?
- ☐ Are single pieces being handled where unit loads could be used?
- ☐ Are floors and ramps dirty and in need of repair?
- ☐ Is handling equipment being overloaded?
- ☐ Is there unnecessary transfer of material from one container to another?
- ☐ Are inadequate storage areas hampering efficient scheduling of movement?
- ☐ Is it difficult to analyze the system because there is no detailed flow chart?
- ☐ Are indirect labor costs too high?

Fig. 38.11 Material-handling checklist.

The operations process chart, shown in Fig. 38.14, provides an even more detailed depiction of material flow patterns, including sequences of production and assembly operations. It begins to afford an idea of the relative space requirements for the process.

The flow process chart, illustrated in Fig. 38.15, tabulates the steps involved in a process, using a set of standard symbols adopted by the American Society of Mechanical Engineers (ASME). Shown at the top of the chart, these five symbols allow one to ascribe a specific status to an item at each step in processing. The leftmost column in the flow process chart lists the identifiable activities comprising the process, in sequential order. In the next column, one of the five standard symbols is selected to identify the activity as an operation, transportation, inspection, delay, or storage. The remaining columns permit the recording of more detailed information.

Note that in the flow process chart in Fig. 38.16, for each step recorded as a "transport," a distance (in feet) is recorded. Also, in some of the leftmost columns associated with a transport activity, the type of material handling equipment used to make the move is recorded—for example, "fork lift." However, material-handling equipment could be used for any of the activities shown in this chart. For example, automated storage and retrieval systems (AS/RSs) can be used to store materials, accumulating conveyors can be used to queue materials during a delay in processing, or conveyors can be configured as a moving assembly line so that operations can be performed on the product while it is being transported through the facility.

In the columns grouped under the heading *possibilities,* opportunities for improvement or simplification of each activity can be noted.

The flow diagram, depicted in Fig. 38.16, provides a graphical record of the sequence of activities required in the production process, superimposed upon an area layout of a facility. This graphical technique uses the ASME standard symbol set and augments the flow process chart.

The "from–to" chart, illustrated in Fig. 38.17, provides a matrix representation of the required number of material moves (unit loads) in the production process. A separate from–to chart can also be constructed that contains the distances materials must be moved between activities in the production process. Of course, such a chart will be tied to a specific facility layout and usually contains assumptions about the material-handling equipment to be used in making the required moves.

The activity relationship chart, shown in Fig. 38.18, can be used to record qualitative information regarding the flow of materials between activities or departments in a facility. Read like a highway mileage table in a typical road atlas, which indicates the distances between pairs of cities, the activity relationship chart allows the analyst to record a qualitative relationship that should exist between each pair of activities or departments in a facility layout. The relationships recorded in this chart show the importance that each pair of activities be located at varying degrees of closeness to each

The 20 Principles of Material Handling

1. Planning Principle. Plan all material handling and storage activities to obtain maximum overall operating efficiency.

2. Systems Principle. Integrate as many handling activities as is practical into a coordinated system of operations, covering vendor, receiving, storage, production, inspection, packaging, warehousing, shipping, transportation, and customer.

3. Material Flow Principle. Provide an operation sequence and equipment layout optimizing material flow.

4. Simplification Principle. Simplify handling by reducing, eliminating, or combining unnecessary movements and/or equipment.

5. Gravity Principle. Utilize gravity to move material wherever practical.

6. Space Utilization Principle. Make optimum utilization of building cube.

7. Unit Size Principle. Increase the quantity, size, or weight of unit loads or flow rate.

8. Mechanization Principle. Mechanize handling operations.

9. Automation Principle. Provide automation to include production, handling, and storage functions.

10. Equipment Selection Principle. In selecting handling equipment consider all aspects of the material handled — the movement and the method to be used.

11. Standardization Principle. Standardize handling methods as well as types and sizes of handling equipment.

12. Adaptability Principle. Use methods and equipment that can best perform a variety of tasks and applications where special purpose equipment is not justified.

13. Dead Weight Principle. Reduce ratio of dead weight of mobile handling equipment to load carried.

14. Utilization Principle. Plan for optimum utilization of handling equipment and manpower.

15. Maintenance Principle. Plan for preventive maintenance and scheduled repairs of all handling equipment.

16. Obsolescence Principle. Replace obsolete handling methods and equipment when more efficient methods or equipment will improve operations.

17. Control Principle. Use material handling activities to improve control of production, inventory and order handling.

18. Capacity Principle. Use handling equipment to help achieve desired production capacity.

19. Performance Principle. Determine effectiveness of handling performance in terms of expense per unit handled.

20. Safety Principle. Provide suitable methods and equipment for safe handling.

Fig. 38.12 Twenty principles of material handling.

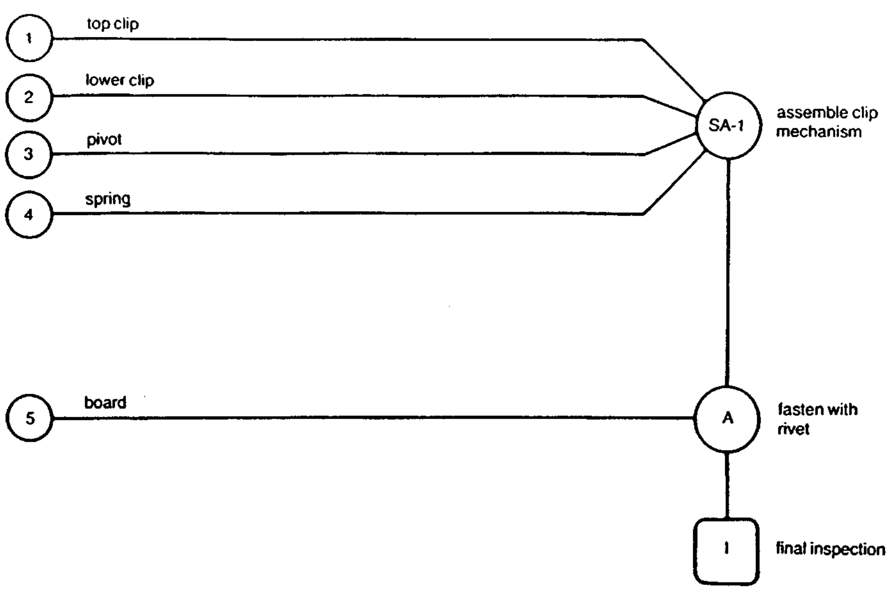


Fig. 38.13 Assembly chart.

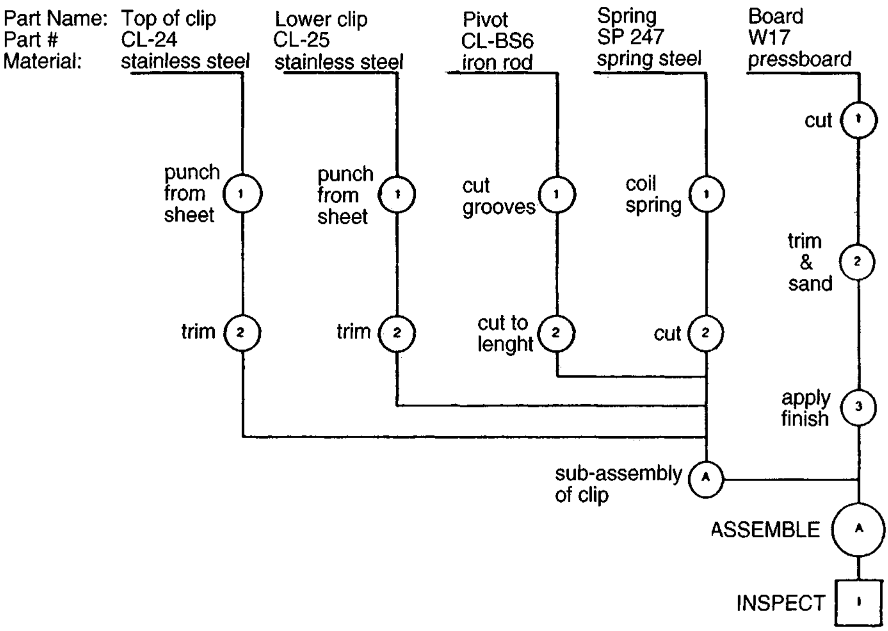


Fig. 38.14 Operations process chart.

other (using an alphabetic symbol) and the reason for the assignment of that rating (using a numeric symbol). Together these charting techniques provide the analyst extensive, qualitative data about the layout to support a production process. This is very useful from the standpoint of designing a material handling system.

38.4.5 Unitizing Loads

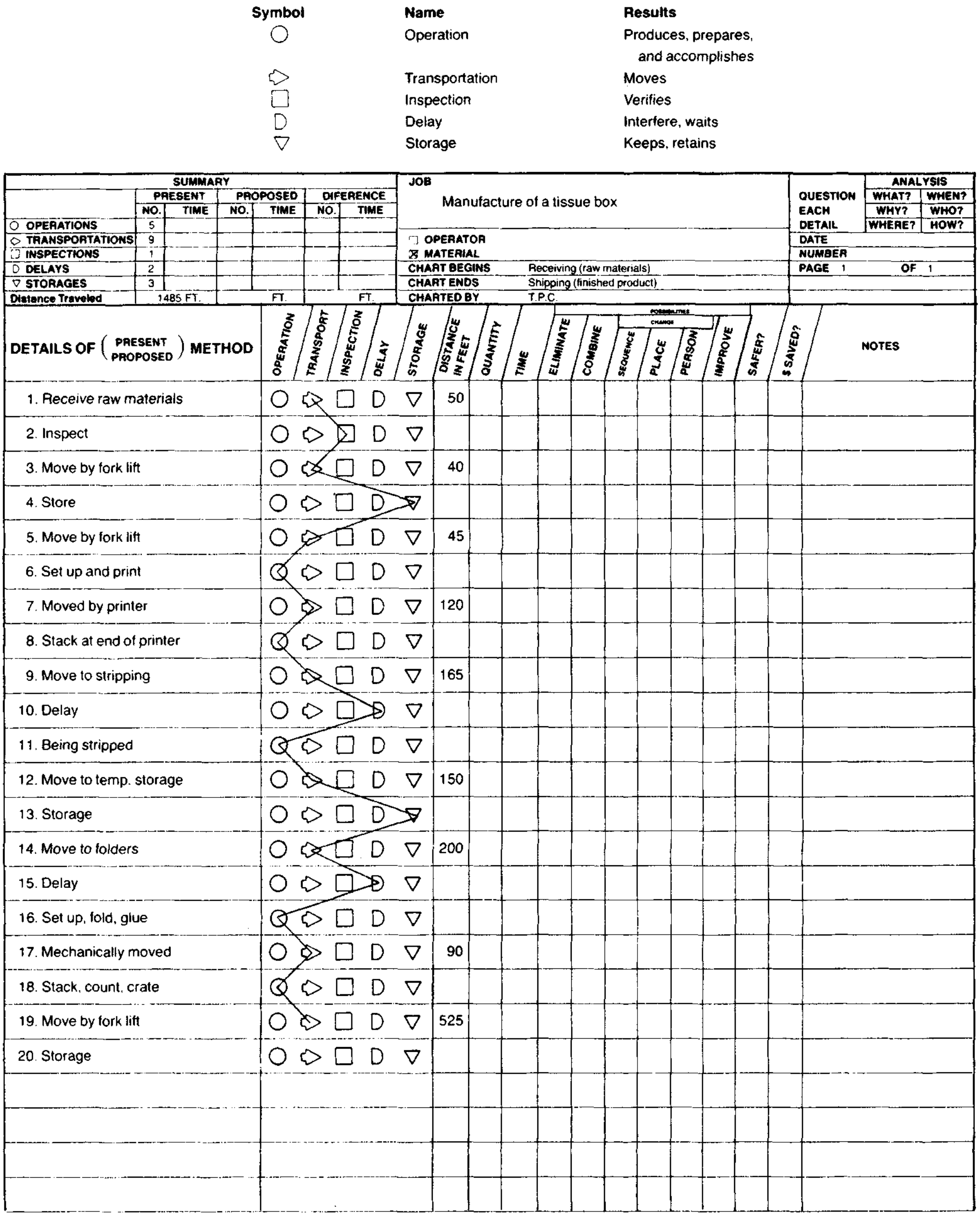
Principle number 7 of the MHI Twenty Principles of Material Handling (Fig. 38.12) is the *unit size principle,* also known as the *unit load principle,* which states, " Increase the quantity, size, or weight of unit loads or flow rate." The idea behind this principle is that if materials are consolidated into large quantities or sizes, fewer moves of this material will have to be made to meet needs of the production processes. Therefore, less time will be required to move the unitized material than that required to move the same quantity of non-unitized material. So, unitizing materials usually results in low-cost, efficient material-handling practices.

The decision to unitize is really a design decision in itself, as illustrated in Fig. 38.19. Unitization can consist of individual pieces through unit packs, inner packs, shipping cartons, tiers on pallets, pallet loads, containers of pallets, truckloads, and so on. The material-handling system must then be designed to accommodate the level of unitized parts at each step of the production process.

As shown in Fig. 38.19, once products or components have been unitized into shipping cartons, further consolidation may easily be achieved by placing the cartons on a pallet, slip sheet, or some other load-support medium for layers (or tiers) of cartons comprising the unit load. Since the unit load principle requires the maximum utilization of the area on the pallet surface, another design problem is to devise a carton stacking pattern that achieves this objective. Examples of pallet loading patterns that can achieve optimal surface utilization are illustrated in Fig. 38.20. Charts of such patterns are available from the U.S. Government (General Services Administration). There are also a number of providers of computer software programs for personal computers that generate pallet-loading patterns.

Highly automated palletizer machines as well as palletizing robots are available that can be programmed to form unit loads in any desired configuration. Depending upon the dimensions of the cartons to be palletized, and the resulting optimal loading pattern selected, the palletized load may be inherently stable due to overlapping of cartons in successive tiers; for example, the various pin-wheel patterns shown in Fig. 38.20.

However, other pallet-loading patterns may be unstable, such as the block pattern in Fig. 38.21, particularly when cartons are stacked several tiers high. In such instances, the loads may be stabilized by stretch-wrapping the entire pallet load with plastic film, or by placing bands around the individual



Symbol	Name	Results
○	Operation	Produces, prepares, and accomplishes
⇨	Transportation	Moves
□	Inspection	Verifies
D	Delay	Interfere, waits
▽	Storage	Keeps, retains

SUMMARY	PRESENT NO.	PRESENT TIME	PROPOSED NO.	PROPOSED TIME	DIFERENCE NO.	DIFERENCE TIME
○ OPERATIONS	5					
⇨ TRANSPORTATIONS	9					
□ INSPECTIONS	1					
D DELAYS	2					
▽ STORAGES	3					
Distance Traveled	1485 FT.		FT.		FT.	

JOB: Manufacture of a tissue box
□ OPERATOR
☒ MATERIAL
CHART BEGINS: Receiving (raw materials)
CHART ENDS: Shipping (finished product)
CHARTED BY: T.P.C.

ANALYSIS — QUESTION EACH DETAIL: WHAT? WHEN? WHY? WHO? WHERE? HOW?
DATE
NUMBER
PAGE 1 OF 1

DETAILS OF (PRESENT / PROPOSED) METHOD	DISTANCE IN FEET
1. Receive raw materials	50
2. Inspect	
3. Move by fork lift	40
4. Store	
5. Move by fork lift	45
6. Set up and print	
7. Moved by printer	120
8. Stack at end of printer	
9. Move to stripping	165
10. Delay	
11. Being stripped	
12. Move to temp. storage	150
13. Storage	
14. Move to folders	200
15. Delay	
16. Set up, fold, glue	
17. Mechanically moved	90
18. Stack, count, crate	
19. Move by fork lift	525
20. Storage	

Fig. 38.15 Flow process chart.

tiers. The wrapping or banding operations themselves can be automated by use of equipment that exists in the market today.

Once the unit load has been formed, there are only four basic ways it can be handled while being moved. These are illustrated in Fig. 38.22 and consist of the following:

1. Support the load from below.
2. Support or grasp the load from above.
3. Squeeze opposing sides of the load.
4. Pierce the load.

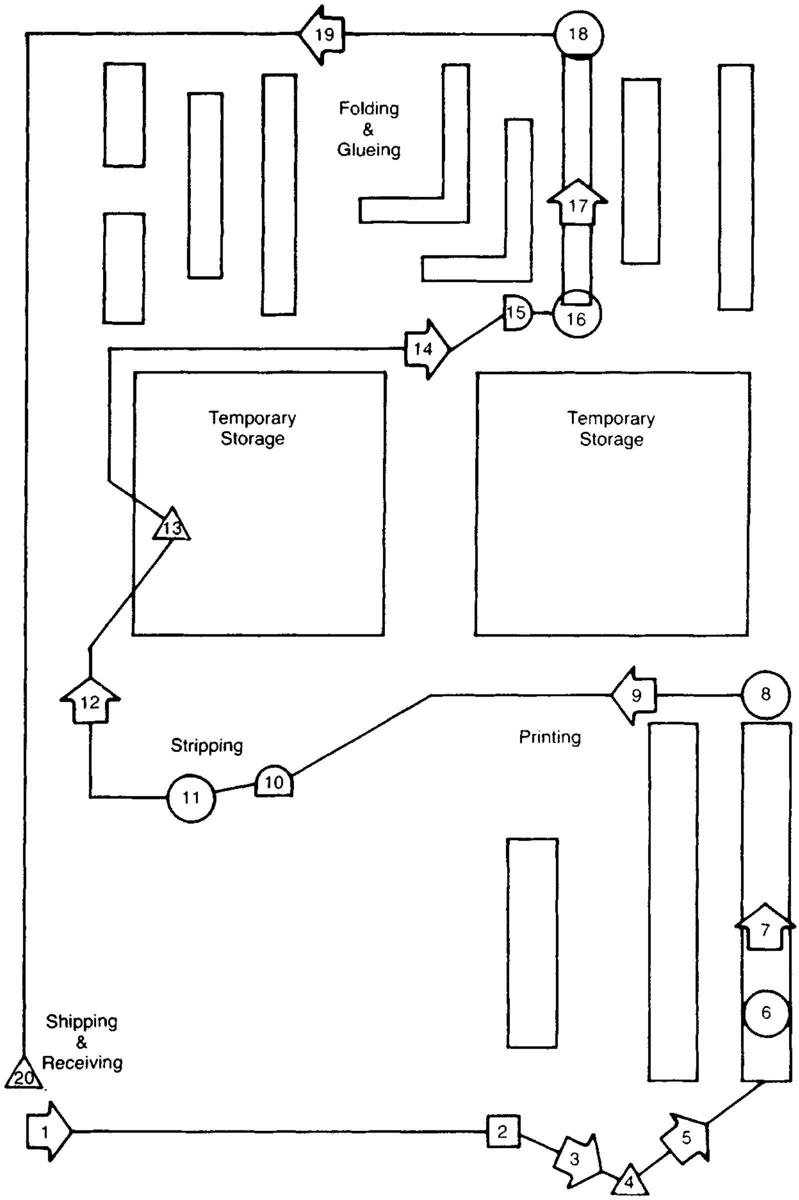


Fig. 38.16 Flow diagram.

These handling methods are implemented individually, or in combination, by commercially available material-handling equipment types.

38.5 MATERIAL-HANDLING EQUIPMENT CONSIDERATIONS AND EXAMPLES

38.5.1 Developing the Plan

Once the material-handling problem has been identified and the relevant data have been collected and analyzed, the next step in the design process is to develop a plan for solving the problem. This usually involves the design and/or selection of appropriate types, sizes, and capacities of material-handling equipment. In order to properly select material handling equipment, it must be realized that in most cases, the solution to the problem does not consist merely of selecting a particular piece of