CHAPTER 10

TRANSFER AND TRANSPORT

In the field of solid waste management, the functional element of transfer and transport refers to the means, facilities, and appurtenances used to effect the transfer of wastes from one location to another, usually more distant, location. Typically, the contents of relatively small collection vehicles are transferred to larger vehicles that are used to transport the waste over extended distances either to MRFs or to disposal sites. Transfer and transport operations are also used in conjunction with MRFs to transport recovered materials to markets or waste-to-energy facilities and to transport residual materials to landfills.

10-1 THE NEED FOR TRANSFER OPERATIONS

Transfer and transport operations become a necessity when haul distances to available processing centers or disposal sites increase so that direct hauling is no longer economically feasible [5]. They also become a necessity when processing centers or disposal sites are sited in remote locations and cannot be reached directly by highway. Transfer operations are an integral part of all types of MRFs. Transfer stations are also an integral part of large integrated MR/TFs. For reasons of public safety, the use of a small transfer station, for individuals hauling wastes in automobiles and pickups and other noncommercial haulers, at landfills is gaining in popularity.

Transfer operations can be used successfully with all types of collection vehicles and conveyor systems. Additional factors that tend to make the use of transfer operations attractive include (1) the occurrence of illegal dumping due to excessive haul distances, (2) the location of disposal sites relatively far from collection routes (typically more than 10 mi), (3) the use of small-capacity collection vehicles (generally under 20 yd^3), (4) the existence of low-density residential service areas, (5) the use of a hauled container system with relatively small containers for the collection of wastes from commercial sources, and (6) the use of hydraulic or pneumatic collection systems.

Excessive Haul Distances

In the early days when horse-drawn carts were used for the collection of solid wastes, it was common practice to empty the contents of the loaded carts into some auxiliary vehicle for transport to some intermediate point for processing or to the disposal site. However, with the advent of the modern motor truck and the availability of low-cost fuel, transfer operations in most cities were abandoned and direct hauling was adopted. Today, with rising labor, operating, and fuel costs and the absence of nearby solid waste disposal sites the trend is reversing, and transfer stations are again becoming common. For example, wastes from the city of Portland, OR, are hauled to a disposal site 150 mi away.

Usually, the decision to use a transfer operation is based on economics. For example, in Examples 8-2 and 8-5 the time and economic advantages of the stationary container system over the hauled container system were demonstrated clearly. Simply stated, it is cheaper to haul a large volume of wastes in large increments over a long distance than it is to haul a large volume of wastes in small increments over a long distance. The economic advantage of a transfer operation is illustrated in Example 10-1.

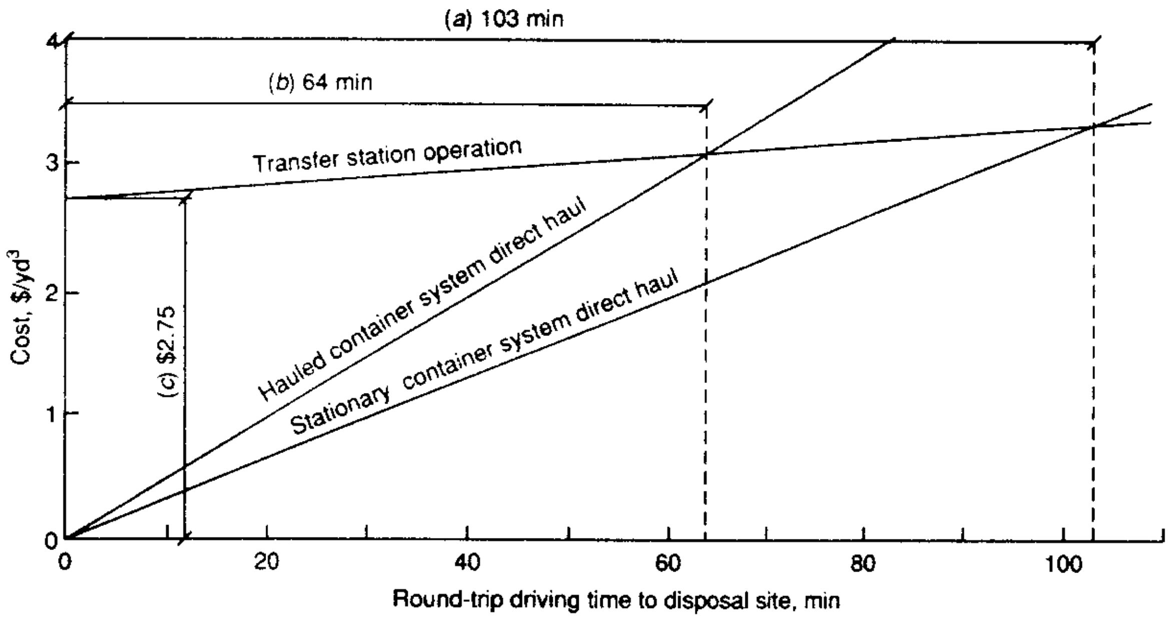
Example 10-1 Economic comparison of transport alternatives. Determine, based on operating costs, the break-even points for a hauled and a stationary container system as compared with a system using transfer and transport operations for transporting wastes collected from a metropolitan area to a landfill disposal site. Assume that the following cost data are applicable:

1. Operating costs
   (*a*) Haul container system using a hoist truck with an 8-yd^3 container = \$25/h
   (*b*) Stationary container system using a 20-yd^3 compactor = \$40/h
   (*c*) Tractor-semitrailer transport unit with a capacity of 105 yd^3 = \$40/h
   (*d*) Transfer station operation cost = \$2.75/yd^3

Solution

1. Convert the haul cost data to units of dollars per cubic yard per minute (see comment at end of this example).
   (*a*) Hoist truck = \$0.052/$yd^3 \cdot$ min
   (*b*) Compactor = \$0.033/$yd^3 \cdot$ min
   (*c*) Transfer station transport equipment = \$0.0063/$yd^3 \cdot$ min

2. Prepare a plot of the cost per cubic yard versus the round-trip driving time expressed in minutes for the three alternatives. The required plot is presented below.



(a) Break-even time for stationary container system
(b) Break-even time for hauled container system
(c) Transfer station operating cost

3. Determine the break-even times for the hauled and stationary container systems using the plot prepared in Step 2.
   (*a*) Hauled container system = 64 min
   (*b*) Stationary container system = 103 min

   Thus, for example, if a stationary container system is used and the round-trip driving time to the disposal site is more than 103 min, the use of a transfer station should be investigated.

Comment. In most cases, articles, and reference books dealing with the long-distance hauling of solid wastes, cost data are expressed in terms of dollars per ton per minute or dollars per ton per mile. This practice is widely accepted for transfer station analysis because weight is the most critical measure for efficient highway or rail movement. Such cost data can be misleading, however, when the densities of solid wastes vary significantly from location to location or container to container. For example, if the density of the wastes in two hoist-truck containers varies by a factor of three, then comparing the costs of hauling two containers of the same size on a per-ton basis would tend to be misleading because the actual cost is the same for both. On the other hand, a comparison based on dollars per cubic yard per minute or dollars per minute would be valuable in comparing the two operations.

Remote Processing Facilities or Disposal Sites

Transfer operations must be used when the processing facilities or disposal sites are in such a remote location that conventional highway transportation alone is not feasible. For example, transfer stations are required when rail cars or ocean-going barges must be used to transport wastes to the final point of deposition. If solid wastes are transported by pipeline, a combination transfer-processing station is usually necessary. These subjects are considered further in Section 10-2.

Materials Recovery Facilities

In the materials recovery flow diagrams in Chapter 9, it is clear that the transfer of waste components is an integral part of the operation of a MRF. Because much of the material has been removed from the waste stream, the transfer facilities tend to be smaller.

Materials Recovery/Transfer Facilities

A recent trend in the waste management field is the development of large integrated MR/TFs. Integrated MR/TFs are multipurpose facilities that may include the functions of drop-off center, separation, composting, bioconversion processes, production of refuse-derived fuel, and transport. The use of large integrated MR/TFs is attractive because of the cost savings that are possible by combining several waste management activities in a single facility.

Convenience Transfer Station at Landfill

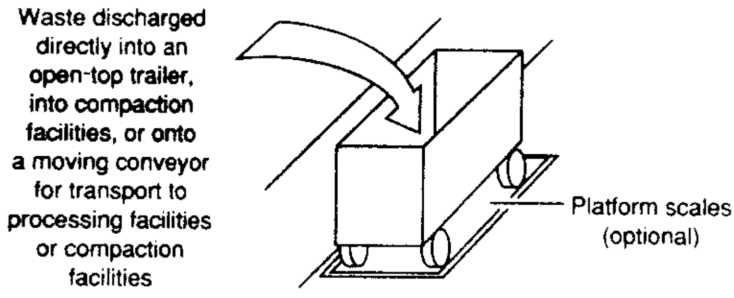
Because of safety concerns and the many new restrictions governing the operation of landfills, many landfill operators have constructed convenience transfer stations at the landfill site for the unloading of wastes brought to the site by individuals and small-quantity haulers. By diverting private individuals and small-quantity haulers to a separate transfer facility, the potential for accidents at the working face of the landfill is reduced significantly.

10-2 TYPES OF TRANSFER STATIONS

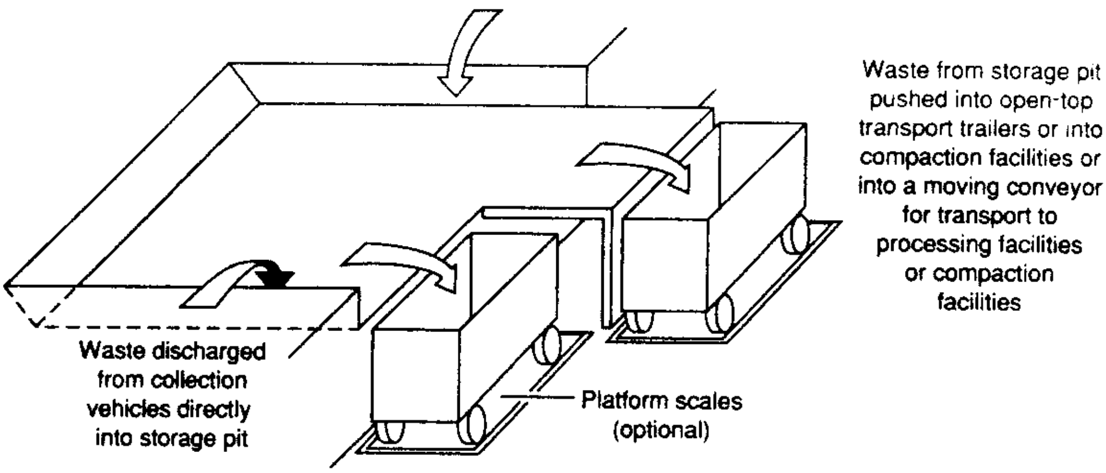
Transfer stations are used to accomplish transfer of solid wastes from collection and other small vehicles to larger transport equipment. Depending on the method used to load the transport vehicles, transfer stations may be classified into three general types: (1) direct-load, (2) storage-load, and (3) combined direct-load and discharge-load (see Fig. 10-1). Transfer stations may be classified with respect to throughput capacity (the amount of material that can be transferred and hauled) as follows: small, less than 100 ton/d; medium, between 100 and 500 ton/d; and large, more than 500 ton/d.

Direct-Load Transfer Stations

At direct-load transfer stations, the wastes in the collection vehicles are emptied directly into the vehicle to be used to transport them to a place of final disposition or into facilities to compact the wastes into transport vehicles or into waste bales



(*a*)



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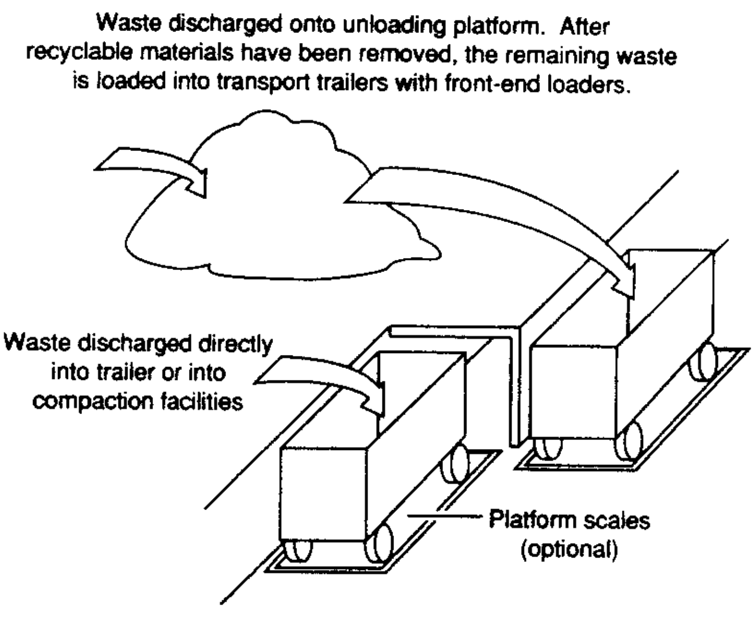


(*c*)

FIGURE 10-1
Definition sketch for the types of transfer stations: (*a*) direct-load, (*b*) storage-load, and (*c*) combined direct-load and discharge-load.

that are transported to the disposal site (see Fig. 10-1*a*). In some cases, the wastes may be emptied onto an unloading platform and then pushed into the transfer vehicles, after recyclable materials have been removed. The volume of waste that can be stored temporarily on the unloading platform is often defined as the *surge capacity* or the *emergency storage capacity* of the station.

Large Capacity Direct-Load Transfer Station without Compaction. In a large-capacity direct-load transfer station, the wastes in the collection vehicles usually are emptied directly into the transport vehicle. To accomplish this, these transfer stations usually are constructed in a two-level arrangement. The unloading dock or platform from which wastes from collection vehicles are discharged into the transport trailers can be elevated (see Fig. 10-2), or the transport trailers can be located in a depressed ramp (see Fig. 10-3). Photographs of a facility like that shown in Fig. 10-3 and some of the equipment used are shown in Fig. 10-4. In some direct-load transfer stations, the contents of the collection vehicles can be emptied temporarily onto the unloading platform if the trailers are filled or are being hauled to the disposal sites. The wastes are then pushed into the transport trailers.

The operation of the direct-load transfer station shown in Fig. 10-3 may be summarized as follows. Upon arrival at the transfer station, all vehicles hauling wastes are weighed by the weighmaster, who then indicates where the wastes should be unloaded by giving the driver an appropriate stall number. After the collection vehicles have been unloaded, they are reweighed and the disposal fee is determined. Commercial vehicles that regularly use the transfer station are issued credit cards showing the firm name and the truck tare weight, thereby eliminating the second weighing for these vehicles. As the trailers become loaded, the wastes in the trailer are shifted and compacted with a clamshell mounted on a rubber-tired tractor (see Fig. 10-4*b*). When the trailers are full or the maximum allowable tonnage has been placed in them, as indicated by the weighmaster, they are removed and prepared for the haul operation. Trailer volume and weight are the variables that must be checked by the operator before sending out loaded trailers.

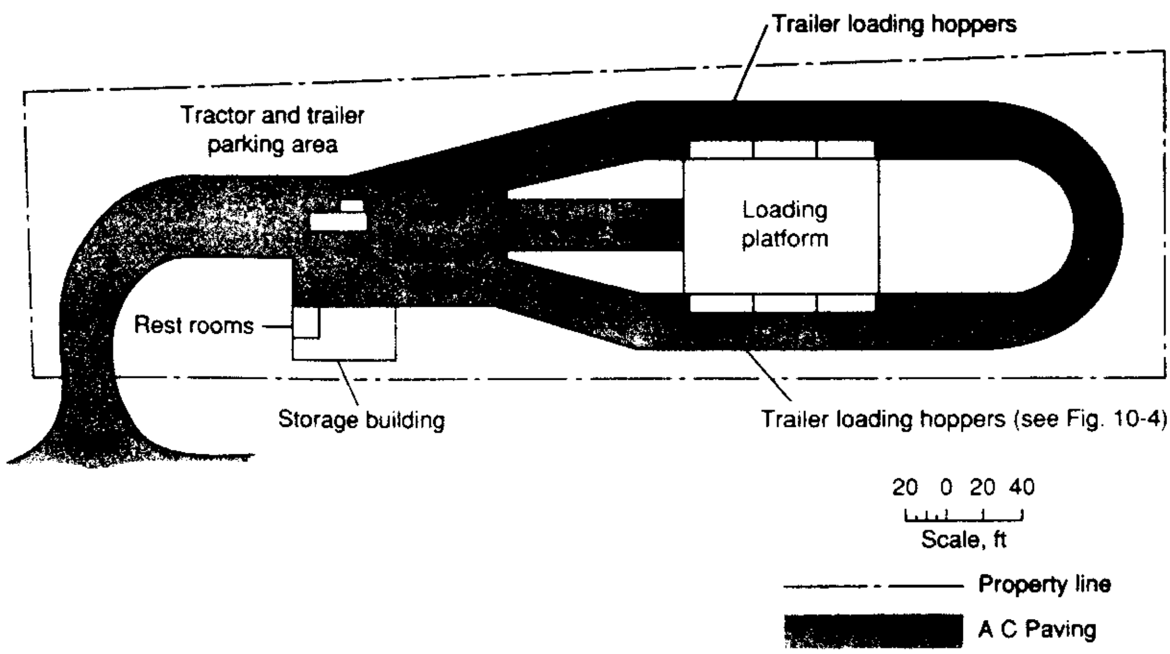


FIGURE 10-2
Typical direct-load transfer station with elevated unloading platform.

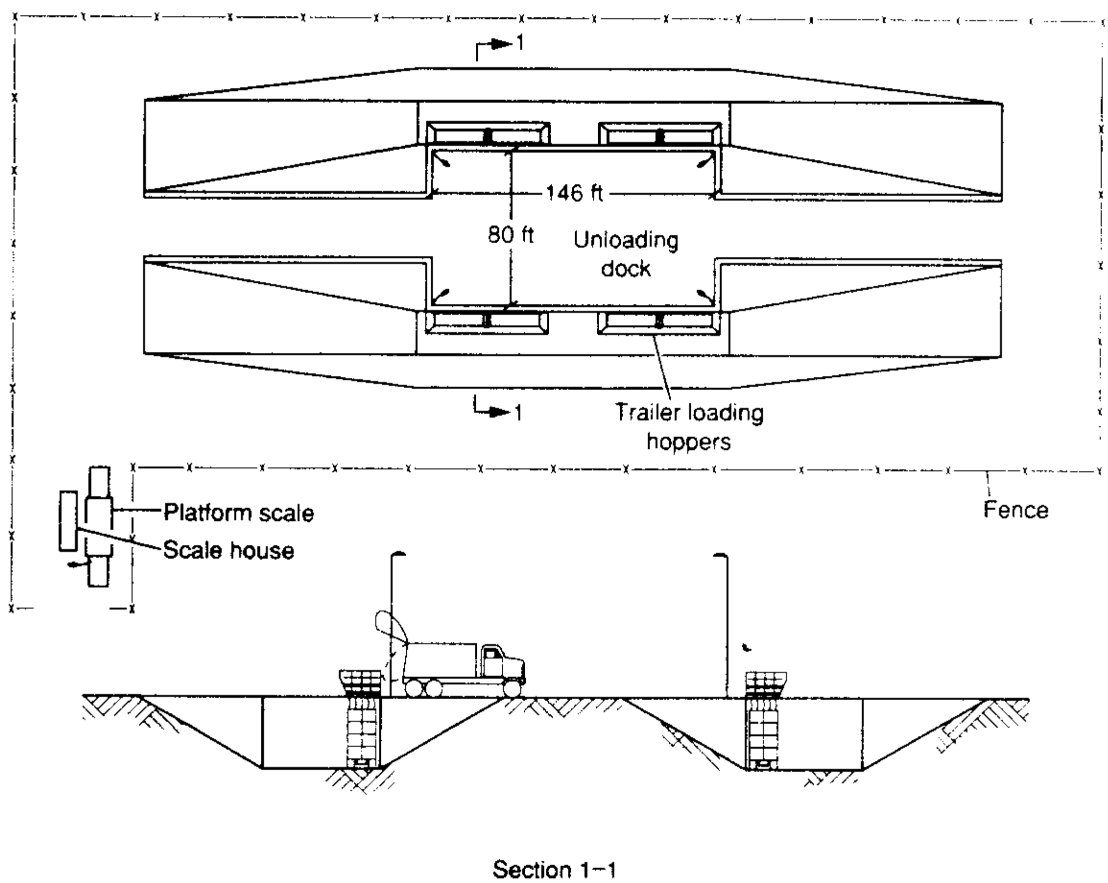
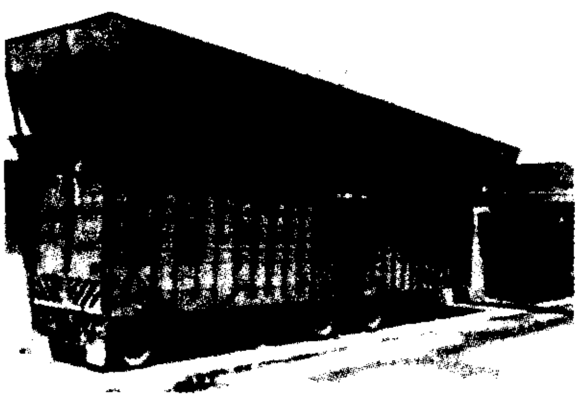
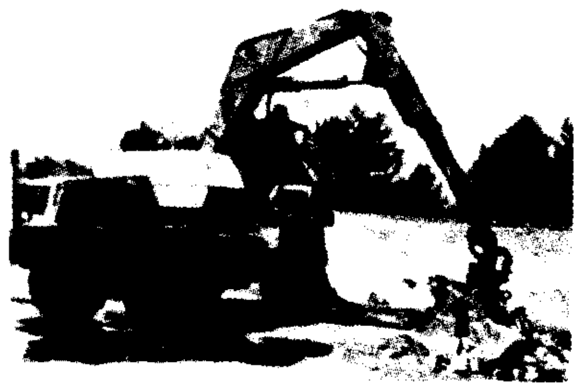


FIGURE 10-3
Typical direct-load transfer station with transport trailers located in depressed ramps. Note the heavy chain sections hung from bottom of hopper are used to direct wastes into transfer trailers.



(*a*)



(*b*)

FIGURE 10-4
Facilities and equipment used at transfer station shown in Fig. 10-3: (*a*) end view showing trailers positioned under loading hopper in depressed ramp and (*b*) clamshell mounted on rubber-tired tractor on ground-level unloading platform is used to distribute and compact wastes in trailers and to pick up wastes spilled on unloading platform.

Large-Capacity Direct-Load Transfer Stations with Compactors. A popular variation of the direct-load transfer station described above is the replacement of the open-top transfer vehicles in which the wastes are not compacted with compaction facilities. The compaction facilities can be used to compact wastes directly into the transfer trailers or to produce waste bales. The operation of a direct-load transfer station with compaction facilities is essentially the same as the operation of a direct-load transfer station with open trailers except that the wastes are compacted into large transfer trailers using stationary compactors. In some cases, the wastes are conveyed to the compaction facilities.

In the direct-load transfer station with compaction facilities in which large waste bales are produced (see Fig. 10-5), wastes from the collection vehicles are unloaded directly onto the unloading platform or directly into the compaction pit hopper. After recyclable materials have been removed, a rubber-tired vehicle is

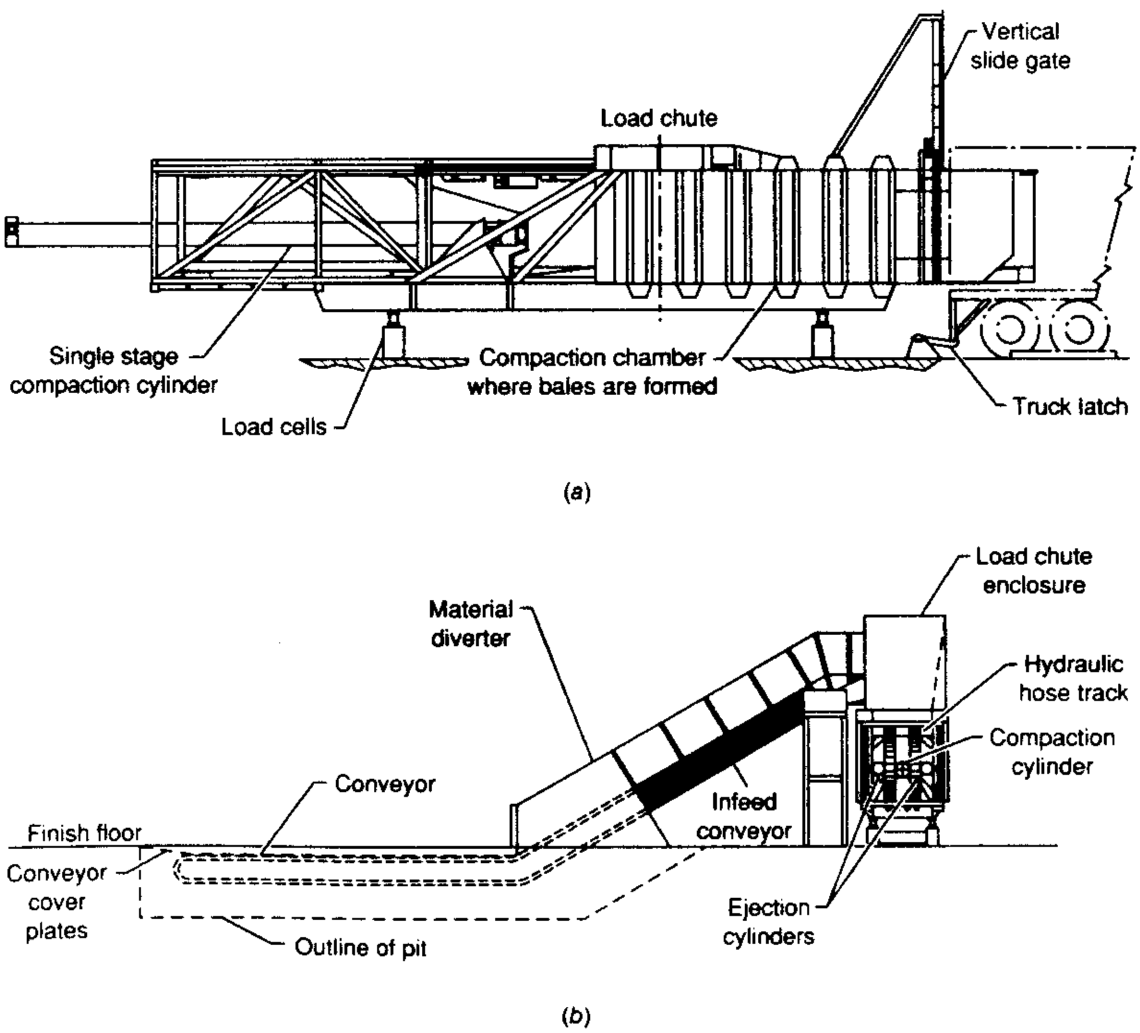


FIGURE 10-5
Compaction facilities used to produce waste bales at transfer stations: (*a*) side view of compactor with open-top direct-load chute (once a bale has been formed by compacting waste into the compaction chamber, the vertical slide gate is lifted and the bale is pushed into the transport trailer or semitrailer) and (*b*) end view of large-capacity baler equipped with enclosed load chute. Wastes are loaded into the baler with a continuous feed conveyor. (Courtesy of SSI Shredding Systems, Inc.)

used to push the wastes discharged on the unloading platform into the compactor. The compressed waste bale is loaded onto the semitrailer for transport to the disposal site. By producing a bale which, after partial expansion, is smaller than the inside dimensions of the leak-proof semitrailer transport vehicle, the cost of the transfer can be minimized.

Medium- and Small-Capacity Direct-Load Transfer Stations with Compactors. A typical medium-capacity direct-load transfer station with compaction facilities is shown in Fig. 10-6. Operationally, after the trucks are weighed, they enter the transfer station where they are directed to an unloading location. The

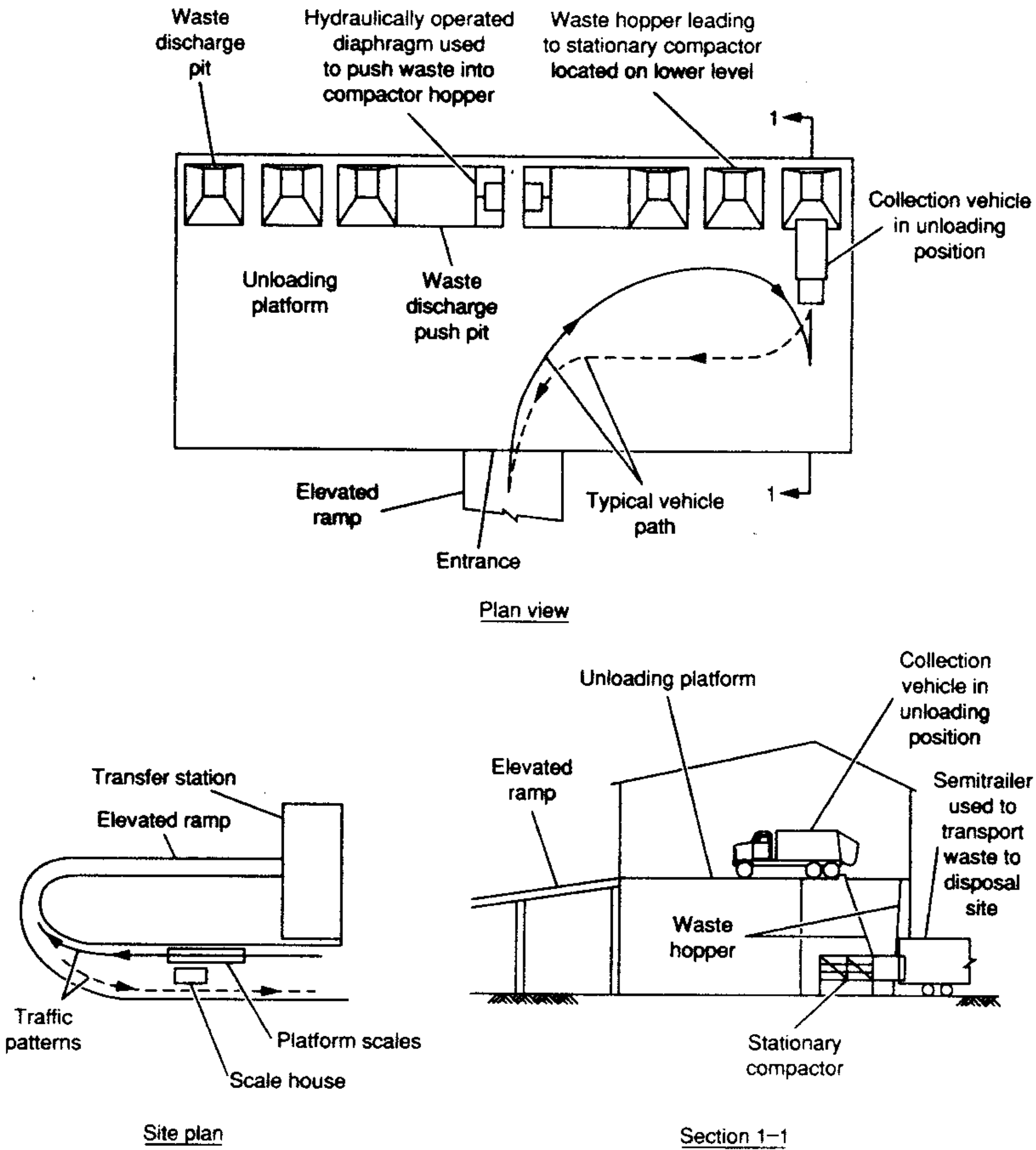


FIGURE 10-6
Enclosed medium-capacity direct-load transfer station equipped with stationary compactors.

unloading location may be one of the individual hoppers leading to a compactor or one of the rectangular waste receiving pits. Each pit is equipped with a hydraulically powered diaphram that is used to push the accumulated waste to the compactor hopper located at the opposite end of the pit. If there are no semitrailers to load, wastes are discharged temporarily on the unloading platform, from where they are loaded into the compactor hoppers with a rubber-tired front-end loader. Views of the transfer station of Fig. 10-6 are shown in Fig. 10-7.

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

FIGURE 10-7
View of transfer station shown in Fig. 10-6: (*a*) collection vehicle being weighed at entrance to transfer station, (*b*) unloading contents of collection vehicle into compactor hopper, (*c*) horizontal compactor used to compress wastes into transport trailers, and (*d*) transfer trailer being backed up to horizontal compactor, Bogota, Colombia.

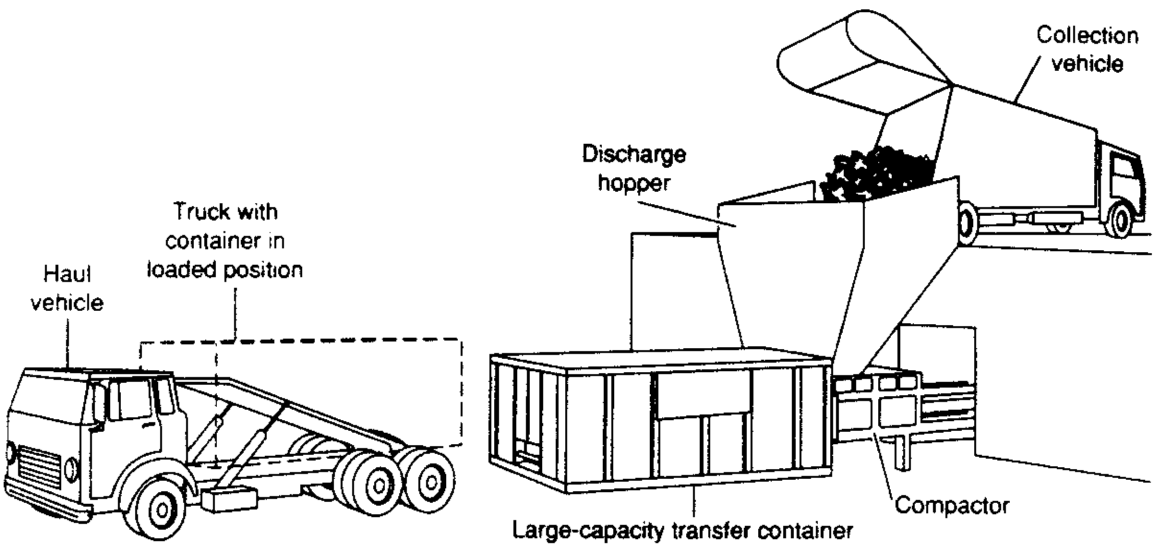


FIGURE 10-8
Small-capacity direct-load a transfer station equipped with a stationary compactor. (Adapted from Schindler Waggon AG, Prattein.)

A small-capacity direct-load transfer station with compaction facilities is shown in Fig. 10-8. As shown, a large container is used with this type of transfer station as opposed to a transfer trailer. The container is hauled to the disposal site using a tilt-frame vehicle (see Fig. 8-10). Depending on the length of time required to haul the loaded container to the disposal site and to return, an empty container may be attached to the compactor before the full container is hauled to the disposal site.

Small-Capacity Direct-Load Transfer Stations Used in Rural Areas. Used in rural and recreational areas, small-capacity direct-load transfer stations like those shown in Figs. 10-9 and 10-10 are designed so that the loaded containers are emptied into a collection vehicle for transport to the disposal site. In the design and layout of such stations, which are usually unattended, the key consideration should be simplicity. Complex mechanical systems are not suitable in such locations. The number of containers used depends on the area served and the collection frequency that can be provided. To facilitate unloading, the tops of the containers may be set about 3 ft above the top of the unloading-area platform (see Fig. 10-9). Alternatively, the tops of the containers may be set level with the unloading area (see Fig. 10-10), and the area behind the containers can be excavated to provide space for maneuvering the collection vehicles when the contents of the containers are emptied.

Small-Capacity Direct-Load Transfer Station Used at Landfill Disposal Site. The transfer station shown in Fig. 10-11 is of the type used at landfill disposal sites for individuals and small-quantity haulers. The transfer facilities are also used for the recovery of recyclable materials. After any recyclable items are dropped off, waste materials are emptied into two large transfer trailers each of which is hauled to the disposal site, emptied, and returned to the transfer station.

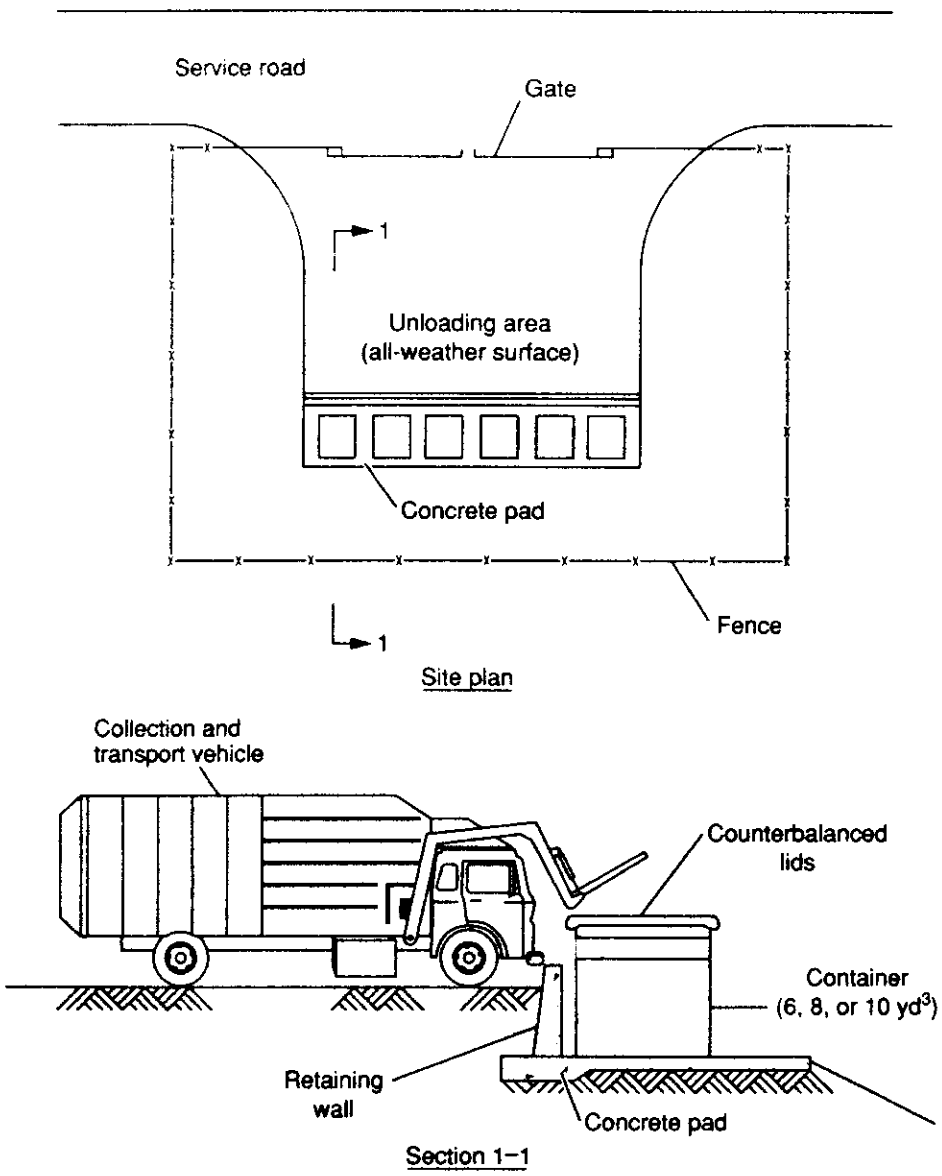


FIGURE 10-9
Small-capacity direct-load transfer station for rural or recreational areas.

Storage-Load Transfer Station

In the storage-load transfer station, wastes are emptied directly into a storage pit from which they are loaded into transport vehicles by various types of auxiliary equipment (see Fig. 10-1*b*). The difference between a direct-load and a storage-load transfer station is that the latter is designed with a capacity to store waste (typically 1–3 days).

Large-Capacity Storage-Load Transfer Station without Compaction. Perhaps the best known example of the storage-load type of transfer station is the San Francisco facility, shown schematically in Fig. 10-12 and pictorially in Fig. 10-13. In this station, all incoming collection trucks are routed to a computerized weigh station for weighing. In addition, the weighmaster records the name of

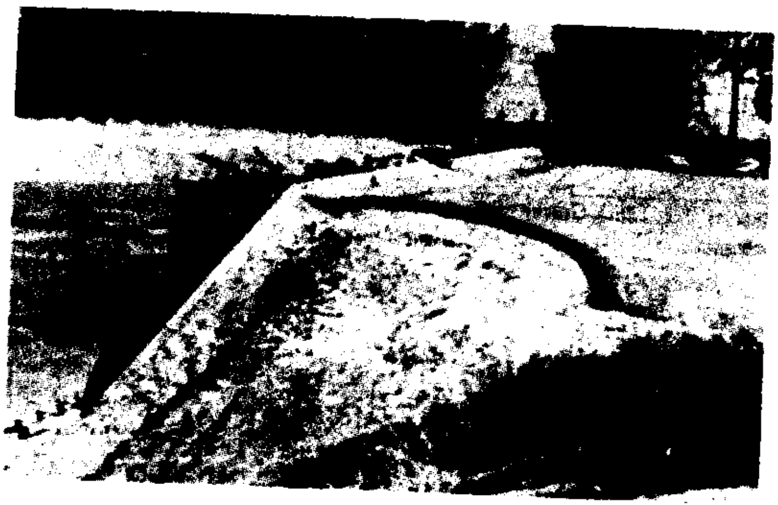
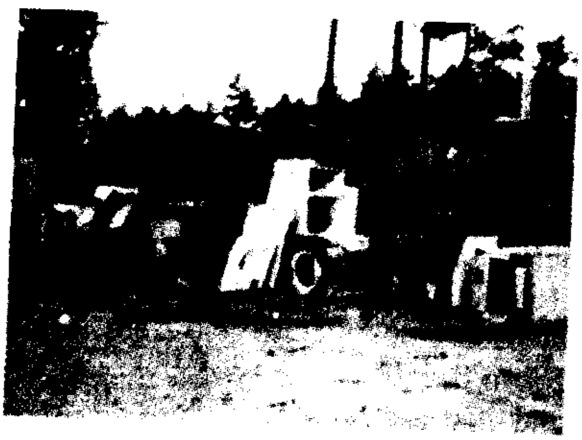


FIGURE 10-10
Small direct-load rural public convenience transfer stations. In transfer station shown on left, the open top containers are placed against retaining wall at same level as unloading platform for ease of loading.



(a)

(b)

FIGURE 10-11
Convenience transfer station located at landfill disposal site. Transfer station is used by individuals hauling wastes in automobiles and pickup trucks and other noncommercial haulers: (a) white goods and other recyclable materials are unloaded first and (b) other wastes are placed in large open-top containers of trailers for transport to the landfill.

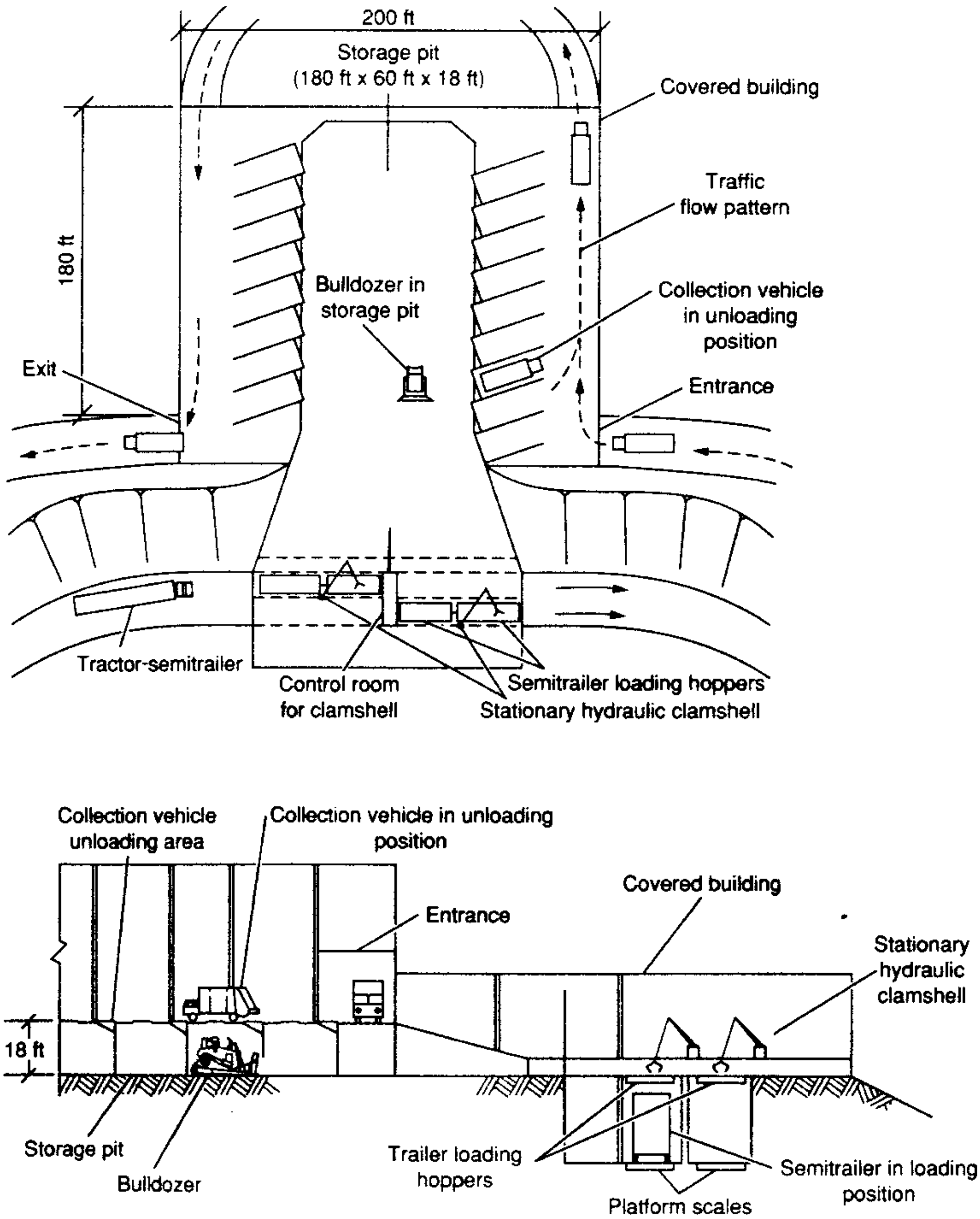
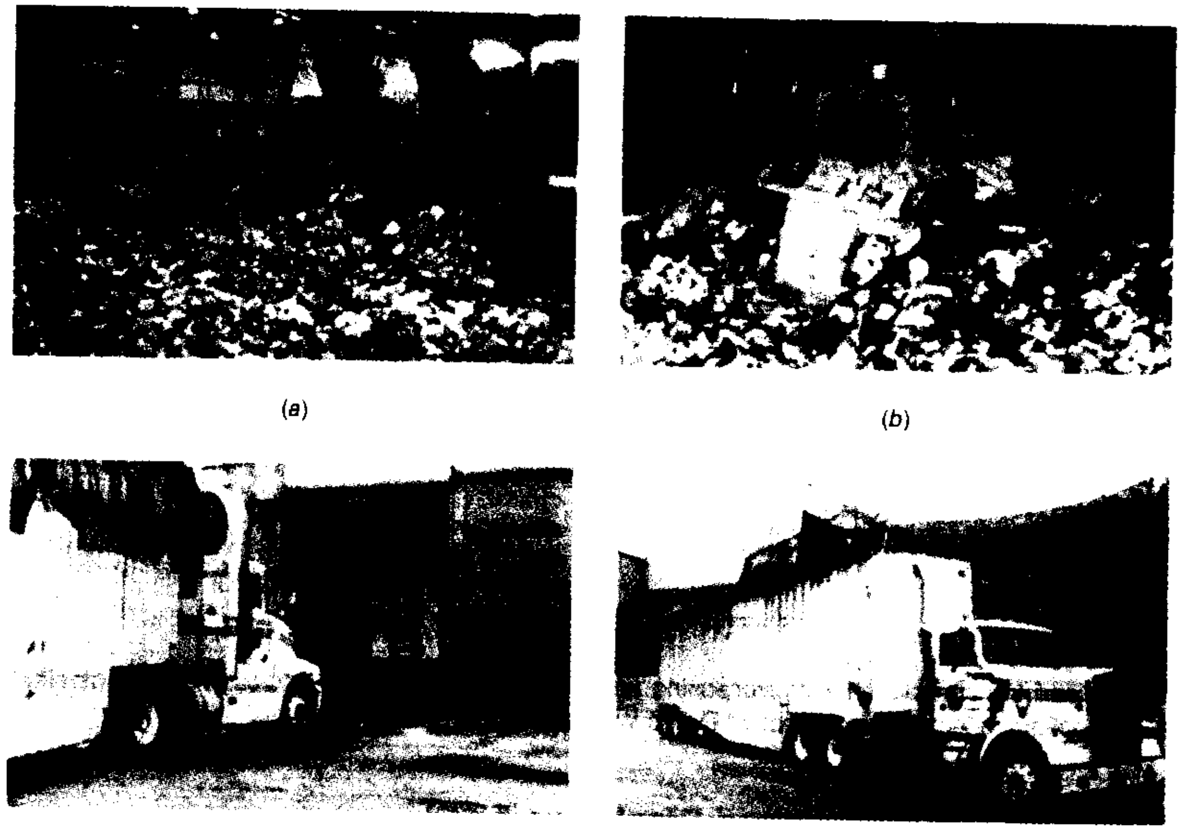


FIGURE 10-12
Enclosed large-capacity (2000 ton/d) storage-load transfer station, San Francisco, CA.

the unloading company, the identification of the particular truck, and the time it entered. Then the weighmaster directs the driver to either the east or the west side of the main entrance of the enclosed transfer station. Once inside, the driver backs up the collection vehicle at a 50° angle to the edge of a depressed central waste storage pit. The contents of the vehicle are emptied into the pit (see Fig. 10-13*a*), and the empty vehicle is driven out of the transfer station.

Within the pit, two bulldozers are used to break up the wastes and to push them into loading hoppers that are located at one end of the pit (see Fig. 10-13*b*).



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

FIGURE 10-13
Operation details for storage-load transfer station shown in Fig. 10-12: (*a*) inside the transfer station, contents of collection vehicles are emptied into storage pit (two crawler tractors are used to break up wastes and push them to the hoppers used to load the semi-trailers), (*b*) solid wastes being pushed into loading hoppers where they fall by gravity into truck-trailer rig parked on platform scales located on lower level (a stationary articulated hydraulic clamshell is used to assist in the loading operation), (*c*) exterior view showing tractor-semitrailer positioned under loading hopper and tractor semitrailer waiting to be filled, and (*d*) screen being placed over loaded drop-bottom semitrailer to prevent the blowing of paper and other materials during the haul operation.

Two articulated bucket-type hoists, located on the other side of the hoppers, are used to remove any wastes that could damage the transport trailers. The wastes fall through the hoppers into trailers located on scales on a lower level (see Fig. 10-13*c*). When the allowable weight limit has been reached, the hoist operator signals the truck driver. The loaded trailers are then driven out of the loading area, and wire screens are placed over the open trailer tops to prevent any papers or other solid wastes from blowing away during transport.

Medium-Capacity Storage-Load Transfer Station with Processing and Compaction Facilities. In the transfer station shown in Fig. 10-14, the wastes are first discharged into a storage pit (also identified as a surge pit). From the storage pit, the wastes are pushed onto a conveyor system to be transported to the shredder. After shredding, ferous metal is removed and the wastes are compacted into transfer trailers for transport to the disposal site.

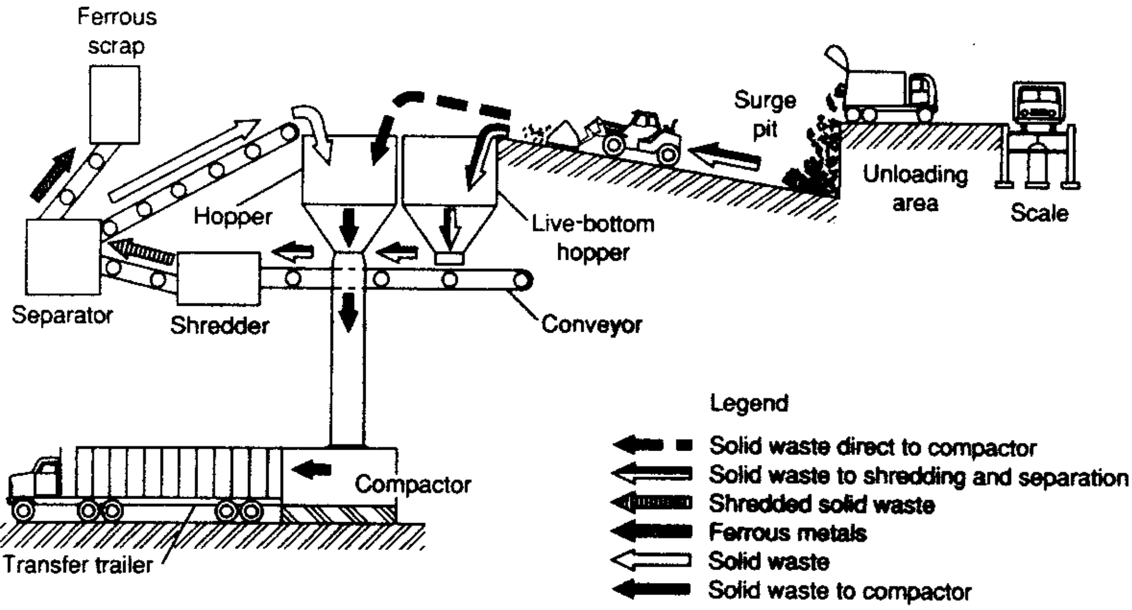


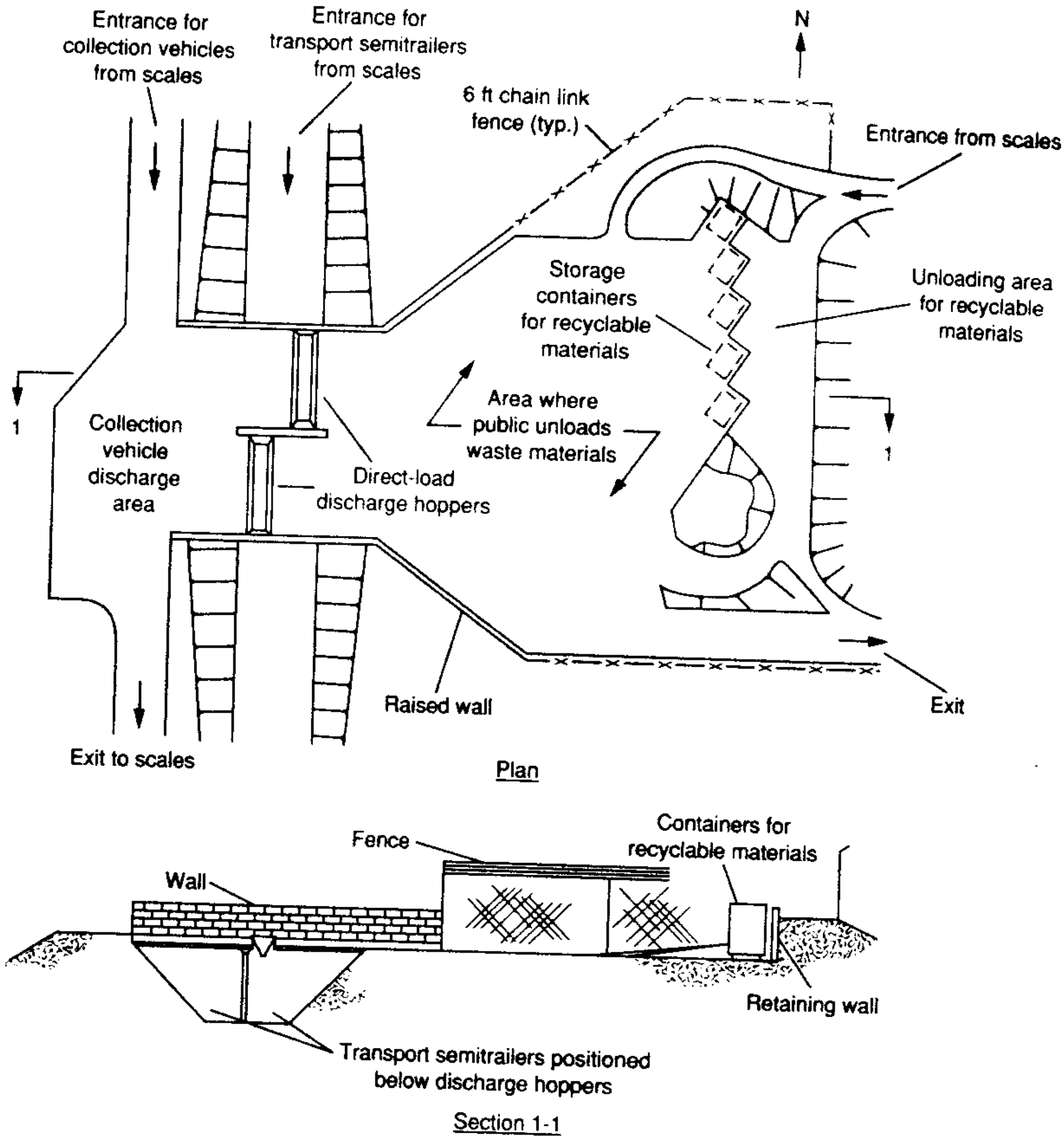
FIGURE 10-14
Storage-load transfer station with processing and compaction facilities. (Courtesy of Municipality of Metropolitan Toronto, Department of Public Works.)

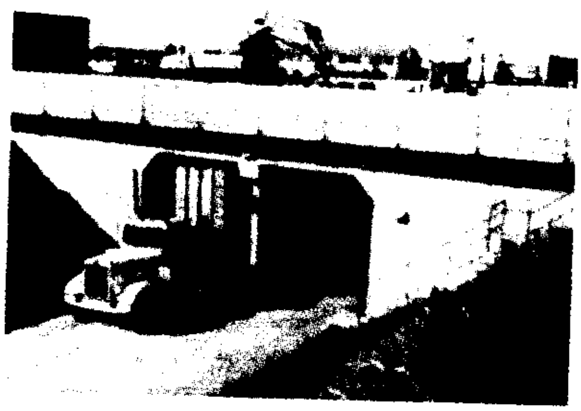
Combined Direct-Load and Discharge-Load Transfer Station

In some transfer stations, both direct-load and discharge-load methods are used (see Fig. 10-1*c*). Usually these are multipurpose facilities that service a broader range of users than a single-purpose facility. A multipurpose transfer station can also house a materials recovery operation. The layout of a multipurpose transfer station, designed for use by the general public and by various waste collection agencies, is shown in Fig. 10-15.

The operation may be described as follows. All waste haulers (general public as well as commercial haulers) wishing to use the transfer station must check in at the scale house. Large commercial collection vehicles are weighed, and a commercial customer ticket is stamped and given to the vehicle driver. The driver then proceeds to the unloading platform and empties the contents of the collection vehicle directly into the transport trailer. After unloading the collection vehicle, the driver returns the vehicle to the scale house for reweighing and turns in her or his customer ticket. The weight of the empty vehicle is recorded while a discharge fee is calculated.

Individual residents as well as small independent noncommercial haulers haul significant quantities of yard wastes, tree trimmings, and bulky wastes (stoves, lawn mowers, refrigerators, etc.) to the transfer station. All automobiles pulling trailers and pickup trucks containing wastes must be checked in at the scale house. These vehicles are not weighed, but users do pay a discharge fee that is collected at the scale house by the attendant, who gives the user a cash receipt. The scale attendant visually checks the waste load to determine if it contains any recyclable materials. If it does, the attendant instructs the driver to deposit the





(a)

(b)

FIGURE 10-15
Combination direct-load and discharge-load transfer station with materials recovery activities: (*a*) view of depressed ramp where transfer trailers are located and (*b*) view of individuals unloading wastes in the public unloading area.

materials at the recycling area before proceeding to the public unloading area. A transfer station employee assists in unloading all recyclable materials. If the waste load contains a predetermined amount of recyclable materials, the driver is given a free pass for a vehicle of the type in which the wastes were delivered for future use. After unloading any recyclable materials, the driver proceeds to the unloading platform and unloads any remaining wastes.

If there are no recyclable materials, the driver proceeds directly to the public unloading area. This area is separated from the direct-load area used by commercial vehicles, by the two 40-ft trailer-loading hopper openings. Wastes that accumulate in the unloading area are pushed periodically into the transfer trailer loading hoppers by a rubber-tired loader. Sometimes additional items are recovered from the unloading area used by the public.

Caution must be used in selecting and designing such transfer stations, for the cost of adding multipurpose facilities is often not justified in terms of the benefits achieved. Station users should be separated to prevent interferences and accidents between the large collection trucks and the smaller private vehicles. The physical separation of the discharge areas usually is the only positive way to maintain system efficiency.

Transfer and Transport Operations at MRFs and MR/TFs

In general, the transfer operations at MRFs involve the loading of trailers with materials that have been separated, materials that have been separated and processed (e.g., baled paper, cardboard, and plastics), and residual materials for landfill disposal. Where open top trailers are used, the transfer operation would be classed as a direct-load. Where processed wastes such as bales are loaded onto transfer trailers, the transfer operation would be classified as storage-load.

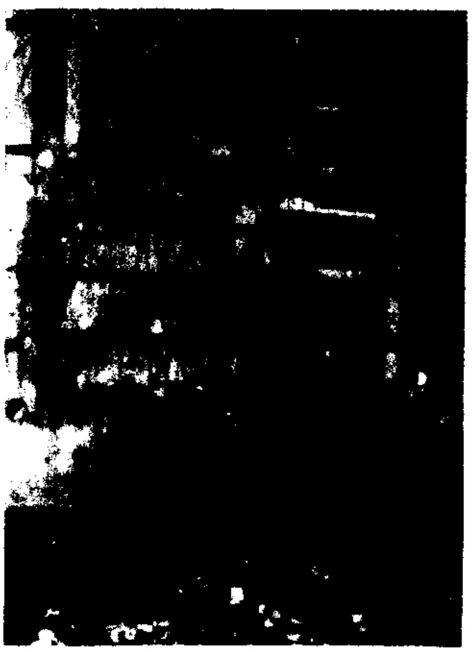


FIGURE 10-16
Conveyor discharging residual waste materials remaining after sorting into storage-load transfer station at a MRF.

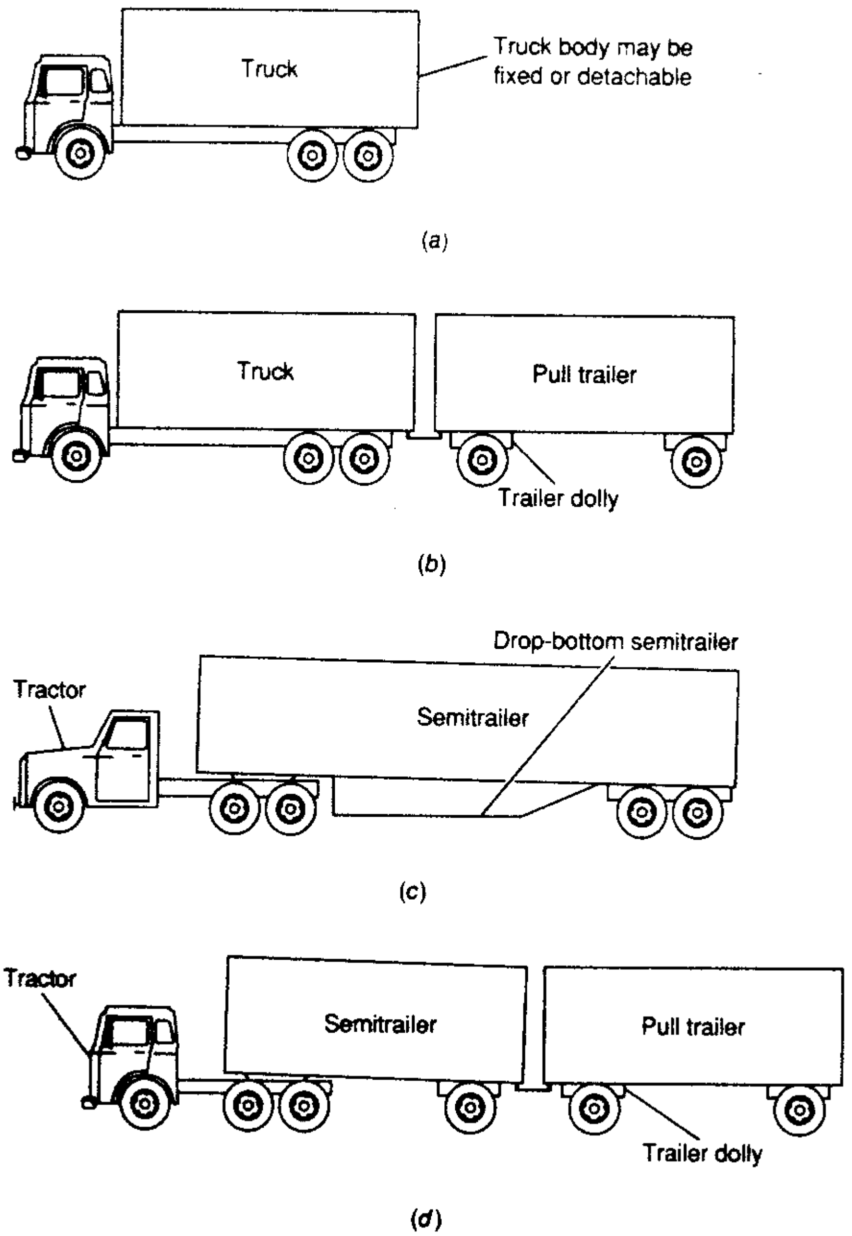
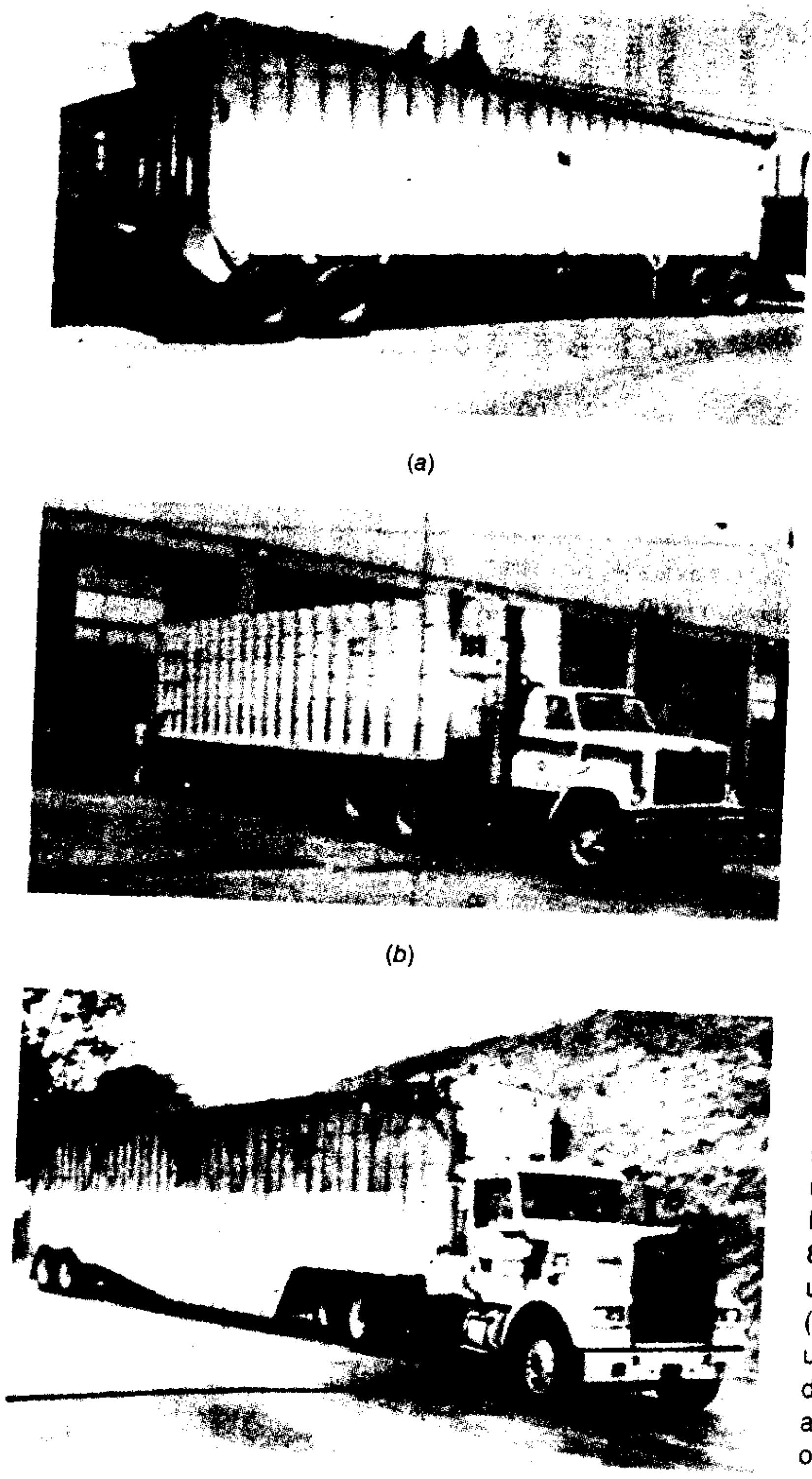


FIGURE 10-17
Definition sketch for the types of vehicles used in conjunction with transfer stations for the transport of wastes: (*a*) truck (also truck chassis with detachable body), (*b*) truck-trailer combination, (*c*) tractor-semitrailer combination (see Fig. 10-18*c*), and (*d*) tractor-semitrailer-pull trailer combination (often identified as a *set of doubles*).

of vehicles, as well as the weight per axle and the total weight. To maximize the payload, transport trailers are often designed with additional axles. Typical data on physical characteristics of the transport trailers are summarized in Table 10-1. Typical values for the amount of solid waste transported by various tractor-trailer, tractor-semitrailer, and tractor-semitrailer-pull trailer combinations are reported in Table 10-2.

Methods used to unload the transport trucks, trailers, semitrailers, and pull trailers may be classified as (1) self-emptying and (2) requiring the aid of auxiliary equipment. Self-emptying transport trucks and semitrailers have mechanisms such



(a)

(b)

(c)

FIGURE 10-18
Typical transport vehicles used in conjunction with transfer facilities: (a) 105-yd^3 open-top semitrailer with moving-floor unloading mechanism (see Figs. 10-19b and 10-20), (b) 85-yd^3 enclosed semitrailer used with stationary compactor (see Fig. 10-7c). Semitrailer is unloaded with movable internal diaphragm (see Fig. 10-19a), and (c) 100-yd^3 drop-bottom open-top semitrailer unloaded with hydraulic tipping ramp (see Fig. 10-21).

as hydraulic dump beds, powered internal diaphragms, and moving floors that are part of the vehicle (see Fig. 10-19). The use of powered internal diaphragms (using a hydraulic piston or moving cables) is the most common method of unloading trucks, semitrailers, and trailers. Moving floors are an adaptation of equipment used in the construction industry for unloading trailers that carry gravel and asphalt. The moving floor usually has two or more sections extending across the

TABLE 10-1

Data on haul vehicles used at large- and medium-capacity transfer stations

Station			Capacity per trailer		Dimensions for single trailer					
Location	Capacity tons/day	Type of trailer	yd^3	tons	Width, ft	Length, ft	Approx. height, empty, ft	Approx. length of tractor and trailer units, ft	Method used for covering wastes	Method used for unloading trailers
Dade Co., FL	4200	Semitrailer	85	20–25[a]	8	41	13	55–57[b]	Nylon-mesh hinged cover and enclosed	Internal diaphragm
Marin, CA	960	Semitrailer	105	25	8	45	13.5	60	Nylon-mesh hinged cover	Moving floor
Portland, OR	3500	Semitrailer	96	29	8	48	12.75	68	Completely enclosed	Internal diaphragm
San Francisco, CA	2000	Semitrailer	100	25	8	47.5	13.5	61	Wire-screen hinged cover	Tilting ramp at disposal site
Seattle, WA	2000	Semitrailer	96	19	8	40	13.5	60	Completely enclosed	Tilting ramp at disposal site

Note: $yd^3/day \times 0.7646 = m^3/day$

$yd^3 \times 0.7646 = m^3$

$ft \times 0.3048 = m$

[a] Light loads are for general debris, including yard wastes, tree trimmings, etc.

[b] Length varies depending on the type of tractor used.

TABLE 10-2
Solid waste payload hauled by various truck tractor-semitrailer combinations

	Weight, lb		
	Type of trailer		
	No compaction top load (conventional construction)	No compaction top load (monoque construction)[a]	Waste bale
Truck tractor	16,000	16,000	16,000
Semitrailer	26,000	18,000	13,000
Solid waste payload	36,000	46,000	50,000[b]
Total	78,000	80,000	79,000

[a] In monoque construction the bed of the trailer also serves as the frame of the trailer (see Fig. 10-18).
[b] Increased payloads can be hauled by increasing the number of axles.

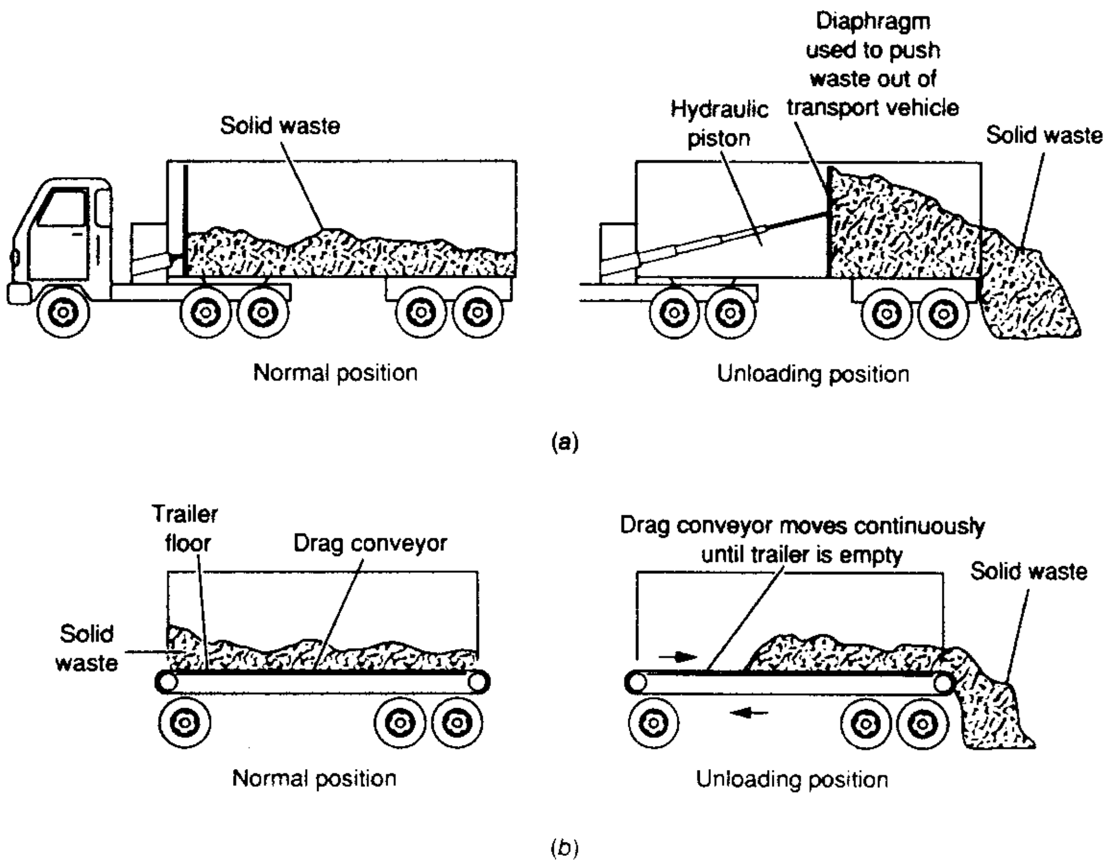
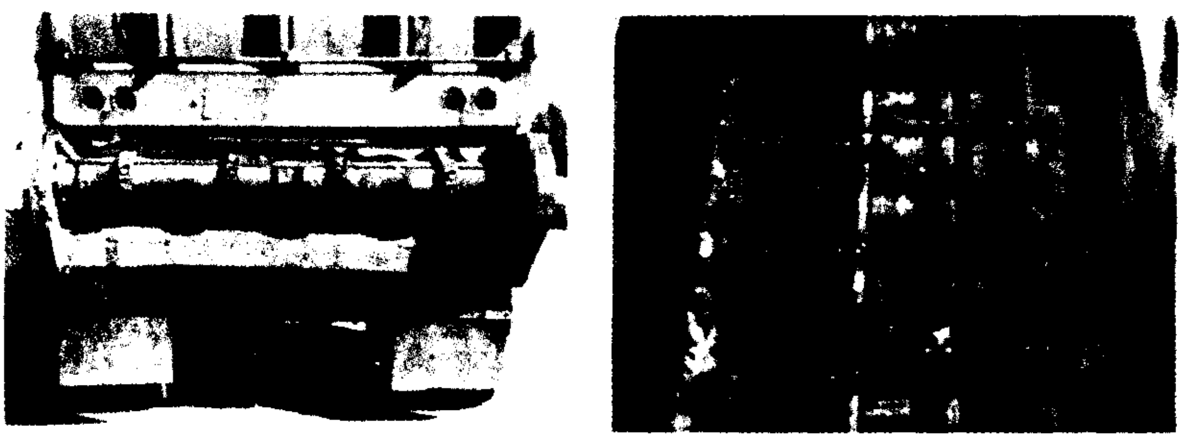


FIGURE 10-19
Methods used to unload semitrailers: (*a*) semitrailer equipped with movable internal diaphragm and (*b*) semitrailer equipped with continuous moving drag conveyor.

width of the trailer (see Fig. 10-20). Thus, if one section becomes inoperable, the moving floor does not prevent unloading because the system will function with the remaining operable section(s). Another type of moving floor uses reciprocating panels, 3 to 6 in wide, that alternate in the backward and forward directions. The use of multiple floor sections is an important feature in terms of system reliability. Another advantage of the moving-floor trailer is the rapid turnaround time (typically 6 to 10 min) achieved at the disposal site without the need for auxiliary equipment. In some designs the rear of the trailer is made larger to facilitate the unloading operation. Trailers such as those shown in Fig. 10-19 are sometimes equipped with sumps to collect any liquids that accumulate from the solid wastes. The sumps are equipped with drains so that they can be emptied at the disposal site.

Unloading systems that require auxiliary equipment are usually of the *pull-off* type, in which the wastes are pulled out of the truck by either a movable bulkhead or wire-cable slings placed forward of the load. The disadvantage of requiring auxiliary equipment and work force to help in the unloading operation at the disposal site is relatively minor in view of the simplicity and reliability of the method. An additional disadvantage, however, is the unavoidable waiting time during which the haul vehicle remains idle at the disposal site until the auxiliary equipment can be placed in the required position.

Another auxiliary unloading system that has proved very effective and efficient involves the use of movable, hydraulically operated tipping ramps. Operationally, the trailer of a tractor-trailer combination is backed up onto a tipping ramp and uncoupled from the truck (see Fig. 10-21). Once uncoupled, the truck is backed up onto a second tipping ramp. The backs of the trailer and truck are opened, and the units are then tilted up until the wastes fall by gravity onto the disposal area. After being emptied, the truck and trailer are returned to their original positions. The truck is driven off the ramp and is backed up to the ramp used



(a) (b)

FIGURE 10-20
Views of continuous moving chain-type drag conveyor used in self-unloading waste transport trailers: (a) drive sprockets for chain conveyors located at rear of trailer and (b) chain-type drag conveyor in bottom of trailer.

(*a*) (*b*)

FIGURE 10-21
Unloading operations using hydraulically operated tipping ramps: (*a*) drop-bottom semitrailer is backed onto tipping ramp and disconnected from the tractor for unloading and (*b*) tipping ramp is elevated and solid wastes fall out by gravity.

for the semitrailer. The semitrailer is reattached, and the transfer rig is returned to the transfer station. The time required for the entire unloading operation typically is about 6 min/trip.

Transport Vehicles and Containers Used in Conjunction with Waste Compaction Facilities. The semitrailers used in conjunction with compaction facilities are designed to function together. Typically, the stationary compactor (see Fig. 10-6*c*) will compact the wastes against the internal diaphram of the trailer. When the pressure of the diaphram reaches a predetermined value, the diaphram moves inward allowing more waste to be compacted into the trailer. The diaphram is also used to unload the semitrailer at the disposal site. An example of the type of semitrailer used in conjunction with a transfer station in which wastes are compacted into a bale is shown in Fig. 10-22.

In smaller transfer stations, large-capacity containers are often used in conjunction with stationary compactors (see Fig. 10-8). In some cases, the compaction mechanism is an integral part of the container. Representative data for such units are reported in Table 10-3. When containers are equipped with a self-contained

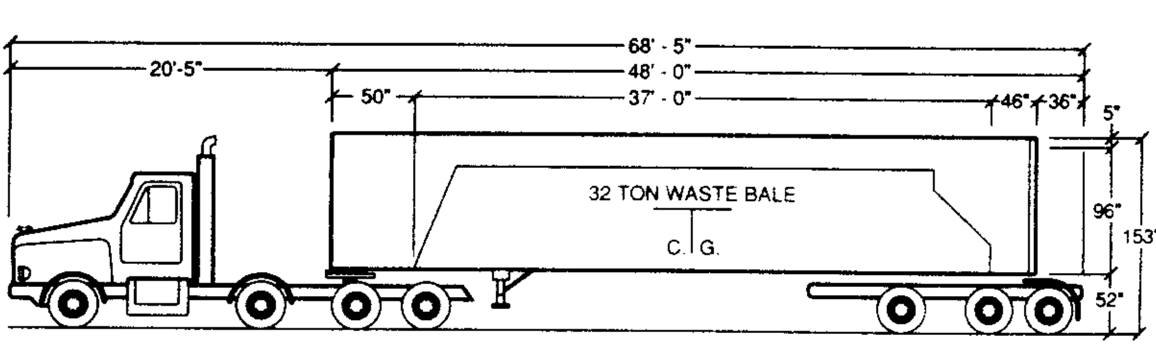


FIGURE 10-22
Typical semitrailer used to transport waste bales. (Courtesy of Jack Gray Transport, Inc.)

TABLE 10-3
Typical data on containers used with stationary compactors and container-compactor units for medium and small transfer stations

Type	Rated capacity, yd^3	Dimensions, ft			Approx. tare weight, lb	Remarks
		Width	Length	Height		
Container						
Small	20	8	14	6	8,000	Door openings where containers are attached to stationary compactor are usually reinforced.
Medium	30	8	18	6	10,000	
Large	45	8	22	9	10,000	
Container-compactor						
Small	3.7	6.5	6.5	4.5	1,500	Available with water-tight sumps and leak-proof doors. Other features on request.
Medium	15	7.5	15	6	6,000	
Large	30	8	22	8	10,000	

Note: $yd^3 \times 0.7646 = m^3$
$ft \times 0.3048 = m$
$lb \times 0.4536 = kg$

compaction mechanism, the movable bulkhead used to compress the waste is also used to discharge the compacted wastes. The contents of containers used with stationary compactors usually are unloaded by tilting the container and allowing the contents to fall out by gravity. If the wastes are compressed too tightly, unloading can be a problem. Various ejection devices also are available to empty the contents of the containers. The most common device is the movable hydraulically operated diaphragm.

Railroad Transport

Although railroads were commonly used for the transport of solid wastes in the past, they are now used by only a few communities. However, renewed interest is again developing in the use of railroads for hauling solid wastes, especially to remote landfill areas where highway travel is difficult and railroad lines now exist. One of the largest rail haul operations currently in use is used to transport wastes from the city of Seattle, WA to the Columbia Ridge Landfill located approximately 300 miles away in Gilliam, OR. Operationally, 25 to 28 tons of waste are compacted into a 40 ft, sealed shipping container mounted on a trailer chassis. The loaded containers are transported to the Union Pacific railyard in the city where they are loaded onto railcars. After dropping off the full container, the truck driver picks up an empty container and returns to the transfer station. Each container is weighed as it goes into the railyard. A computerized manifest and container tracking system allow the city to track the location and status of every container in the system.

The train is made up of approximately 50 railcars, carrying 100 "piggy-backed" containers. It leaves Seattle three evenings a week. The train travels south to Portland and then continues eastward along the Columbia River Gorge to Arlington, OR where it proceeds southward approximately 10 miles to an intermodal siding at the Columbia Ridge Landfill, arriving early in the morning. The containers are unloaded and placed on a truck chassis for the short trip up to the landfill operating face. Hydraulic tippers (see Fig. 10-21) tilt the chassis and container to discharge the waste. The waste is immediately spread and compacted, and is covered each day with six inches of compacted dirt [3].

Water Transport

Barges, scows, and special boats have been used in the past to transport solid wastes to processing locations and to seaside and ocean disposal sites. It should be noted that ocean disposal is no longer practiced by the United States. Although some self-propelled vessels (such as United States Navy garbage scows and other special boats) have been used, the most common practice is to use vessels towed by tugs or other special boats. In England, river barges are used to transport wastes [2].

One of the major problems encountered when ocean vessels are used for the transport of solid wastes is that it is often impossible to move the barges and boats during times of heavy seas. In such cases, the wastes must be stored, entailing the construction of costly storage facilities.

Pneumatic, Hydraulic, and Other Systems of Transport

Both low-pressure air and vacuum conduit transport systems have been used to transport solid wastes (see Fig. 9-17). The most common application is the transport of wastes from high-density apartments or commercial activities to a central location for processing or for loading into transport vehicles. The largest pneumatic system in the United States was installed at the Walt Disney World amusement park in Orlando, FL. The layout of this system is shown schematically in Fig. 10-23. A pneumatic system used for the collection of wastes from an apartment complex is shown in Fig. 7-6.

From a design and operational standpoint, pneumatic systems are more complex than hydraulic systems because of the complex control valves and ancillary mechanisms that are required. The need to use blowers or high-speed turbines further complicates the installation from a maintenance standpoint. Because installation costs for such systems are quite high, they are most cost-effective when used in new facilities.

The concept of using water to transport wastes is not new. Hydraulic transport is now commonly used for the transport of a portion of food wastes (where home grinders are used). One of the major problems with this method is that ultimately the water or wastewater used for transporting the wastes must be treated. As a result of solubilization, the concentration of organics in this wastewater is

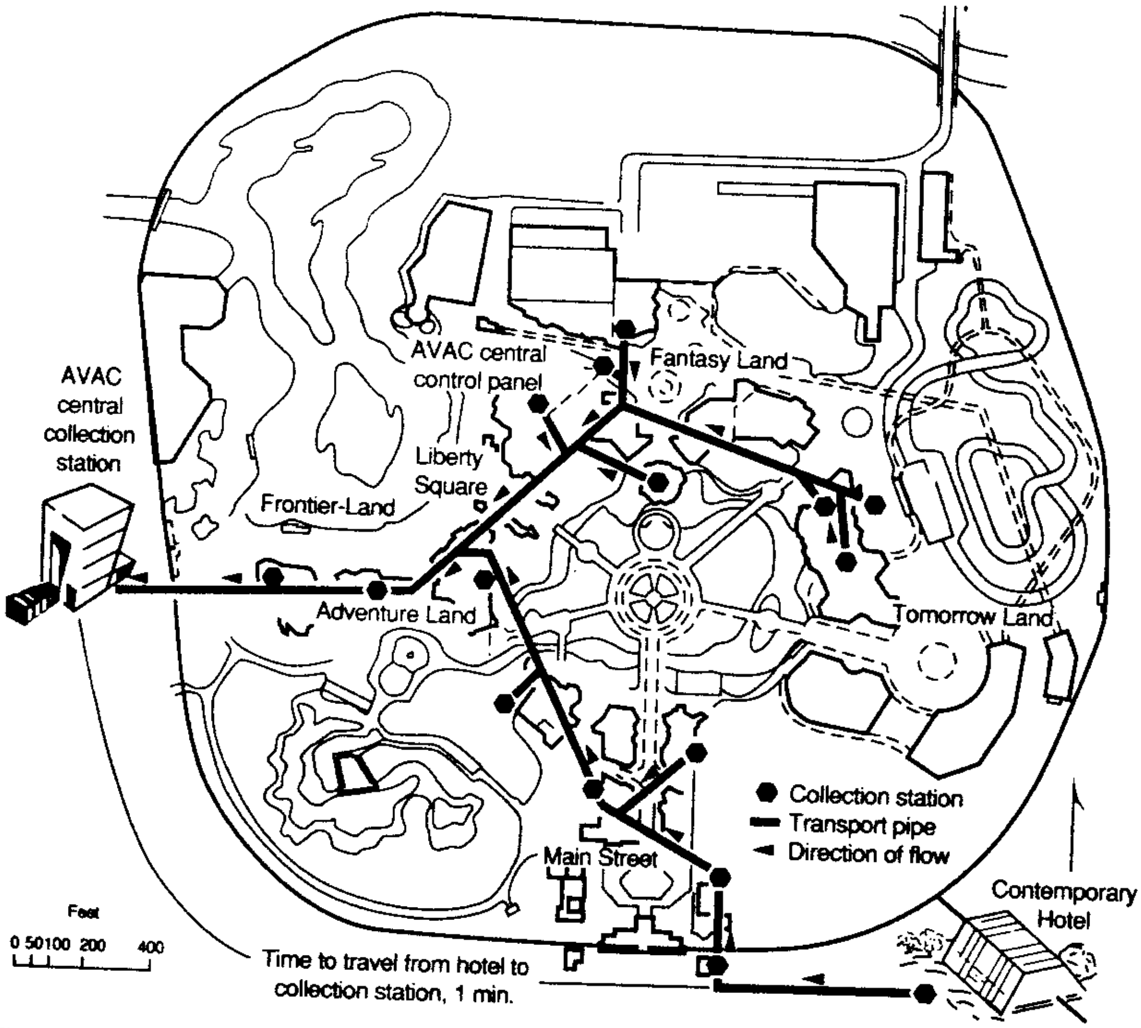


FIGURE 10-23
Pneumatic solid waste collection system for Walt Disney World, Orlando, FL.

considerably greater than in other domestic waste water. Hydraulic systems may be practical in areas where proper preprocessing and postprocessing facilities are incorporated into the treatment system. Usually, such applications are limited to areas with high population densities.

Other systems that have been suggested for the transport of solid wastes include various types of conveyors, air-cushion and rubber-tired trolleys, and underground conduits with magnetically transported gondolas, but these systems have never been put into operation.

10-4 TRANSFER STATION DESIGN REQUIREMENTS

Although specific details vary with size, important factors that must be considered in the design of transfer stations include (1) the type of transfer operation to be used, (2) storage and throughput capacity requirements, (3) equipment and accessory requirements, and (4) sanitation requirements.

Type of Transfer Station

The basic types of transfer station have been described in the previous sections. From a design standpoint the key issue is whether waste recovery operations will be incorporated into the transfer station facility. If waste recovery is to be accomplished at the transfer station, then an adequate area must be available for the collection vehicles to unload.

Transfer Station Capacity Requirements

Both the throughput and storage capacity requirements must be evaluated carefully in planning and designing transfer facilities. The throughput capacity of a transfer station must be such that the collection vehicles do not have to wait too long to unload. In most cases, it will not be cost-effective to design the station to handle the ultimate peak number of hourly loads. Ideally, an economic trade-off analysis should be made. For example, for both types of transfer stations, the annual cost of the time spent by the collection vehicles waiting to unload must be traded off against the incremental annual cost of a larger transfer station and/or the use of more transport equipment.

Because of the increased cost of transport equipment, a trade-off analysis must also be made between the capacity of the transfer station and the cost of the transport operation, including both equipment and labor components. For instance, in a given situation it may be more cost-effective to increase the capacity of a transfer station and to operate with fewer transport vehicles by increasing the working hours than to use a smaller transfer station and purchase more transport vehicles. In a storage-load transfer station, the equivalent storage capacity varies from about one-half to one day's volume of wastes. The capacity also varies with the type of auxiliary equipment used to load the transport vehicles. Seldom will the nominal storage capacity exceed three days' volume of waste.

Equipment and Accessory Requirements

The equipment and accessories used in conjunction with a transfer station depend on the function of the transfer station in the waste management system. In a direct-load transfer station, some sort of rig, usually rubber-tired, is required to push the wastes into the transfer vehicles. Another rig is required to push the wastes and to equalize the load in the transfer vehicles. The types and amounts of equipment required vary with the capacity of the station. In a pit type storage-load transfer station, one or more tractors are required to break up the wastes and to push them into the loading hopper. Additional equipment is required to distribute the wastes and to equalize the loads. In some installations an overhead clamshell crane has been used successfully for both purposes.

Scales (see Fig. 10-7*a*) should be provided at all medium- and large-sized transfer stations, both to monitor the operation and to develop meaningful management and engineering data. Scales are also necessary when the transfer station is to be used by the public and the charges are to be based on weight. If scales are to be used, it will usually be necessary to provide an enclosure for them. The scale house, as it is commonly called, should also have an office equipped with a telephone and a two-way speaker system so that the weighmaster can talk with the drivers.

If the transfer station is to be used as a dispatch center or district headquarters for a solid waste collection operation, a more complete facility should be constructed. For a headquarters facility, a lunch room, meeting rooms, offices, locker rooms, showers, and toilets should be provided. Facilities for providing equipment maintenance may also be incorporated.

Environmental Requirements

By proper construction and operation, the objectionable features of transfer stations can be minimized. Most of the modern, large transfer stations are enclosed and are constructed of materials that can be maintained and cleaned easily. To eliminate inadvertent emissions, enclosed facilities should have air-handling equipment that creates a negative pressure within the facility. In most cases, fireproof construction is used for direct-load transfer stations with open loading areas. Special attention must be given to the problem of blowing papers. Wind screens or other barriers are commonly used. Regardless of the type of station, the design and construction should be such that all areas where rubbish or paper can accumulate are eliminated [2]. The best way to maintain overall sanitation of a transfer station is to monitor the operation continually. Spilled solid wastes should be picked up immediately or in any case should not be allowed to accumulate for more than 1 or 2 h. The area should also be washed down. In some large facilities, wastewater pretreatment facilities may be required to treat plant wastewater before it is discharged to the local sewer. In remote areas, complete wastewater treatment facilities may be required.

Health and Safety

Health and safety issues at transfer stations are related to dust inhalation and other OSHA requirements. Overhead water sprays are used to keep the dust down in the storage area of a storage-load transfer station. To prevent dust inhalation, workers should wear dust masks. In storage-load transfer stations, tractors in the pit area should have enclosed cabs equipped with air-conditioning and dust-filtering units (see Fig. 10-13*b*). For reasons of safety, the public should not be allowed to discharge wastes directly into the pit at large storage-load transfer stations.

10-5 LOCATION OF TRANSFER STATIONS

Whenever possible, transfer stations should be located (1) as near as possible to the weighted center of the individual solid waste production areas to be served, (2) within easy access of major arterial highway routes as well as near secondary or supplemental means of transportation, (3) where there will be a minimum of public and environmental objection to the transfer operations, and (4) where construction and operation will be most economical [2]. Additionally, if the transfer station site is to be used for processing operations involving materials recovery and/or energy production, the requirements for those operations must also be assessed. In some cases, these latter requirements may be controlling.

Because all the above considerations can seldom if ever be satisfied simultaneously, it is usually necessary to perform a trade-off analysis among these factors. The analysis of different locations based on haul cost is described in this section. This method is applicable in those cases where a selection must be made from among several potential transfer station locations. A more complex situation in which two or more transfer stations and disposal sites are to be used is also considered.

Site Selection Based on Transportation Costs

Under ideal conditions, the transfer stations should be located so as to minimize transportation costs. However, given the difficulty most waste management agencies have had in recent times in locating transfer stations, transportation costs have become somewhat less important in the selection of an appropriate location of a transfer station. The siting of transfer stations is considered further in Chapter 18.

Site Selection Based on Operational Constraints

In situations where two or more transfer stations and disposal sites are to be used the basic question that must be answered is this: What is the optimum allocation of wastes from each transfer station to each disposal site? In the discussion that follows, this allocation problem is described, and methods of solution are suggested.

The waste allocation problem can be analyzed as follows. Assume that a determination must be made of the amount of solid wastes that should be hauled to each of three disposal sites from each of three transfer stations, so that the total haul cost will be the minimum possible value. A definition sketch for this situation is shown in Fig. 10-24. Also assume (1) that the total amount of wastes hauled to all the disposal sites must be equal to the amount delivered to the transfer station (materials-balance requirements), (2) that only specified amounts of wastes can be accepted at each disposal site (this constraint could arise as a result of limited highway access to a given disposal site), and (3) that the amount of wastes hauled from each transfer station is equal to or greater than zero. In the symbolic form, the allocation problem is set up as follows:

1. Let the transfer station sites be designated by i.
2. Let the disposal sites be designated by j.
3. Then let X_{ij} = the amount of wastes hauled from transfer station i to disposal site j.
4. Let C_{ij} = the cost of hauling wastes from transfer station i to disposal site j.

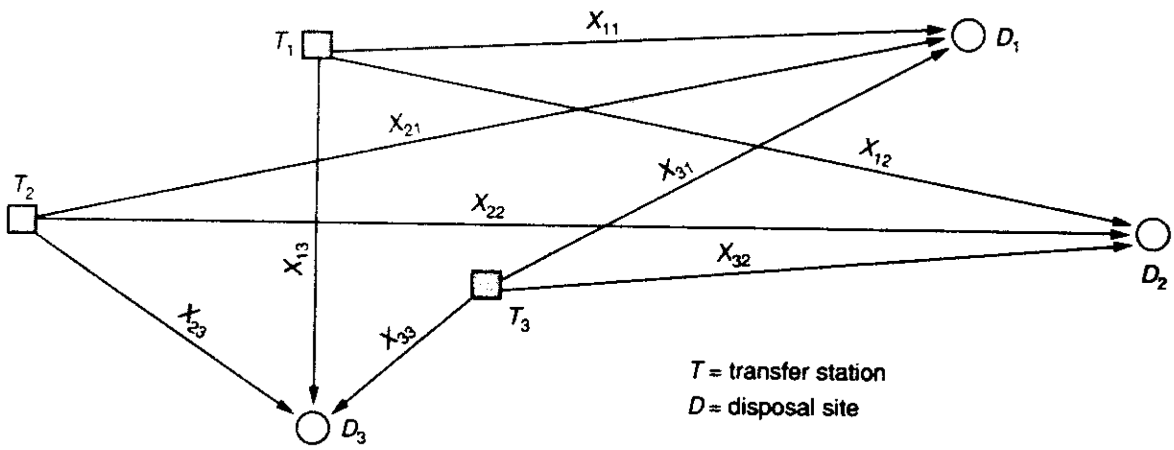


FIGURE 10-24
Definition sketch for allocation of solid wastes from three transfer stations to three disposal sites.

5. Let R_i = the total amount of wastes delivered to transfer station i.
6. Let D_j = the total amount of wastes that can be accepted at disposal site j.
7. If the total haul costs are to be minimized, then an objective function, which is defined as the sum of the following terms, must be minimized subject to the problem constraints:

$$X_{11}C_{11} + X_{12}C_{12} + X_{21}C_{21} + X_{22}C_{22} + X_{23}C_{23} + X_{31}C_{31} + X_{32}C_{32} + X_{33}C_{33} = \text{objective function}$$

8. Expressed in mathematical summation form, the problem is to minimize the function

$$\text{Objective function} = \sum_{j=1}^{3}\sum_{i=1}^{3} X_{ij}C_{ij} \tag{10-1}$$

subject to the following constraints:

$$\sum_{j=1}^{3} X_{ij} = R_i \qquad i = 1 \text{ to } 3 \tag{10-2}$$

$$\sum_{j=1}^{3} X_{ij} \leq D_j \qquad j = 1 \text{ to } 3 \tag{10-3}$$

$$X_{ij} \geq 0 \tag{10-4}$$

The fact that the amount of waste hauled to the disposal sites must be equal to the amount brought to the transfer station is given by the first constraint. The condition that the total amount of waste hauled from the transfer station must be equal to or less than the capacity of the disposal sites is given by the second constraint. The third constraint is that the amount of waste hauled from the transfer station must be equal to or greater than zero.

Solutions to Waste Allocation Problem

The problem as set up in Step 8 is commonly known as the *transportation problem* in the field of operations research. At present, a number of solution methods are available. However, most of the methods require the aid of microcomputers. As an alternative, several approximate solution techniques have been developed [1, 4]. Because the solution obtained with the approximate methods will be close to the optimum solution (within 10 percent), they are sufficiently accurate for most practical applications in the field of solid waste management. The optimum solution may be obtained by any number of methods outlined in standard texts on linear programming.

10-6 DISCUSSION TOPICS AND PROBLEMS

10-1. Given the following data on transportation costs, determine the break-even times for the two stationary container systems versus the use of a transfer and transport system. Base your computations on dollars per ton per minute.

Operating costs
Stationary container systems
4-ton capacity = $25.00/h
10-ton capacity = $36.00/h
Truck-semitrailer combination (25-ton capacity) = $55.00/h
Transfer station costs = $3.00/ton

10-2. Determine the round-trip break-even time for solid waste collection systems in which the 30-yd^3 self-loading compactors used for collection are driven to the disposal site and compare that with using a transfer and transport system. Assume that the following data are applicable.

(*a*) Specific weight of wastes in self-loading compactor = 600 lb/yd^3
(*b*) Specific weight of wastes in transport trailers = 325 lb/yd^3
(*c*) Volume of tractor-semitrailer transport unit = 105 yd^3
(*d*) Operational cost for self-loading compactor = $40/h
(*e*) Operational cost for tractor-semitrailer transport unit = $60/h
(*f*) Transfer station operational costs including amortization = $3.25/ton
(*g*) Extra unloading time cost for transport units, compared with compactors = $0.40/ton

10-3. What would the graph in Example 10-1 and Problems 10-1 and 10-2 look like based on total cost versus round-trip haul distance?

10-4. Using the following data and information and the cost information given in Appendix E, estimate how far away a disposal site can be located from the city before the use of a transfer station is economical.

(*a*) Population = 50,000 persons
(*b*) Waste generation = 4 lb/capita · d
(*c*) Capacity of rear (manually) loaded waste collection vehicles = 20 yd^3
(*d*) Specific weight of wastes in collection vehicles = 525 lb/yd^3
(*e*) Time required to load collection vehicles = 2.4 h/trip

(*f*) Current number of collection trips made per day = 2
(*g*) Number of collection vehicles currently owned by city = 5
(*h*) Operational cost for collection vehicles = \$35/h
(*i*) Transfer station type = direct-load with compactor that produces bales with a total weight of 26 tons
(*j*) Transfer station transport vehicle = tractor-semitrailer
(*k*) Operational cost for tractor-semitrailer unit = \$50/h
(*l*) Discount rate = 7.5%
(*m*) Return period = 10 yr

10-5. Estimate the peak hourly capacity of the transfer station shown in Fig. 10-2. Express your answer in vehicles and in tons per hour. Assume the average volume per vehicle and the specific weight of the waste is 15.0 yd^3 and 475 lb/yd^3, respectively. State all of the assumptions made in solving this problem.

10-6. Estimate the peak hourly capacity of the transfer station shown in Fig. 10-3. Assume the average volume per vehicle and the specific weight of the waste is 16.5 yd^3 and 510 lb/yd^3, respectively. State all of the assumptions made in solving this problem.

10-7. How would you increase the peak hourly capacity of the transfer stations shown in Fig. 10-2 and 10-6 by 25 percent?

Do either Problem 10-8 or 10-9, depending on whether your community has a transfer station.

10-8. If your community does not have a transfer station, estimate the break-even time at which a transfer station operation would become feasible. How does this time compare to the actual time now spent by the collection vehicles in the haul operation? State all your assumptions.

10-9. If your community has a transfer station, determine what the break-even time would be for a direct-haul operation. How does this time compare to the actual time now spent by the transport units in transport operation? State clearly all your assumptions.

10-10. A 1000 ton/d transfer station is to be constructed. Consideration is being given to both a direct-load transfer station employing stationary compactors such as shown in Fig. 10-4 and a storage-load type such as shown in Fig. 10-8. Identify and discuss the important factors that must be considered in selecting one of these two choices.

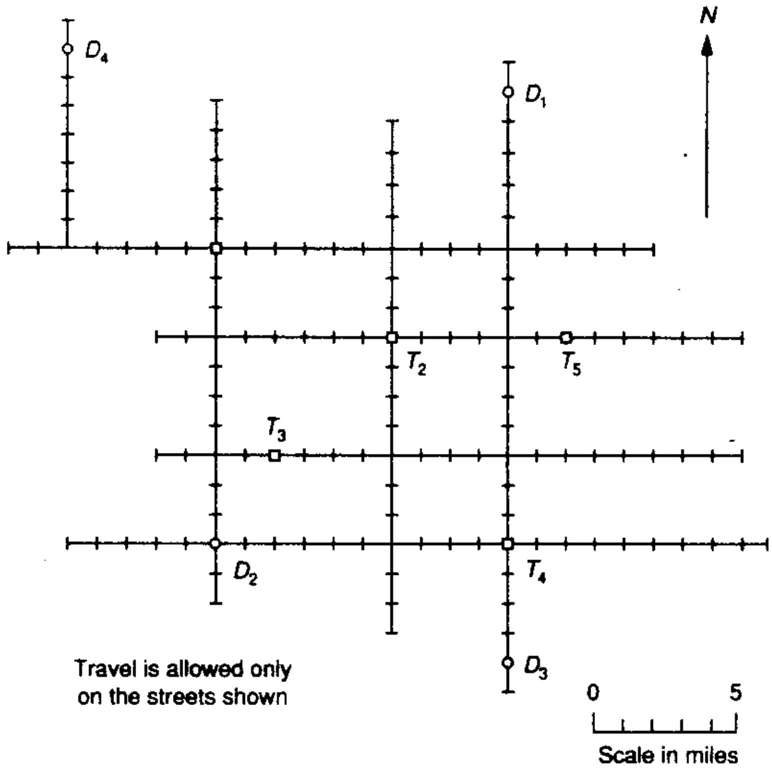
10-11. Discuss the advantages and disadvantages of developing a single large MR/TF for a community compared with developing source separation programs and the use of smaller MRFs in conjunction with a transfer station.

10-12. Given the following information, determine—by the long-hand method of evaluating every possibility—the most economical allocation of wastes from each of two disposal sites on the basis of transportation cost only. Check your answer with a computer or spreadsheet program.

Transfer station	Waste, units/d	Disposal site	Capacity, units/d
1	4	1	4
2	2	2	4

The round-trip haul distance from transfer station 1 to disposal sites 1 and 2 is 10 and 20 mi, respectively. The distances from transfer station 2 to disposal sites 1 and 2 are 30 and 40 mi, respectively. Assume that the transport time in hours per trip is given by the expression [0.08 h/trip + 0.025 h/mi (x)], where x is the round-trip-haul distance in miles per trip, and that the transportation cost is \$35/h.

10-13. The city shown in the accompanying figure has four disposal sites D1, D2, D3, and D4 and needs four transfer stations to handle the solid waste. The location of transfer sites T1, T2, and T3 have already been selected. The fourth site has been narrowed to two possibilities, T4 and T5 as shown. The following disposal site and transfer station data were collected for the city.



Disposal site	Capacity, units/d	Transfer station	Waste, units/d
D_1	4	T_1	3
D_2	10	T_2	3
D_3	3	T_3	5
D_4	8	T_4 or T_5	2

On the basis of transport cost alone, determine the more economical location for transfer station 4 (T4 or T5). Assume that the transport time in hours per trip is given by the expression [0.08 h/trip + 0.025 h/mi (x)], where x is the round-trip-haul distance in miles per trip, and that the transport cost is \$35/h.

10-14. Once collected, how are household and other hazardous wastes from your community transported to treatment or disposal facilities. What is your assessment of the arrangements that are now used? Can you suggest any improvements?

10-15. In the late 1960s and early 1970s much was written about the use of simulation and other techniques from the field of operations research for optimizing the location of transfer stations. Based on a review of one or two articles from that period (i.e., 1965 to 1975) and any other pertinent information, prepare an analysis of why the techniques proposed during that period have not been adopted to any major extent in the siting of transfer stations.

10-7 REFERENCES

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