CHAPTER IV. STORAGE AND COLLECTION

A. Introduction

Storage and collection of waste are some of the more visible signs of successful or unsuccessful solid waste management systems. If successful, the result is clean surroundings and good public sanitation; if unsuccessful, litter and poor public sanitation are everywhere self evident to the knowledgeable observer. Good public sanitation begins with a properly designed and operated waste storage and collection system. The institution of successful storage and collection systems in developing countries requires not only a knowledge of appropriate technologies and operating practices, but also recognition of the types of problems faced by these countries relevant to storage and collection.

Before a presentation is made on the technical methods associated with waste storage and collection, a brief discussion of some of the more critical problems associated with the poor performance of the waste collection service in developing countries is given. A number of factors contribute to the relatively low level of waste collection service that is common in many developing countries. Some of these factors are financial, institutional, technical, and social ones.

A1. LOW coverage in the provision of services

In most situations evaluated by the authors, the urban poor receive minimal, if any, solid waste collection services. Even when collection service is provided in poor or marginal areas, the level (i.e., quality and coverage) of service is much lower than that made available to middle- and high-income areas. For instance, in La Paz, Bolivia, one report estimated that a very small percentage of the waste generated in poor neighbourhoods was collected in 1986; whereas, about 60% to 80% of the waste was collected in upper-income residential areas [1]. Similar situations have been observed throughout large metropolitan areas in Latin America, Africa, and Asia. Clearly, the communities inhabited by high-density, low-income populations have a great need for quality collection services.

Several reasons exist for the poor levels of service generally achieved in low-income communities. Two of the more important reasons are: 1) the communities usually evolve without any type of planning and, thus, it is difficult for collection vehicles to reach them; and 2) since these communities often are illegal settlements, they generally do not pay any municipal taxes.

A2. APPLICATION of inappropriate technology

The use of inappropriate technology for the collection of wastes in developing countries is a common problem. A waste collection vehicle that has been designed to accommodate a particular type of waste may not be able to properly collect and transport another type of waste. Vehicles that are designed to operate in low-density urban areas with wide, well-paved roads do not perform to the same level of service and in the same manner in locations with narrow, poor quality roads and with a high-density population. Generally, communities strive to standardise their collection vehicles assuming that similarity will result in cost-efficient operation and maintenance. This standardisation has resulted in the exclusion of large areas of cities from collection service. Vehicle design standards based on the requirements of the middle- and high-income areas rarely are suited to the needs and conditions of low-income areas.

In industrialised countries, where the economic lifetimes of collection vehicles are 5 to 8 years and preventive maintenance is practiced fastidiously, the cost of maintenance alone generally is only a small fraction of the costs associated with ownership and operation of a collection vehicle. On the other hand, this condition is not prevalent in developing countries, where collection vehicles commonly are kept well beyond their useful economic life even when maintenance costs and downtime are sufficiently high to warrant vehicle replacement. We have observed that in many cities in developing countries, the collection fleet is comprised of vehicles that are on the order of 10 to 15 years old. In some cases, such as that in Chittagong, Bangladesh, some of the collection vehicles were more than 30 years old. Obviously, the continued use of vehicles beyond their economic life has a serious negative impact on the efficiency and reliability of the collection system [2].

Inappropriate technology also is reflected by the incorrect balance between labour and equipment, or by poor selection of low-technology equipment. This situation also leads to inefficient and costly collection processes. An excellent example of inappropriate application of low technology is the interface between handcarts or tricycles and motorised vehicles. In many locations, basic collection is carried out in handcarts. Once full, the carts are taken to a specific location, where the waste is discharged on the ground. The waste eventually is transferred onto motorised transport vehicles by means of rakes, baskets, and shovels. In low-income developing countries, vehicle costs as well as fuel costs generally are high, while labour is relatively inexpensive. In these situations, the application of labour-intensive methods would result in optimum system cost efficiency and high vehicle productivity. On the other hand, in middle-income countries (i.e., economies in transition), we have found that it is necessary to conduct a careful, thorough analysis in order to determine the optimum level of mechanisation.

In some situations, inappropriateness might be related to the fact that the collection equipment cannot be properly maintained under the conditions in which it is operated. Generally, in most developing countries the resources allocated to maintenance are grossly inadequate. Thus, the specification of equipment that requires continuous and precise maintenance procedures, as well as the use of imported spare parts, will result in extraordinarily high maintenance expenses and long periods of downtime.

Another important, and often overlooked, aspect of equipment and system selection is the almost complete lack of consideration (and in some cases understanding) of cultural and socioeconomic conditions of the country. Consideration must be given to the behavioural responses of the public with respect to the planned collection equipment and system. The neglect of cultural and socioeconomic considerations has oftentimes led to the application of equipment and systems that have not been accepted by the population that they were intended to serve and, thus, the systems failed in a relatively short period of time.

A3. TENDENCIES to acquire imported equipment

In developing countries, municipal revenue generally is only 1% to 5% of the base available in industrialised countries. Consequently, internal revenue for the financing of capital equipment is limited. This shortage of revenue is further exacerbated in the case of procurement of foreign equipment and vehicles. Instead of the use of or reliance on foreign equipment and systems, improvements in solid waste collection services in developing countries, in many cases, can be best promoted through improvements in the system of municipal finance, through the application of labour-intensive methods, and through the development of local capability for manufacturing vehicles and equipment.

Generally, the ratio of external funds to national funds for capital investments is high. In many cases, the foreign exchange component of the costs of solid waste projects averages about 50% of the total costs. However, heavy reliance on external funding, inevitable as it may seem if progress is to be achieved in the short-term, probably is not a wise alternative for long-term development. In most cases, efforts should be made to complement external funding with sufficient levels of internal funds.

For solid waste projects in developing countries, the level and degree of use of appropriate technology can be gauged by the level of foreign exchange component. Projects that rely too heavily on foreign exchange are usually too capital intensive. In addition, in the long-term, these projects may have difficulties in obtaining the sources of foreign exchange necessary for the operation and maintenance of the vehicles and equipment.

A4. INADEQUATE resource mobilisation

In most situations, waste management services are financed through revenue obtained from property taxes. Unfortunately, the systems for collection of municipal taxes generally are outdated, poorly administered, and inefficient, and the rate of collection is extremely low. The relatively low levels of funds obtained from the taxes normally are used for programs that are considered the most critical and that provide services to only portions of the municipality. Low-income communities, especially in marginal areas, generally receive limited or no collection services.

A5. INAPPROPRIATE methods of finance

Due to the severe duty, mechanical equipment used for the collection of waste has a relatively short lifespan, on the order of 5 to 8 years. The higher end of the range is achieved by conscientiously following recommended levels of maintenance. Nevertheless, in most cases, developing countries finance the acquisition of waste collection equipment using medium-term and long-term loans (i.e., 20 to 30 years). In addition, representatives from developing countries do not ensure that the particular municipality will have sufficient sources and levels of revenue to service the loan. The potential of a shortfall of revenues is particularly high when the collection service is to be provided to a large area of low-income population. Although low-income areas typically are in dire need of basic municipal services, the residents of these areas typically have the lowest capacity to pay for the services. Failure to assess the capacity of some municipalities to generate sufficient revenue, and their ability to service their debt, has left municipalities without prospects for adequately operating, maintaining, or replacing equipment.

B. Overview of present situation

The following is a brief overview of the methods of storing and collecting wastes that are commonly used by a large number of developing countries.

The average quantity of municipal solid waste generated throughout Latin America, Asia, and some countries in Africa is on the order of 400 g/cap/day. This is approximately 30% to 40% of the daily per capita waste generation in the United States and in western European countries. Furthermore, it has been estimated that about 30% to 50% of the wastes generated in developing countries are never collected. Uncollected wastes accumulate in vacant lots or are simply discharged into bodies of water. Because of improper disposal and excessive littering, in many instances, the burden of waste collection is transferred from the collection system to the street cleaning system.

Typical productivity of a refuse collection worker in developing countries (defined as total weight of waste collected by the entire system, divided by the number of collection workers) is approximately 250 kg/day. Average expenditure (at 2002 price level) on solid waste management, including street cleaning and final disposition, ranges from about US$1/cap/yr to nearly US$5/cap/yr.

In many cities in Asia, most domestic and light commercial wastes are stored in communal containers. The wastes are delivered to the containers by the users. Several types of communal containers are used. Containers usually are made from either steel, concrete, or wood; are equipped with lids; and have a capacity ranging between 1 and 2 m^3. Portable steel bins have a capacity of about 100 L. Spacing of communal containers is determined primarily by their capacity. The authors have observed that, in most situations, communal containers lead to a series of problems. In some instances, the containers are overfilled or waste is discharged around them. In others cases, the containers are disturbed by scavengers or by animals. In Latin America, domestic and light commercial wastes are stored in a variety of individual containers.

Compactor vehicles are not, as yet, very common in developing countries, although they are now used in several of the large cities. The vehicles that typically are used for the collection of refuse from communal sites are open bodies on standard commercial chassis. Some of the vehicles commonly used for waste collection include the typical dump truck and side-loaders with curved sliding shutters. Both of these units are equipped with hydraulic tipping gear. Only in a few cases have we observed the use of low-loading chassis. Trucks with low-loading chassis eliminate the need to have a crew member stationed in the back. An inexpensive and useful vehicle used in some cities in Southeast Asia is a two-wheel trailer towed by a standard farm tractor. The trailer is low, can be loaded from the side, and is covered.

The collection of wastes from house to house is not well established. Containers of a standard size rarely are used. In several cities, the use of baskets, plastics bags, and kerosene or lard containers is fairly common. In some cases, the bins are kept permanently on the curb outside the house. In other cases, the baskets and other containers are put outside only during the period when kerbside collection is expected or when the collection crew announces its arrival.

Most vehicles are not equipped with tipping gear to discharge the load of wastes. Loading the vehicles usually is a cumbersome process of either filling baskets or similar containers, carrying them to the vehicle and handing them to a person on the vehicle, or using a shovel to load the wastes directly onto the collection vehicle. The vehicles usually are manually unloaded at the disposal sites. Manual unloading of the vehicles takes a considerable amount of time and leads to congestion at the disposal sites.

Another system of house-to-house collection used in developing countries involves the use of handcarts. The handcarts have a capacity of about 1.5 m^3. In some cases, the handcarts deliver the materials directly to a collection truck, while in others the wastes are taken to a large communal container or to a transfer station. The latter two approaches are relatively common in large cities in the People's Republic of China.

Industrial wastes generated in large cities and metropolitan areas generally are collected along with the municipal wastes.

The recovery of materials from wastes (scavenging) is practiced throughout the developing world. This type of resource recovery usually is labour-intensive and begins at the point of generation where householders keep reusable materials such as newspapers, glass containers, and cans for their own use or for sale to individuals who ply the streets buying different types of scrap materials. Communal bins generally are searched by scavengers. Scavenging is continued by the refuse collectors and by scavengers at the disposal site.

C. Problems of storage and collection

Most of the problems associated with the storage and collection of solid waste in developing countries can be summarised as follows:

- Large numbers of open communal storage sites and unofficial dumps encourage the breeding of flies and rodents.

- Methods of collection often result in workers coming into direct contact with wastes that sometimes contain faecal matter.

- Collection vehicles generally are too old and too few in number. This problem is primarily due to poor maintenance and the lack of a vehicle replacement policy.

In many cities, the work of refuse collection vehicles is impeded by extremely dense traffic and/or areas where the roads are too narrow to allow passage of motor vehicles. It is common for the residents of these areas to be ignored, leading to the dumping and accumulation of wastes in empty lots or on the banks of streams or drainage canals.

Most of the cost of refuse collection is incurred in the form of manual labour, acquisition of motor vehicles, and operation and maintenance of the vehicles. Economically developing countries have the advantage of low wages, and it is reasonable to suggest that the cost of manual labour can be sustained. Motor vehicles, however, present serious problems. Because of their cost, imported vehicles are difficult to purchase. The difficulty lies in the limited availability of foreign exchange.

Climatic conditions, such as those in tropical areas (high heat and humidity), often dictate certain standards of service in order to protect public health and safety, and the environment, e.g., daily collection of refuse. Daily collection obviously is more costly to provide than the once-a-week service typically provided in North America and in Europe.

In many cases, the management of solid wastes in developing countries is also constrained by social and religious factors. Many families live in crowded conditions in one room, leaving little or no space to store waste. There may also be religious beliefs that forbid the storage of waste within a dwelling.

Many cities lack a network of district depots that could serve as central points of service, offices for district supervisors, and transfer points for wastes collected in small vehicles.

A large portion of the motor vehicles in use has high sidewalls of 2 m or more. Consequently, the loading of waste is a two-person process, i.e., collectors have to stand on the truck to receive the containers passed up to them from personnel located at ground level.

Many vehicles used for collection do not have tipping gear for emptying the load of waste. The lack of tipping equipment leads to loss of time due to manual unloading. Most loads of waste are not covered, resulting in spillage and litter.

Some of the most immediate needs for collection that have been identified include:

- more efficient vehicle design, based to the extent possible on local manufacturing capacity;

- enclosure of wastes at all stages of storage and collection to reduce health risks to the public and to workers;

- use of labour-intensive systems;
- efficient use of motor vehicles in order to achieve high productivity and to minimise the number of vehicles required;
- provision of decentralised control by using district depots with offices and enclosed transfer points; and
- efficient management structure, supported by trained personnel.

D. Components of refuse collection

A refuse collection service requires vehicles and labour. In order to deploy the vehicles and workers efficiently, a clear understanding of the three main components of refuse collection is necessary:

1. travel to and from the collection area;
2. the collection process (transfer of the wastes from storage to collection vehicles, and travel between successive collection points); and
3. the delivery process (transport of the contents of the vehicle to the processing or the disposal site).

During non-working hours, collection vehicles should be kept in a garage with enclosed parking space. The distance between the garage and the collection area should be kept to a minimum because time spent travelling to and from the collection area is not productive. In the case of motor vehicles, this requirement may have to be balanced against the need to centralise facilities for maintenance and fuel supplies, and to centralise the allocation and control of drivers and vehicles.

The slow speed of animal carts and handcarts requires the provision of closely spaced district depots. District depots also are efficient tools for the control of the collectors.

The many methods of transferring wastes from storage to the collection vehicle fall into the following three main categories:

1. Direct emptying of a portable storage container into the vehicle, normally used when the vehicle can be positioned close to the containers.
2. Emptying of a portable storage container into a transfer container (usually a larger container or basket), which is then emptied into the storage compartment of the vehicle; the large container is normally used when the location of the storage container is a long distance from the route of the vehicle in order to avoid non-productive time.
3. Transfer of loose wastes stored on the ground, which usually requires that the wastes be raked or shovelled into the vehicle.

These three categories have been presented in descending order of level of effort required. Thus, the first is the most efficient in terms of labour and vehicle productivity; it is also the method that maintains human contact with the wastes to a minimum.

Travel time between successive collection points depends, first of all, upon the distance between them. When collection points are located some distance apart (as is the case with large communal storage sites), travel by motor vehicle will be at normal road speed and the collectors will ride on the vehicle. This is an efficient method of transporting the workers between sites.

However, when collection is from house to house, the collectors generally walk the short distances between containers and the collection vehicle correspondingly moves slowly and at intervals. For this element of travel, the motor vehicle is not used efficiently. The vehicle incurs heavy wear on the clutch and transmission, as well as high fuel consumption. Handcarts and animal carts are much more efficient in this situation, because they can operate at their optimum speeds and no energy is used while they are stationary.

For collectors walking from house to house, the distance to be walked is proportional to the number of people in a team. A single individual walks from one house to the next. In a three-person team, each person collects from every third house; thus, labour productivity declines as team size increases. On the other hand, vehicle productivity increases with team size since the vehicle is loaded more quickly.

In the delivery process, a full vehicle usually travels at normal road speed from the last collection point to the processing or disposal site. This represents maximum productivity for the vehicle, but lost time for the collectors if they accompany it. Handcarts and animal carts are inefficient for this operation because of their slow speeds and limited capacities.

The following conclusions can be drawn:

- Minimum physical infrastructure for waste collection includes a central garage, with parking space for motor vehicles, and district depots for assembling and controlling collectors, handcarts, and animal carts. The locations of the depots should minimise travel time between depot and working area.

- Systems that provide for the direct emptying of portable storage containers into a vehicle offer the highest productivity and the lowest health risk to workers.

- Large teams yield low labour productivity and high vehicle productivity in the direct collection of wastes from residences.

- Handcarts and animal carts may be more efficient than motor vehicles for the house-to-house collection activities.

- Motor vehicles are usually the most efficient means of transport of full (large) loads from the last collection point on a collection route to the processing or disposal site.

D1. SOURCES and characteristics of the refuse

Solid waste generation is a relentless, continuous process. Nearly every member of the population generates wastes of one kind or another. Despite the successful use of pneumatic transfer (i.e., air conveyance) in underground pipes at several residential developments in the United States, Europe, and Japan, this method certainly is not practical for the collection of solid wastes in economically developing countries. This means that refuse collection in developing countries must be regarded as a batch process, or a series of batch processes, whereby wastes are stored at the point of origin for a certain period of time before being transferred to a vehicle.

The main sources of solid wastes for which a municipality normally assumes the responsibility of collection are residences, commerce, light industry, and public institutions, as well as refuse swept from the streets. Residential wastes usually account for about 50% to 80% of the total quantities of wastes generated by the aforementioned sources.

The main components (e.g., paper, glass, etc.) of solid wastes are similar throughout the world. However, the proportions of each component vary widely from country to country, from city to city, and even within a city. The results of waste characterisation analyses are presented in Table IV-1. The analyses, carried out in accordance with the methodology described in Chapter III, very clearly show the variations that exist.

The data in the table generally demonstrate that as the concentration of paper in the waste increases, the per capita rate of generation also increases. The relation is not entirely straightforward because of the substantial variations in the concentrations of ceramics, dust, and stones among the locations shown in the table.

Generally, there are local variations in waste generation, and the proportions of constituents change over weekly and seasonal cycles. Weekly variations are related to the pattern of work and leisure. Seasonal cycles are impacted by climate, seasonal food products, and sometimes by fuel residues (i.e., ash) arising from space heating in winter.

Table IV-1. Quantity and composition of municipal solid waste[a] in some developing countries (% wet wt)

Material	Ulaanbaatar, Mongolia [9]	Quezon City, Philippines [10]	Olongapo City, Philippines [5]	Lima, Peru [5]	Buenos Aires, Argentina [11]
Putrescibles	24.0	52.0	44.4	34.3	30.5
Paper	12.9	17.1	17.5	24.3	22.9
Metals	2.5	3.2	3.1	3.4	5.1
Glass	6.4	3.1	2.0	1.7	2.8
Plastics, rubber, leather	13.1	22.0	8.7	2.9	14.6
Textiles	4.4	0.3	2.9	1.7	2.5
Ceramics, dust, stones	36.7	2.3	21.4	31.7	21.6
Wt/cap/day (kg)	0.33	0.55	.44	0.96	3 to 1.0

[a] Based on actual measurement; percentages may not sum to 100.0 due to round-off error.

The amount of work involved in refuse collection depends upon the type, weight, and volume of wastes generated; the number of collection points from which the wastes must be removed; the type of storage containers; and the type of collection equipment.

The role of bulk density in determining the volume to be stored and collected is demonstrated by the fact that a low-income dwelling, having daily collection, generates about 4 L of waste. On the other hand, a North American dwelling would generate about 120 L, with a collection frequency of once per week.

The higher rate of residential occupancy in economically developing countries helps to reduce the number of collection points. However, the fewer number of collection points is far outweighed by the usual need to provide more frequent collection service.

The use of communal containers under some conditions could conceivably reduce the total number of collection points. This simplifies the organisation of the collection activity, but may cause problems related to public health and safety, the environment, and convenience of use.

D2. FREQUENCY of collection

The necessary frequency of collection is governed by a number of factors, including: characteristics of the wastes, climate, type of storage (communal or individual), and degree of involvement by householders. Frequency of collection also has a substantial bearing on the cost of collection.

The concentration of putrescible matter in wastes generated in economically developing countries usually is high. Putrescible materials serve as breeding media for flies and are potential sources of foul doors. The eggs of the housefly can hatch in as little as one day. However, the larvae feed for about five days before pupation, which takes an additional three days. The total period to reach maturation may be as little as seven days in tropical countries. A weekly collection, therefore, prevents the production of adult flies in the stored wastes, provided that the larvae are unable to migrate from the container. On the other hand, decomposition of the wastes becomes noticeable during the first two to three days of storage. Consequently, aesthetic standards may be a more critical factor than the lifecycle of the fly.

D3. COMMUNAL storage

The design of communal storage facilities must take into consideration climatic conditions. Climate is important because decomposition of organic matter proceeds much more rapidly in a hot environment than in a temperate one.

When communal storage is used, loss of living space or unacceptable hygienic conditions in the premises is not a problem since the occupants can deliver the wastes to the communal site as frequently as necessary. On the other hand, potential problems are transferred from the domicile to the communal storage site because there generally is no control exercised over proper containment of the wastes, nor over the age of the wastes deposited there. In the event that the wastes have been kept at the premises for several days, the wastes may already be infested with fly larvae. Controlling the migration of larvae from a communal site generally is a much more difficult problem than in a single residence that stores waste in a small container with a lid. To prevent the breeding of flies, the frequency of collection for systems using communal storage ideally should be either daily or at least three times per week, and the storage containers should have lids.

D4. HOUSE-TO-HOUSE collection

In this type of collection system, the general design of the dwelling or building plays a major role in the frequency of collection. Dwellings with relatively large open areas rarely have any problems with the storage of wastes in enclosed containers for periods of up to a week. For example, there are several areas in the United States that have sub-tropical climates, but where weekly waste collection is quite common. This frequency is acceptable only because the following two conditions are satisfied: space is available for storing the container outdoors, and containers are equipped with well-fitting lids to prevent unpleasant doors from escaping and to prevent access by insects and other animals. In addition, the majority of dwellings are equipped with garbage disposal units for the disposal of kitchen wastes by way of the sewer system.

At the other extreme is the small apartment where the only space in which a waste container can be stored is in the working area of the kitchen. Aesthetic standards and space limitation combine to impose a maximum storage period of 24 hours. Under such conditions, it is necessary to either provide daily collection from each apartment or provide a communal container.

Small shops and large markets where stalls are rented present a similar problem. Daily collection usually is necessary for the shops. On the other hand, market stalls may need collection service several times a day.

In developing countries, the population density of large areas of the major cities is much higher than that in most industrialised countries. In these densely populated areas, external sites for storage of waste usually are lacking. Therefore, the collection frequency for these areas may need to be on a daily basis.

The extent to which statutory duties are imposed upon residents may affect frequency of collection. Where there is a duty to place the domestic container at the kerbside, frequency of collection must be high enough to limit the weight and size of the container to the lifting capacity of an elderly person. Where "block collection" has been instituted (whereby residents deliver their wastes to the vehicle, which stops for a short time at each road intersection), the constraint on weight and volume assumes greater importance because of the longer distance the wastes must be carried.

D5. COST

The unit cost (US$/Mg) for the manual collection of wastes increases rapidly as the frequency of collection is increased. This is due to the fact that the key parameters that determine the level of effort for a collection route are: 1) the total number of containers to be emptied, and 2) the total distance to be walked and driven among them. These parameters are almost constant for frequencies between one and seven days. In this case, the main variable becomes the weight of the filled containers; therefore, as the frequency increases, the total weight collected decreases and the unit cost increases.

When all the factors are taken into consideration, the following general conclusions emerge:

- Communal containers preferably should be picked up on a daily basis, or at least three times per week.
- Twice-per-week collection is adequate for dwellings having outside storage space, provided that closed, portable containers are used.
- Dwellings and buildings that lack outside storage space should have daily collection, unless communal containers are provided.
- Because frequent collection generally implies high cost, unconventional systems and transport methods may need to be employed to maintain the costs at a minimum level.

E. Methods of refuse storage

E1. DOMESTIC and commercial wastes

The variables that impact the volume required for the storage of domestic wastes are: individual rate of waste generation, number of individuals living in the premises, and frequency of collection. Based on an average of six persons per family, the probable range required for storage in many economically developing countries is as follows [4]:

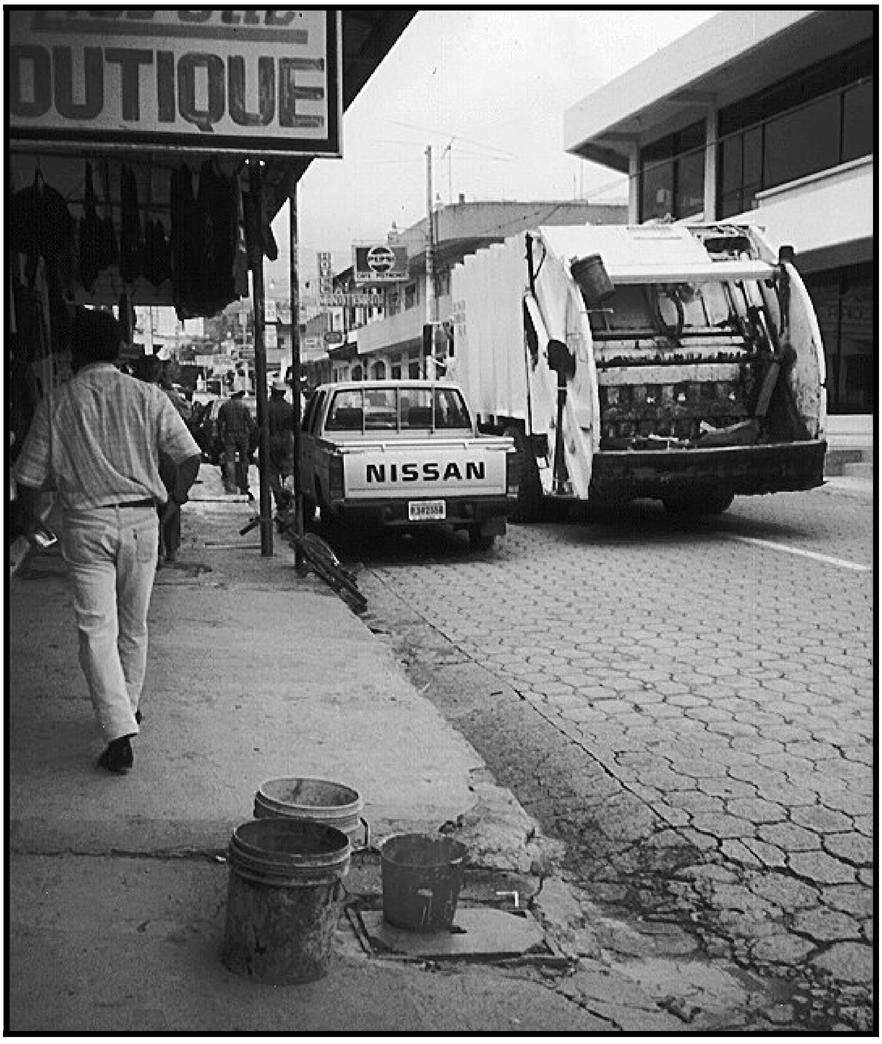
Collection Frequency	Minimum Volume (L)	Maximum Volume (L)
Daily	4	10
Twice/wk (maximum 4 days)	20	50

The following types of storage containers are available in most countries:

- Plastic buckets (with lids), with capacities between 7 and 10 L, provide sufficient volume for the storage of domestic wastes generated by a family of six for daily collection (see Figure IV-1).

- Plastic bins (with lids), with capacities between 30 and 60 L and equipped with handles, are suitable for a twice-per-week collection.

- Galvanised steel or plastic bins (with lids), with a capacity between 50 and 70 L, are necessary when collection is twice per week from high-income groups, or for daily collection from stores and commercial establishments. Bins of this size are more expensive than the smaller sizes because they are required to have a relatively long lifespan. Steel bins (such as shown in Figure IV-2) should be galvanised after manufacture and plastic bins should be made of high-density polyethylene (HDPE), or plastics of similar characteristics.



Courtesy: CalRecovery, Inc.

Figure IV-1. Plastic buckets typically used for storage

Courtesy: CalRecovery, Inc.

Figure IV-2. Galvanised waste containers (50 to 70 L)

- Disposable plastic bags have a number of advantages. However, cost would be a constraint if the bags are purchased. In economically developing countries, where annual expenditure on refuse collection per family may be on the order of US$15, the supply of 150 bags/yr, even at the very low cost of US$0.10/bag, would cost US$15/family/yr. In many cases, the plastic bags supplied at supermarkets and stores are used for storage and disposal of the wastes (Figure IV-3).

- Other items commonly used for the storage of wastes include cardboard boxes, kerosene cans, and containers made out of truck tires, as shown in Figure IV-4.

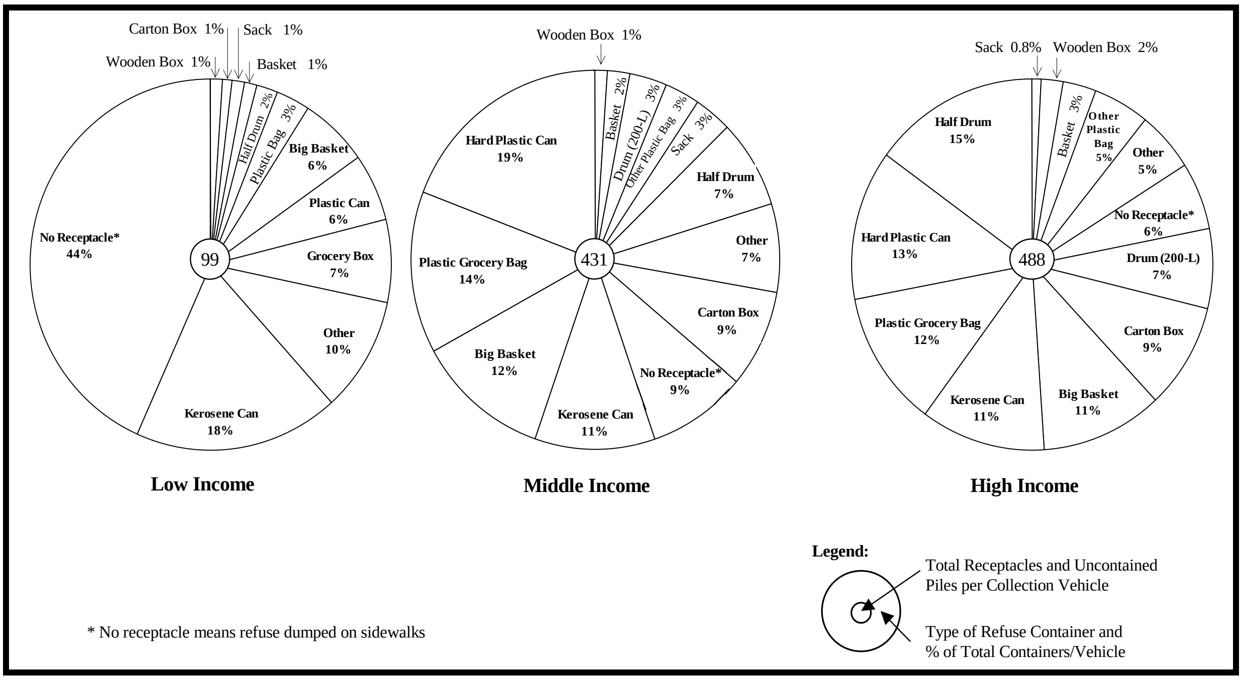
An indication of the variety and number of containers used by various types of families in Metropolitan Manila, Philippines can be gained by the data presented in Figure IV-5. The data summarise the results of analyses carried out in low-, middle-, and high-income areas of Metro Manila [3].

Courtesy: CalRecovery, Inc.

Figure IV-3. Plastic bags used for storage of wastes

Courtesy: CalRecovery, Inc.

Figure IV-4. Waste container made from a truck tire



Source: Reference 3.

Figure IV-5. Typical refuse receptacles used within a service area in Metro Manila, Philippines

The problems associated with the provision of standard bins in densely populated, poor areas should not be underestimated. Some of the difficulties include:

- the organisation, distribution, maintenance, and replacement of the bins if they are supplied by the municipality;
- diversion of bins from their intended use (e.g., used for the storage of food or water); and

- loss of containers by theft and when residents move from one location to another.

It is likely that in some areas these problems would be extremely difficult to solve and that the only feasible solution would be in the form of improved standards of communal storage. The use of standardised containers with a capacity of 50 to 70 L is an acceptable method of communal storage at premises subject to inspection and control. Such premises include: shops and market stalls, multiple-dwelling units, schools, hotels, offices, and small industries.

One of the strongest arguments for imposing a standardised container is that it is a necessary foundation for the achievement of maximum productivity in manual collection.

Based on the preceding information, the following general conclusions emerge:

- The use of one type of standardised container in densely populated areas may not be practical.

- A bucket with a lid may be a suitable storage container for most families, but the provision of buckets may have to be voluntary and should be encouraged by public education.

- When the conditions are such that the quantity of wastes generated by residences reaches a level that requires containers exceeding about 25 L of daily capacity, the financial and organisational abilities of the municipality may be adequate to enforce the use of standardised containers.

- Because of the physical limitations on a refuse collector's lifting ability, the use of covered containers of a maximum size, probably from 50 to 70 L for high-density areas, should be enforced for certain types of wastes (i.e., institutional and multi-dwelling wastes). This type and volume of container combines hygienic storage with low collection cost. The exception would be in the situation where total generation is so large as to justify mobile storage containers (drop boxes) of very large capacity (i.e., 30 to 40 m^3).

F. Communal storage methods

A refuse collection service generally evolves in the following manner. Initially, wastes are discarded indiscriminately in the streets, rivers, canals, vacant lots, and similar locations. Later, specific locations at which householders deposit their wastes evolve or are imposed. These storage sites are nuisances, particularly to people who live adjacent to them. These sites can be eliminated only by the universal use of household waste storage containers, a solution that is not practical in some areas. In their attempts to alleviate the problems of communal storage, local authorities throughout the world have devised several methods for partially or entirely enclosing wastes. Some of these methods include: depots; enclosures of timber, steel, brick, or concrete; fixed storage bins; sections of concrete pipe; 200-L drums; and portable steel containers [4].

F1. DEPOTS

A depot typically consists of a single-story building about the size of a large garage or the ground floor of a multi-purpose building. Depots commonly are used for storage of domestic and commercial wastes in a number of cities. Many depots are sited on the perimeter of densely populated areas, and residents, shopkeepers, sweepers, and private collectors deliver the wastes to them. The capacity of such depots may be as great as 25 m^3. Such large storage places are suitable for very densely populated areas; otherwise, convenience to the user and reasonableness of collection costs are sacrificed.

Waste storage depots solve some of the problems normally associated with communal storage, such as: the wastes are protected from rain, and scavengers and animals can be prevented from gaining access to them because the size of the installation is large enough to justify placing personnel to exercise continuous control over the depot.

The most difficult problem normally associated with the use of depots is their siting. The land area occupied by the depots described in the previous paragraphs is equivalent to that of a large shop. In addition, the location must be on a road sufficiently wide for vehicle access. Generally, such sites are difficult to find and very costly to acquire.

The major criticism of the depots is the manner in which they are operated. Typically, the wastes are discharged on the ground and, thus, the process of collection involves filling baskets that are then carried to a vehicle. This is a dirty and unhealthy procedure for the collectors, who are brought in direct and continuous contact with the wastes.

One possible solution to this problem is to modify the design of the depots to allow the placement of trailers or exchangeable containers into which wastes can be emptied directly by the users.

F2. ENCLOSURES

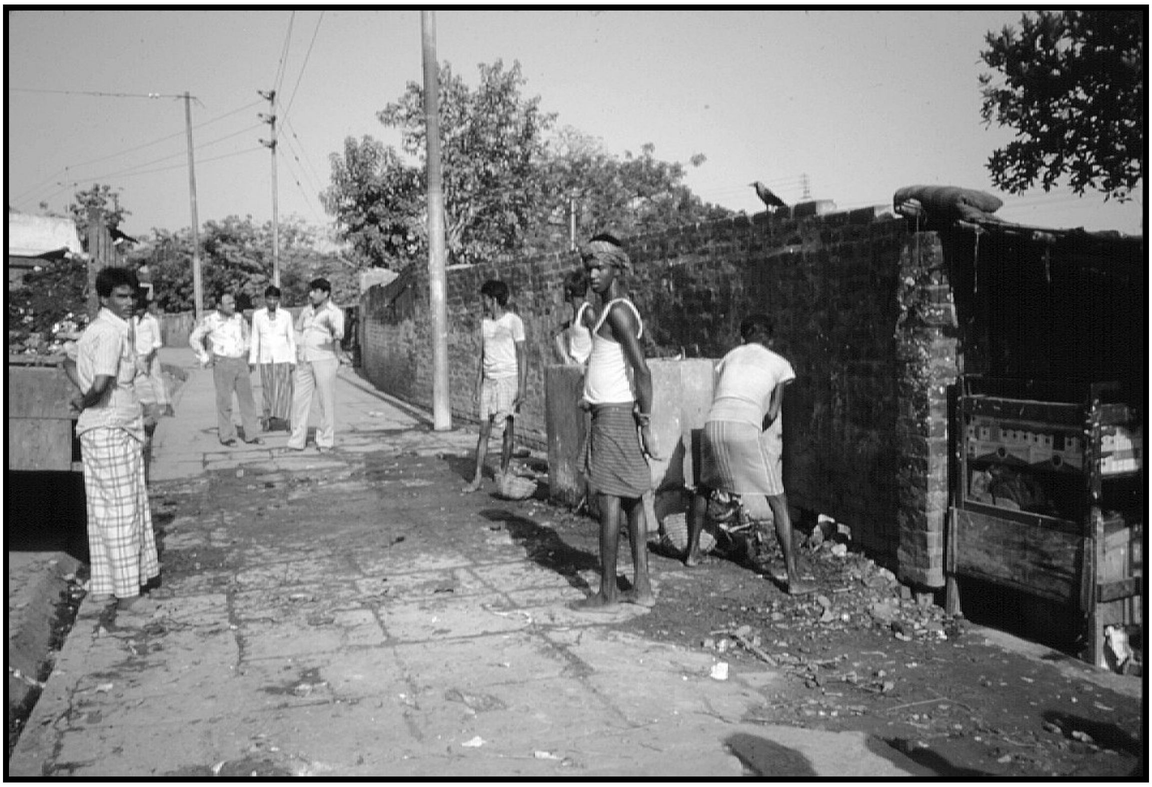
An enclosure is probably the most common communal storage method in Asia. The main feature of an enclosure is a wall made out of timber, corrugated steel sheet, brick, or concrete, and having a roof. The wall contains the wastes and screens them from view and the wind. Enclosures can have capacities from 1 to 10 m^3. At the minimum rate of waste generation, an enclosure having an average throughput of 2 m^3/day would serve about 2,000 people. Enclosures usually are located along the roadside, or at the boundary of an open space. The wall around the enclosure usually is designed to have one or more openings through which people can enter to throw their wastes on the ground. The openings are also used by collection workers to remove the wastes in baskets or similar containers. The objections to this type of storage are:

- users tend to throw wastes just inside the entrance, where a pile builds up and ultimately blocks access to the main storage area;
- rain, animals, flies, and scavengers have free access;
- the collection process is dirty and non-hygienic; and
- the enclosures are sometimes used for urination and defecation by animals and humans.

F3. FIXED storage bins

This type of container usually is built from concrete blocks. It differs from the screened enclosure in that it has no entrance for the user. The walls are of a suitable height that users can drop wastes over the wall (1.2 to 1.5 m) into the storage area. The capacity of the bins is rarely more than about 2 m^3. A service opening is provided in one wall, sometimes covered by a flap, through which the collectors rake out the wastes. This type of container is shown in Figure IV-6.

Similar rectangular or cylindrical structures fabricated of steel are also used as fixed storage bins. The smallest bins (capacity of about 300 L) are equipped with hinged lids on top and an extraction opening at the bottom. The lids play a substantial role in meeting the primary objectives of communal storage, i.e., the exclusion of animals, insects, and rain. Unfortunately, this device does not keep human scavengers from accessing the waste for the purpose of salvaging materials.



Courtesy: CalRecovery, Inc.

Figure IV-6. Fixed storage bin in Bangladesh

The main objection to using these containers is having to extract the waste by raking it through an opening at ground level. The wastes generally become entwined and compacted and, in practice, their removal through the relatively small aperture is very difficult. Usually, the collectors must climb inside the bins and fill their baskets from the top of the pile. In this process, the collectors come into close contact with the wastes. Sometimes, the flaps covering the extraction opening break off, and then the contents flow out from the opening. The resultant outflow encourages people to discharge their wastes on top of the overflow.

F4. SECTIONS of concrete pipe

One of the key problems of communal storage is that of provision of suitable and adequate storage volume. The required storage volume, in turn, is a function of population density and per capita generation, as well as distance of the storage site from the waste generator. Unless communal storage sites are located within a relatively short distance from the potential user (e.g., within 120 m), people will be tempted to dispose of their wastes at an illegal site that is closer to their homes. For areas of low population density, a need exists for communal containers that have a relatively small volume and are low cost. To meet this need, some communities have adapted short lengths of concrete pipe to this purpose. The most common size of concrete pipe is about 1 m in diameter; the common length is 1 m or less. This provides a volume of approximately 300 L when the pipe is located on a flat area. Although such a container is very sturdy and satisfies the basic need to provide a specific location for wastes, it fails in almost every other aspect, i.e.:

- The wastes are exposed to view.
- The wastes are accessible to flies, rats, domestic animals, and scavengers.
- When the pipes are sited on unpaved surfaces, fly larvae can migrate, pupate, and hatch.

- The wastes have to be removed by means of a rake. This is very strenuous work in an uncomfortable position, and puts the worker in close contact with the wastes.

F5. METAL drums

The metal drum, in particular the 200-L drum, is probably the type of solid waste container most widely used throughout the developing world for communal storage of wastes. The drum used for this purpose usually is a waste product, and has been previously used for the distribution of oil, solvents, or similar materials. Three strong benefits are attributable to the 200-L drum -- it is cheap, readily available, and relatively portable. Drawbacks include the usual lack of a lid, its weight, and its propensity to rust, particularly in moist and salt air climates.

The extent to which a metal, 200-L drum is portable depends upon the weight of the wastes contained within it. The drum itself weighs between 16 and 18 kg. Refuse generated in some areas can have a wet density of about 500 kg/m^3. Under these conditions, the total weight of the drum and its contents would be on the order of 110 kg. On the other hand, in the case of light packaging wastes, the gross weight may be less than 70 kg. Even at the lower end of these weight ranges, a full 200-L drum should always be lifted by two people, because of the awkward size of the drum and the lack of handles. At the maximum of the weight range, the drum cannot safely be carried long distances, but it can be rolled on the bottom rim and emptied by two people. The use of 200-L drums for waste storage has been strongly discouraged in the United States by the U.S. Environmental Protection Agency, because the drums are detrimental to the health and safety of collectors, as well as to the general public, and they contribute to lower collection efficiency and higher costs. Most of the difficulty stems from their weight and absence of lids. The drums rarely are used in the United States and have been replaced in most instances by lighter plastic and lightweight, galvanised steel containers of 120 L capacity, with secure lids.

With respect to collection efficiency and cost, small portable containers are feasible in the United States and most countries in Western Europe. However, there are many other countries in the world where 200-L drums would greatly increase collection efficiency and may offer some advantages over present storage and collection methods. Some of the advantages include:

- labour cost would be less than that of loading by shovel or by basket,
- vehicle cost would be reduced as a result of a faster rate of loading,
- health risks to residents would be reduced by preventing migration of fly larvae, and
- health risks to workers would be reduced by avoiding skin contact with wastes.

A major disadvantage of using the 200-L drum is its excessive weight when fully loaded. Lifting and emptying these heavy loads represents a substantial risk of injury to the collector. However, if the collection frequency is designed such that the drums are only partially full, then the risk of injury is reduced. Another disadvantage exists in those cases where the drums are used without lids. In such cases, rainfall can substantially increase the gross weight of the drums. The authors have observed that in locations where there is excessive rainfall, the bottoms of the drums are perforated with several holes, which allow excess moisture to drain. This practice and resulting drainage has obvious implications concerning the health and safety of the public and pollution of the environment.

A few cities have demonstrated that it is possible to use 200-L drums with reasonable success. In most of these cases, the standard of management by the local authority has been high. Some of the key management programs that have been instituted include:

- the drums have been painted both inside and outside for durability and aesthetics;
- locations have been carefully selected and, where necessary, paved and provided with partial fencing;
- excess capacity has been provided to avoid overflow;
- damaged bins are quickly replaced; and
- collection is conducted on a frequent basis (e.g., daily) in order to maintain the weight of the loaded drum to a safe level.

An example of this application in American Samoa is shown in Figure IV-7.

In all cases in which 200-L drums have been used with success, the standards of human behaviour with respect to waste management and of public cooperation were fostered by the government and were above average. This experience demonstrates that when local authorities set a high standard of service, even at low cost, residents will respond by cooperating with the system.

Courtesy: CalRecovery, Inc.

Figure IV-7. Communal storage containers used in Pago Pago

F6. PORTABLE bins

The conventional steel (or plastic) bin of between 70 and 120 L, typically used in industrialised countries for storage of wastes generated by single-family residences, can also be used for communal storage where generation is low and collection frequency high. Galvanised bins having a capacity of about 100 L, with well-fitting lids, have been observed in Southeast Asia, where each container serves up to 10 families. This, of course, appears to be an excellent solution in terms of hygienic storage, collection efficiency, and the health of residents and workers. On the other hand, this solution requires a significant initial expenditure by the local authority and a very high level of public cooperation. Some cost savings may be achievable by cutting 200-L drums in half and equipping them with legs and lids such as that shown in Figure IV-8.

Courtesy: CalRecovery, Inc.

Figure IV-8. Half-drum (100-L) used as communal container (in foreground)

The types of problems likely to be encountered with the use of portable bins include:

- loss or destruction of bins during use,
- loss or destruction of lids,
- rusting of bins if constructed of steel,
- traffic accidents caused by bins rolling into the road, and
- excessive weight of a loaded bin.

Community metal bins have been successfully used in part of the City of San José, Uruguay. The city placed about 200 2-m^3 metal bins every 100 m. The bins were emptied by means of a front-end loader.

F7. CONCLUSIONS regarding communal waste containers

In most situations, particularly in tropical regions, the collection frequency should be often, i.e., daily or several times per week. In addition, every type of communal container should be thoroughly cleaned from time to time and covered if at all possible in order to provide the greatest degree of health and safety to the public, and of protection to the environment. Systems that do not permit thorough cleansing, such as storage in concrete pipes, should not be adopted.

A review of the methods described in the preceding sections indicates that waste managers in developing countries have, thus far, been unable to arrive at a complete solution to the problem of communal storage. Of all the methods considered, only the 200-L steel drum is inexpensive to install and maintain, offers low collection cost, and provides a tolerable level of health protection to residents and workers. The risk of injury to the workers due to lifting may be overcome by cutting off the top half of the drum. However, the cut edge represents a different type of injury risk. Despite the benefits, the manner in which the drums are normally used for waste storage in developing countries results in rusting and dented drums, a visually unsatisfactory condition that is oftentimes scorned by residents and governmental authorities alike.

F8. CAPACITY margins

The design and selection of containers requires that an allowance be made for a margin of capacity over the average rate of waste generation. This allowance is necessary because the cycle of production varies from day to day. For example, holidays and short periods after them usually give rise to significant surges in waste generation.

When the collection service is provided on a daily basis, it is advisable to allow up to 50% excess capacity above the average generation rate in order to keep containers from overflowing. If the collection service operates only six days/wk, at least 100% over-capacity is necessary in order to contain two days of waste production.

In the case of communal containers, it may be prudent to provide a minimum of 100% margin even for daily service. Such a policy is particularly helpful where 200-L drums are used, because the average drum would then be only partially filled prior to collection. The excess capacity also reduces exposure of the wastes to view or to scavengers.

G. Collection vehicles

The collection of refuse involves all of the steps necessary for transferring the solid wastes from the storage point to the place of treatment or disposal. The process involves emptying the storage container into a vehicle in which the wastes are transported. The collection service may be designed in different ways and can use several transport methods. Transportation methods range from handcarts to 30-Mg vehicles. Solid waste collection is a very costly service and traditionally has been the most expensive phase of waste management. Every jurisdiction should carefully evaluate types of vehicles and collection methods in order to select the system that is most appropriate to local conditions in terms of quality and efficiency of service and cost of operation.

Local conditions vary widely; for example, 1 Mg of municipal wastes in Latin America may occupy a volume of 1 to 2 m^3. On the other hand, 1 Mg of municipal wastes from the United States may occupy a volume of 8 m^3. Daily collection in many developing countries involves a volume-to-dwelling ratio of less than 8 L. Typical weekly collection in the United States requires the removal of more than 100 L/dwelling. Wages in the United States are so high that it generally costs more to employ a worker than to operate a compactor vehicle, including amortisation but excluding driver labour. In most countries in Asia and Latin America, the cost of operating a simple 5-Mg collection vehicle may be 10 to 15 times higher than the cost of employing one person. For these reasons (and others previously mentioned), vehicles and systems used in industrialised countries may be entirely inappropriate for use in a developing country.

The work performed by a refuse collection vehicle can be divided into two main phases. The first phase, while the vehicle is stationary during loading of waste, represents lost time for the prime mover. The second phase, which is spent travelling at normal road speed with a full load, represents efficient use of the prime mover. Thus, to achieve maximum productivity in terms of load transported per unit of distance (Mg/km), the loading time must be kept to a minimum. If the collection unit can be divided into the two parts (the prime mover and the body), loading time can be eliminated by providing an extra body that can be loaded while the other one is transported to the disposal site. If the prime mover can be used solely for the transport of full trailers loaded in its absence, it will be fully employed in travelling. In suitable conditions, it is possible to transport two or three times the weight per day that could be achieved by a conventional vehicle. Those conditions can be: at large sources, such as markets, where a trailer can be sited permanently and used as the container for the market; and in areas where the wastes from multiple small sources, such as dwellings, are collected by other means, such as handcarts, and brought to the trailer.

This chapter presents a partial listing of various types of refuse collection vehicles. At the present time, most of the vehicles manufactured for waste collection are designed for conditions prevalent in industrialised countries. In particular, the designs are based on low-density wastes (i.e., about 130 to 190 kg/m^3), which must be compacted 4 to 1 in order to achieve a reasonable payload. In order to meet the conditions of developing countries, the listing includes many types of vehicles not used in industrialised countries. Some of these vehicles were used in the United States and in Europe several decades ago, but are no longer manufactured. The designs of these vehicles do, however, represent a period when some industrialised countries had wastes of high density (similar to those currently generated in some developing countries) and when mechanisation was of lesser importance. Some of the designs discussed herein may be relevant to the needs of developing countries. The following goals are applicable to collection vehicles of all types:

- The load of waste should be thoroughly covered during transport; this is particularly important for motor vehicles travelling at 30 km/hr or more.
- The loading height of vehicles receiving the contents of containers emptied manually should not exceed 1.6 m.
- The body of a vehicle should have power-operated or hand-operated tipping gear, or a power-operated ejection plate, unless the load of waste is carried in portable containers.
- If the vehicles used for primary collection are handcarts or those drawn by an animal, the vehicles should receive the same standards of mechanical design as motor vehicles, including the use of bearings for the wheels, and rubber or pneumatic tires.

G1. HANDCARTS

Handcarts are almost universally used in developing countries for street sweeping because they cause minimum obstruction to traffic and their capacity is sufficient to keep a sweeper busy for up to two hours. Handcarts, as shown in Figure IV-9, also are used in developing countries for daily house-to-house collection -- in particular, collection along very narrow streets that are inaccessible to motor vehicles. Typically, the handcarts have open boxes that are attached to the frame, which means that the only way of transferring the contents to a larger vehicle is to discharge the wastes on the ground and use a shovel or a basket for reloading, as shown in Figure IV-10. This procedure, of course, is a wasteful use of labour and increases vehicle idling time.

Thus, one of the more important design features of a cart is to ensure that the load is carried in one or several containers that can be lifted off the cart and emptied directly into a larger vehicle. This requirement can be met by building the cart in the form of a light framework of tubular steel or angle with a platform on which four or six 70-L bins can be carried. For instance, in Mexico, handcarts are used that are comprised of a platform, supported by four small wheels and carrying one or two 200-L metal drums (see Figure IV-11). As previously mentioned, a problem with containers of this type and capacity is that two men are needed to safely empty the loaded drums into a vehicle.

Courtesy: CalRecovery, Inc.

Figure IV-9. Handcart with box body

Courtesy: CalRecovery, Inc.

Figure IV-10. Emptying of wastes from handcart for reloading into larger collection vehicle

Courtesy: CalRecovery, Inc.

Figure IV-11. One-bin handcart (100- to 200-L capacity)

For the daily collection of refuse from house to house, one 6-bin handcart load, such as that shown in Figure IV-12, would be sufficient for about 50 dwellings (8 L/dwelling/day). One collector would be able to serve between 200 and 300 dwellings/day. At a density of 500 kg/m^3, the net weight per load would be about 200 kg. This is well within the capacity of the average collection worker to push, provided that the wheels and bearings are of good design. The typical radius of operation of a handcart is about 1 km and, thus, frequent transfer points must be provided.

G2. PEDAL tricycles

Pedal tricycles equipped with a box carrier in front, commonly used in Latin America and in Asia, can be adapted to carry wastes. Unfortunately, their volumetric capacity is less than that of a handcart. Pedal tricycles reduce travelling time and can, therefore, operate over a larger radius than a handcart. Refuse collectors can serve about 200 dwellings/day using tricycles. Productivities on the order of 0.5 to 0.9 Mg/ worker/day have been achieved in paved, residential areas in Lima, Peru. A modified pedal tricycle used for the collection of non-pathogenic wastes in a hospital in Bangladesh is shown in Figure IV-13.

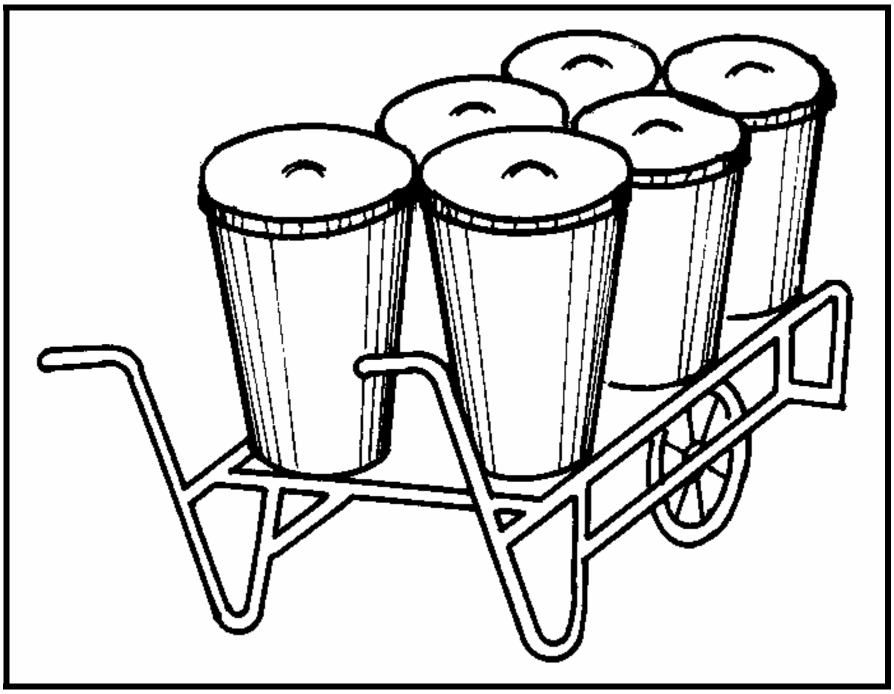


Figure IV-12. Six-bin handcart (300- to 500-L capacity)

Courtesy: CalRecovery, Inc.

Figure IV-13. Modified pedal tricycle used for waste collection

G3. ANIMAL carts

Horses were widely used in North America and in Europe for door-to-door refuse collection up until World War II. Horses, mules, donkeys, and other animals are used for waste collection in several countries around the world. A typical cart is shown in Figure IV-14. The capacity of draught animal carts generally ranges between 2 and 4 m^3. In some cases, the carts are equipped with bodies that can be tipped, by either pivoting the body or by using a manually-operated worm and nut mechanism. Animal carts have the following advantages: no consumption of fossil fuels, very low capital and operational cost compared with motor vehicles, and very quiet operation.

Courtesy: CalRecovery, Inc.

Figure IV-14. Typical animal cart used for waste collection

The low speed of animal carts limits their effective radius of operation to about 3 km. In streets with heavy traffic, animal carts may interfere with motorised traffic. Animal carts can and do operate in conjunction with a two-level transfer station in which they tip their loads directly into a large motor vehicle. Some cities in Asia have successfully operated this system and have taken advantage of both methods of transport: animal carts for the slow “stop-and-go” portion of the operation and motor vehicles for “high-speed” transport from the collection point to the distant final disposal site.

However, despite their popularity, more attention needs to be paid to the design of the carts. Ideally, animal carts should have bodies fabricated from steel and mounted on pneumatic tires. The carts should be low-loading, fitted with sliding shutters, and equipped with manually-operated tipping gear.

G4. MOTORISED tricycles

The two-stroke, three-wheel motorcycle is a very common means of transportation in several developing countries and is a viable alternative for waste collection. A sketch of a motorised tricycle is shown in Figure IV-15. The tricycle can be fitted with a high-level tipping body of about 2 m^3 capacity while retaining a low-loading line. The motorised tricycle is in common use in several cities in Asia, particularly in the old sections of the cities where the streets are too narrow to allow passage of larger vehicles. Its relatively high speed gives this system an operating radius of about 10 km. However, the tricycle does not operate well on rough, unpaved roads such as those in marginal areas or those that typically lead to disposal sites. If the road system to the disposal site is inadequate, tricycles should discharge at either transfer facilities or processing plants.

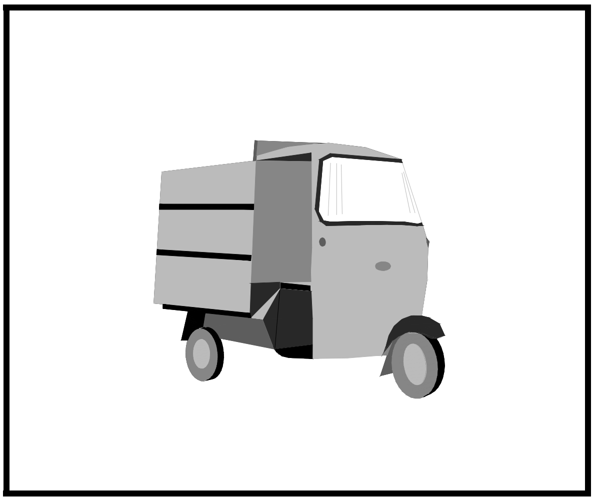


Figure IV-15. Light motorised tricycle (about 2 m^3 capacity)

G5. TRACTOR and trailer systems

The agricultural tractor is one of the most utilised motor vehicles for collecting waste in economically developing countries. A tractor has several advantages over other types of motorised vehicles. Some of these advantages include: relatively low capital cost, capacity to transport a large load relative to energy use, readily available maintenance facilities, manoeuvrability on a landfill due to large tires and high torque, and ability to use the power take-off to operate hydraulic tipping gear on a trailer. Despite its relatively low road speed (about 20 km/hr), tractors offer one of the least expensive methods of motor transport of solid wastes, up to a trailer capacity of about 6 m^3.

There are a number of types of agricultural tractor-trailer systems: mini-agricultural tractors or jeeps can be used with shuttered side-loading trailers up to 4 m^3; full-size agricultural tractors can be used with trailers up to 6 m^3; and articulated semi-trailers are available with capacities up to 30 Mg for long-distance transfer. An example of a tractor-trailer system is presented in Figure IV-16.

The agricultural tractor with trailer often is used as a single unit for the collection of refuse from houses or communal storage points. This combination also has substantial potential as a transfer unit because of the ease with which the tractor can be separated from the trailer.

Courtesy: Alternativa

Figure IV-16. Agricultural tractor with trailer

G6. LIGHT commercial trucks

This type of vehicle is available almost worldwide. It is primarily designed for the transport of construction materials. However, it is also widely used for the collection of wastes from communal sites. The body of the truck is usually made of steel, with a flat platform equipped with hinged sides and tail-boards about 40 to 60 cm high. The volume of the truck is usually about 5 to 6 m^3 and is suitable to carry high-density materials such as bricks and aggregates. One of the major disadvantages of the vehicle in its standard form is that it is rarely able to carry its rated payload of solid wastes. Even high-density wastes piled on the vehicle would be unlikely to exceed 4 Mg. It is, therefore, common practice to extend the height of the sideboards in order to increase the volumetric capacity. This practice, however, makes it necessary to either use ladders to load the vehicle or to place workers inside the body to receive containers handed up to them by collectors.

The advantages of this type of truck are the following: it is relatively inexpensive, it is sturdy and easily obtainable, it has good ground clearance, and it performs well on rough roads.

In applications involving the collection of solid wastes, the truck should have a carrying capacity of at least 2 m^3/Mg. In addition, the loading height should not exceed 1.6 m.

There are some modifications that can be made to a conventional light commercial truck that enable these requirements to be met without complex mechanisation of the body. Some of these modifications include:

- Reduction in the height of the chassis by using wheels of a diameter smaller than standard. This change, however, would result in the reduction of both the maximum permissible load and ground clearance.

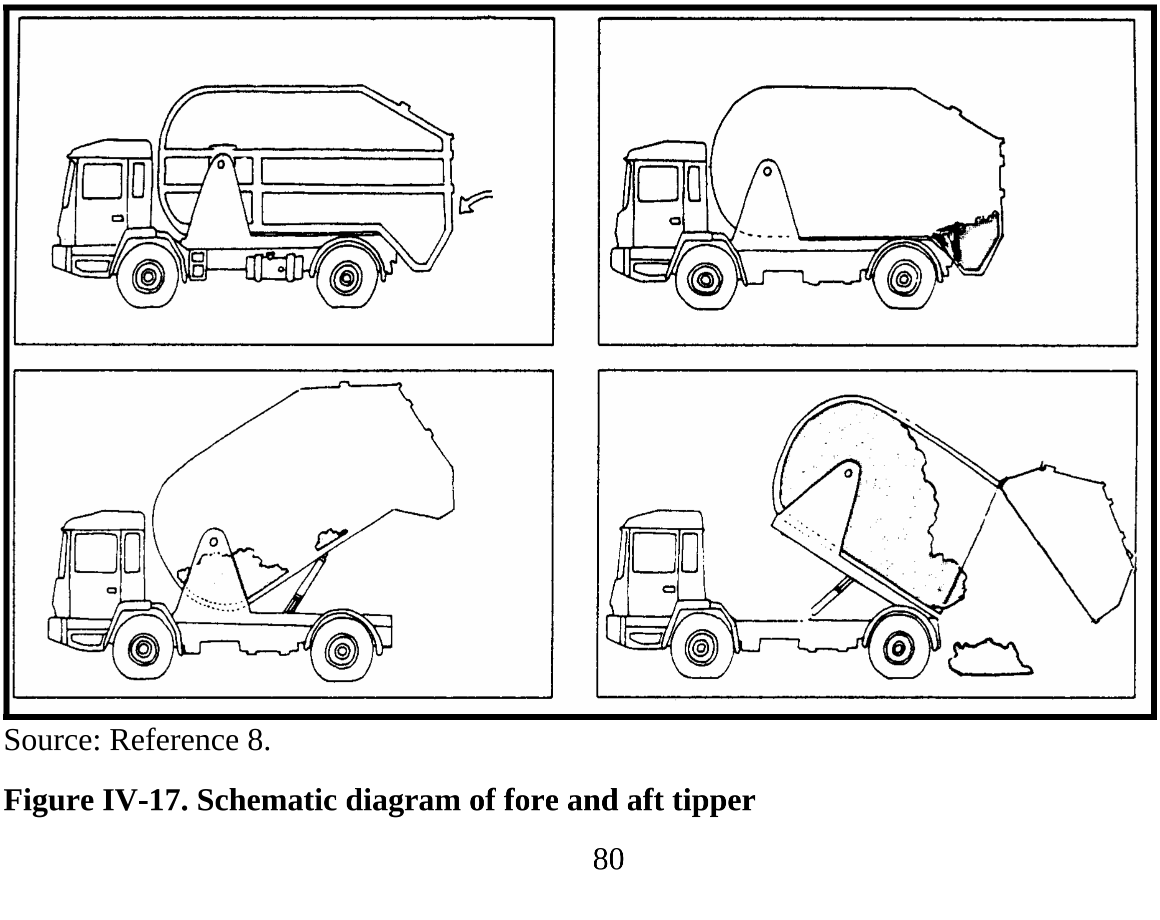
- Use of full forward control (cab-over engine) to increase space on the chassis for the body.
- Extension of rear overhang.
- Use of a long wheelbase.

The application of these design modifications allows the use of an enclosed body. The body could have a capacity of about 8 m^3 without exceeding the desired loading height of 1.6 m. The most common type of body having these design features is the side-loader. The side-loader has three or four loading apertures along each side. The apertures can be closed by means of sliding shutters. The shutters are usually plain sheets of metal running in grooves. The load can be distributed within the body by the use of rakes. During the final stages of loading, the waste can be piled against closed shutters along one side. Because of the potential difficulty of unloading, it is advisable to equip these vehicles with hydraulic tipping gear.

G7. FORE and aft tipper

This design appeared in the mid-1930s and was used in Europe until about ten years ago. Its distinguishing feature is that the body can be tipped two ways: toward the front of the body during the loading process and toward the rear for unloading. This relatively simple mechanism achieves a result similar to the hydraulic ram at the rear of a compactor vehicle. However, the compression effect is much lower than that obtainable with the compaction unit. The forward tipping operation may be required about 12 times per load. A suspended barrier inside the body prevents the wastes from falling back after tipping. This type of vehicle utilises body capacities of about 12 m^3.

This design approximates that of a compactor and is suitable for densities from 250 kg/m^3 and upward. The vehicle can be built on a standard chassis with normal wheel diameter, and presents few maintenance problems. A schematic diagram of the fore and aft tipper is shown in Figure IV-17.



Source: Reference 8.

Figure IV-17. Schematic diagram of fore and aft tipper

G8. CONTAINER-HOIST

This unit utilises a standard commercial chassis (in the range of 5 to 10 Mg) equipped with two hydraulically-operated lifting arms. The arms are used to lift metallic containers on or off the floor of the vehicle. The containers have a capacity of 3 m^3 or more. The containers can be tipped to discharge their contents while in position on the vehicle.

The container-hoist is a viable alternative to tractor-trailer units; it is cheaper, faster, and less liable to be damaged by vandalism than the tractor-trailer units. On the other hand, the cost of a container vehicle is about twice that of an agricultural tractor and in many cases the container transports a considerably smaller load than that possible using a tractor-trailer.

The main reason for the relatively low payload appears to be that the container vehicles are manufactured to collect and transport wastes that have a relatively high bulk density. It is not advisable that developing countries implement container systems based on capacities on the order of 3 to 4 m^3.

G9. VEHICLE standardisation

In the conduct of several projects throughout Asia, Africa, Latin America, and the Caribbean, the authors have observed that a large number of countries have mixed vehicle fleets and extremely low vehicle serviceability. In fact, in extreme situations, the authors have observed municipalities that own and operate vehicles that require metric tools and vehicles that require English tools. In some instances, the serviceability is as low as 50% to 60%. These two factors may be related to one another. If many different models of vehicles or vehicles of different manufacturers compose the collection fleet, it is extremely difficult (and costly) to maintain an adequate stock of spare parts. Consequently, vehicles may be off the road for long periods of time while replacement parts are purchased and delivered, sometimes through a centralised purchasing organisation. In fact, it is very common in developing countries to see a large number of vehicles broken down and used as sources of spare parts. The use of a centralised purchasing organisation may cause additional delay by requiring competitive bidding for even minor items.

Inventory control can be simplified and availability of spare parts improved by standardising the fleet. Furthermore, major spare items (engines, transmissions, axles, and hydraulics) can be kept in stock. These spare items are used to replace defective parts in a vehicle, which can then be put into service within a few hours. The items that have been removed can subsequently be repaired at leisure.

Standardisation, however, does not imply that the same type of vehicle should provide service to every area in a community. As mentioned previously, low-income areas may require different types of vehicles.

Compactor vehicles are not considered in this chapter for the following reasons:

- Compaction ratios achieved with wastes from industrialised countries (with initial densities in the range of 130 to 190 kg/m^3) vary from 2:1 to 4:1, the final density in the vehicle being about 400 to 550 kg/m^3. Wastes in most developing countries have an initial density similar to that of compacted industrialised wastes.

- The compaction mechanism imposes a need for additional maintenance facilities that may not be readily available in some cities.

- Compactor vehicles usually need to be imported, which may lead to problems in foreign exchange and acquisition of spare parts.

- The compaction mechanism substantially increases fuel consumption.

- The capital cost of a compactor vehicle is significantly greater than that of a conventional truck.

H. Access and point of collection

Thus far, the two main elements of a refuse collection system have been considered: storage and collection. These elements are linked at the collection point. The location of the collection point is conditioned by several factors. Some of these factors include: physical characteristics of the buildings, access to the buildings and width of roads, and the share of the work of refuse collection carried out by the householder.

The system for storing solid wastes and the provision of access to the storage point for refuse collectors must be given careful consideration at the design stage of any building. In some countries, city planning and building regulations deal with waste storage and often require that plans for all new buildings be submitted for approval to the department responsible for solid waste services. However, in most countries there has been little, if any, regulation of this type, and every city contains several structures for which it is very difficult to devise a satisfactory storage and collection method. In this section, we review the main problems associated with access to the points for refuse collection. Standards for building construction have an impact on frequency of collection, vehicle type and size, and the number and type of duties that have to be imposed upon the householder.

H1. DETACHED dwellings

Detached dwellings are ideal units for the storage and collection of wastes. The container can be kept outside the house, in the open air. Collection frequency is not critical if the container is impervious and has a lid. Under these conditions, a collection frequency of once or twice weekly would be adequate.

Unless there are compelling financial reasons or resource recovery (recycling) goals, it is unnecessary to impose duties on the householder, other than to require him or her to carry the storage container to a designated collection location. The collector can enter the backyard or garden, carry out the container, empty it, and return it to its normal position. This activity, as opposed to collection at the roadway, increases the time and, therefore, the overall cost of the collection process.

It is essential for tropical countries to have a frequency of collection that takes into account the composition of the wastes, the rate of decomposition of putrescible matter, and the type of storage container. It seems to be generally assumed that the collection frequency of once or twice per week, which is widely used in the United States and in Europe, is due to the temperate climate. However, some portions of these countries also have very hot and humid climates. Therefore, it is arguable that the low collection frequency in the United States and Europe is acceptable also because of the high standards of solid waste storage, which prevent odour emission and access by insects and other animals. Thus, in terms of minimising collection frequency and costs, one of the more important problems for some developing countries is that of attaining nuisance-free waste storage. In those cases where the wastes are not or cannot be properly stored, collection frequency in the range of daily to three times per week may be required to minimise nuisances, to protect the public health and safety, and to protect the environment.

Separate dwellings can range in size from a small cottage to a luxurious villa. In most cases, there is flexibility regarding the types of collection methods that are technically feasible. However, cost is likely to be the main criterion in the selection of vehicles and methods.

H2. MULTI-FAMILY dwellings

Generally, apartments have only one entrance. In this situation, it is possible to provide door-to-door service to each residence. Collectors have been observed to carry large, strong plastic sacks or large, light bins for waste collection into apartment buildings. The collector goes to the door of each apartment, knocks, and waits until the waste is brought out. The waste is then emptied into the collector's container. The container generally is large enough to contain the wastes from several apartments. This process reduces the number of trips that the collector must make to the vehicle.

In some locations, multi-story apartment buildings have balconies at the rear that can be reached by an external staircase. In these circumstances, a full collection service is possible if the solid waste storage container is kept on the rear balcony.

Alternatives for the collection of wastes from multi-family dwellings include either a series of small bins or a large container for communal use. In either case, the frequency of collection from apartment buildings should be daily or every other day because of the limited storage space in the apartments and the likelihood that communal storage may be improperly operated.

H3. SINGLE-ROOM dwellings

It is relatively common that in the very poor areas of many large cities, a single room may be used for cooking, eating, and sleeping. This room may be part of a large dwelling unit, or one of a large group of temporary or permanent shacks. In both situations, the storage of wastes on the premises for more than a few hours is obviously a problem.

In the absence of any private space where a waste container can be kept, public space must be made available. Thus, in these conditions, the most feasible alternative is the provision of communal containers in the streets. The container kept in the dwelling unit should be emptied on a daily basis.

A system of small communal containers spaced not more than 100 m apart is better than a system where large containers are located at greater intervals. Closely spaced containers are more likely to be used. Ideally, communal containers should be placed on paved streets that are sufficiently wide for accommodating a motor vehicle. Small containers, on the other hand, can be moved on hand trolleys to the nearest road.

H4. MARKETS

Most, if not all, cities in developing countries have at least one central market. The size of the market generally is a function of the size of the city. In some cases, one market attracts people from several kilometres away. The market typically has a large number of stalls placed closely together. The stalls face narrow passages that are usually thronged with pedestrians and littered with wastes. Generally, sweepers bring the wastes from the passages to a central storage point, which typically is a large pile on the ground. From time to time, a waste collection crew and vehicle collects and disposes the piles of waste.

In some of the modern markets, every stall is provided with a waste bin of about 50 to 70 L. The stalls are serviced by a sweeper with a cart who exchanges empty bins for full ones, and then empties the bins into a large container stationed in an area immediately adjacent to the market.

A high percentage of the wastes generated in markets is organic and readily biodegradable.

H5. ACCESS for trailer or container exchange

Several types of sources usually generate sufficient quantities of wastes to justify the use of a trailer or a large container for central storage of wastes. Some of these sources include: hospitals (not pathological waste), hotels, factories, office complexes, and some apartment buildings.

The layout and the location of the storage areas need careful planning in order to service the full trailer or container with minimum effort and to avoid interfering with traffic flow. Some of the key factors that should be considered include: the site should be located on an internal road of the source's premises in order to avoid the need for complex vehicle manoeuvres on a main thoroughfare, and the site should have extra space in which the empty trailer or container can be placed. In order to facilitate the collection process, a straight-through approach to the trailer or container location is an advantage.

H6. NARROW paths/alleys

Several countries have very old city centres and marginal areas where paths are too narrow to allow access by motor vehicles. This has been one of the main reasons for the continuing use of large communal sites in developing countries.

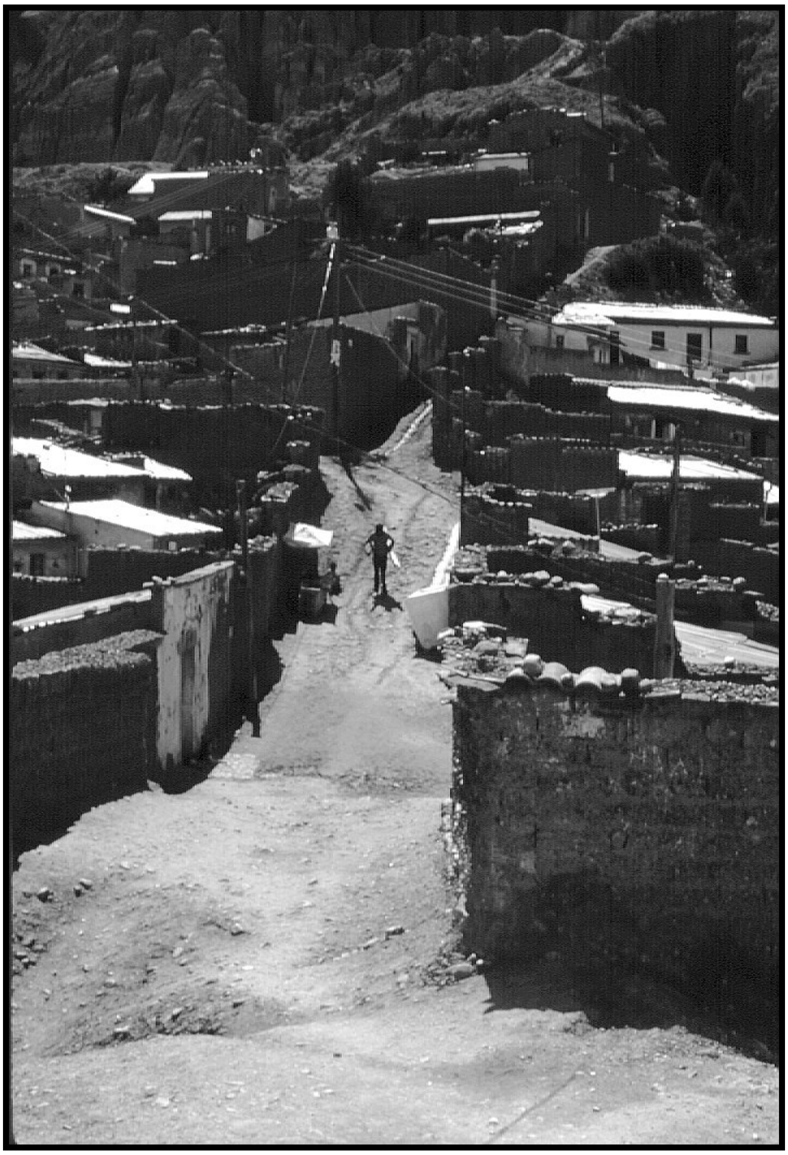
Narrow alleys, sometimes only a meter wide, are also a characteristic of marginal (slum) areas. Their inaccessibility to conventional collection methods has sometimes caused such areas to be entirely denied collection services, with the consequence that wastes are disposed in ditches, canals, and rivers.

Daily collection from these areas, where population density is very high, is essential not only for the protection of the immediate population, but also out of concern for the health of the community as a whole.

The use of manually operated carts is one obvious solution to the access problem. The carts can be used for door-to-door service, or for servicing small communal containers. Sometimes, however, such communities are established on steep hillsides, such as the one shown in Figure IV-18. Collection of waste on steep inclines may be accommodated by the use of animals of burden (mules, donkeys, llamas) equipped with containers in which the wastes can be carried.

I. Basic collection systems

Essentially, there are four basic collection systems, depending upon the level of effort required on the part of the generator. The types of systems are: communal, block, kerbside, and door-to-door. Communal storage and collection may require delivery of the wastes by the generator over some distance. In block collection, the generator delivers the wastes to the vehicle at the time of collection. In kerbside collection, the generator sets out the full container and later retrieves it. In door-to-door collection, the collector enters the premises, and the generator basically is not involved in the collection process. A description of each one of these systems is presented in the following paragraphs.



Courtesy: CalRecovery, Inc.

Figure IV-18. Human settlement located on steep terrain

I1. COMMUNAL collection

The planning and organisation of refuse collection is greatly simplified by the use of large communal storage sites. Although the use of large communal sites may seem to be a fairly inexpensive and simple solution, it may transfer much of the burden of refuse collection onto the street cleaning service and actually increase total costs. It is less expensive to collect refuse directly from a residence or business than to sweep it up from the streets.

The use of large, widely spaced communal storage sites generally fails because the demand placed on the generator goes beyond his willingness to cooperate. If communal storage sites are going to be used, the storage points should be at intervals convenient to the generators.

Large masonry enclosures, as well as small concrete bins, are inefficient in the use of labor and vehicles. As previously indicated, wastes have to be manually removed from these types of containers by rake or shovel and basket. This is a relatively slow process and vehicle waiting time during the loading process is excessively non-productive. In addition, the idle collection vehicles impede other traffic in the street. The following performances have been recorded: 1.4 Mg/worker/day and 7 Mg/vehicle/day for masonry enclosures, and 1.2 Mg/worker/day and 6

Mg/vehicle/day for concrete pipes. Drums having a capacity of 200 L are not an ideal solution; however, two workers can generally empty them into vehicles with a low load line. The use of 200-L drums increases collection performance to about 5 Mg/worker/day and 10 Mg/vehicle/day.

I2. BLOCK collection

In this system, a collection vehicle travels a regular route at a frequency of two to three times per week. The vehicle stops at all street intersections, and a bell is rung. At this signal, the residents of all the streets leading from that intersection bring their containers of waste to the vehicle and hand them to the crew to be emptied. Typically, a driver and a crew of two are sufficient for this type of system since they do not need to leave the vehicle to perform collection of the waste.

Block collection should be operated frequently; otherwise, the quantity of wastes to be carried to the vehicle may require more than one trip or may be beyond the carrying capacity of some of the residents. This method of collection has a significant advantage over kerbside collection since the containers are not left out on the street for long periods of time while awaiting the arrival of the collection vehicle.

Block collection is operated in some cities in Latin America. The results of a study carried out in Mexico City indicated that it took about 2.5 hr to service approximately 840 dwellings. The route was 2.7 km long, and each dwelling delivered about 4.3 kg. The performance achieved by this system was about 3.5 Mg/worker/day and 7.0 Mg/vehicle/day [4].

I3. KERBSIDE collection

This system of collection requires a regular frequency and a fairly precise schedule, for optimal efficiency and convenience. Residents must place their containers on the curb before the time of collection and remove the containers after they have been emptied. It is important that the containers be of a standard type. If standard containers are not used, it is likely that wastes will be set out in any type of container such as baskets or cardboard boxes, or even in piles. Under these conditions, the wastes may be scattered by animals and wind, thus making the collection process very inefficient. In developing countries, kerbside collection is not entirely satisfactory. Some of the problems associated with kerbside collection include: the contents of the containers may be sorted by scavengers; and the containers may either be stolen, overturned by animals, or left on the street for long periods of time.

However, kerbside collection is unavoidable for collection of waste from some types of structures, and it is one of the least expensive methods of house-to-house collection. A high labour productivity can be achieved when the rate of waste generation is high and collection infrequent. For example, in one city in the United States, a one-person crew collects up to 10 Mg/day (400 dwellings at an average of 25 kg/dwelling). In most economically developing countries, however, the rate would be lower since the average quantity of waste collected per dwelling is much less than in the United States.

I4. DOOR-TO-DOOR collection

In this system, the householder does not participate in the collection process. The collector enters the premises (backyard or garden), carries the container to the vehicle, empties it, and returns it to its usual place. This system is costly in terms of labour because of the high proportion of time spent walking in and out of premises and from one dwelling to the next. However, in some situations, it is the only satisfactory system.

The main difficulty with door-to-door waste collection in developing countries is that vehicle productivity would be less than that in Europe or the United States if the collection frequency were high. Since one of the main objectives in developing countries is to achieve high vehicle productivity, door-to-door collection by the conventional western method of heavy reliance on motor vehicle and crew is very unlikely to be a viable system unless the collection frequency is about once a week. This may not be feasible in countries with tropical climates unless high standards of waste containment at the place of generation are practiced and enforced.

I5. EVALUATION of basic systems

The evaluation of collection systems involves a number of considerations. One of the more important considerations is the average population or number of dwellings serviced per collection vehicle. If the productivity is examined on the basis of population served, the values around the world exhibit a wide range, about 3,000 to 20,000 persons served per collection vehicle, as shown by the data in Table IV-2. Many factors, as described in this chapter, govern vehicle productivity.

Table IV-2. Collection vehicle efficiency

Location	**Population Served per Vehicle**
Nigeria	20,000
Norway	5,000
Spain	8,000 to 10,000
Tunisia	6,000
Turkey	5,000 to 12,000
Latin America	7,000 to 10,000
Western Pacific Islands	8,000 to 14,000
United States	3,000 to 5,000

Sources: Reference 7 and CalRecovery, Inc.

An example of an evaluation of collection productivity is demonstrated by the presentation of the data in Table IV-3. The table presents a comparison of productivity for both labour and equipment for various types of collection systems in terms of weight collected (kg/day). In this particular case, the weight generated per dwelling is assumed to be 2 kg/day. This generation rate is equivalent to about 330 g/person/day for a family of six.

Table IV-3. Productivity evaluation of basic collection systems[a]

Method	Frequency	Quantity/ Point (kg)	No. of Crew	Productivity: No. of Dwellings Worker/ Day	Productivity: No. of Dwellings Vehicle/ Day	Productivity: Quantity (kg) Worker/ Day	Productivity: Quantity (kg) Vehicle/ Day[b]
Door-to door	once/day	2	6	160	960	300	2,000
Door-to-door	every 4 days	7	6	140	840	1,000	6,000
Door-to-door	once/wk	14	6	120	720	1,700	10,000
Kerbside	once/day	2	4	300	1,200	600	2,400
Kerbside	every 4 days	7	4	250	1,000	1,800	7,000
Kerbside	once/wk	14	4	200	800	2,800	11,000
Block	every 2 days	4[c]	2	850	1,700	3,500	7,000
Communal enclosures	once/day	3,000	5	700	3,500	1,400	7,000
Communal concrete bins	once/day	300	5	600	3,000	1,200	6,000
Communal 200-L drums	once/day	50	2	2,500	5,000	5,000	10,000

[a] Based on waste generation of 2 kg/dwelling.
[b] Rounded to nearest 500 kg.
[c] Per dwelling.

The data in Table IV-3 indicate that, in general, under similar circumstances: 1) communal storage systems based on portable containers would probably offer the highest productivity, 2) block collection at two-day intervals offers moderate productivity and avoids the problems that arise with communal storage or kerbside collection, and 3) door-to-door collection by a motor vehicle and a large crew may be the least productive system for a developing country if daily service is required. This system may be acceptable in selected areas if a frequency of twice per week is feasible and adopted.

J. Primary and secondary collection

J1. SHORT-HAUL transfer

Short-haul transfer is a system that divides refuse collection into two phases, primary and secondary.

J1.1. Primary collection by handcart

Primary collection (from door to door) is carried out using a small non-motorised vehicle, such as a handcart or animal cart. When full, the primary collection container is emptied directly into a large motor vehicle that is utilised solely for the high-speed transport of full loads. A unit that works well in developing countries is one that uses between two and six detachable bins. Carts of this design were used in some cities in Europe in the late 1940s for the collection of kitchen wastes for processing into animal feed.

J1.2. Secondary collection by tractor-trailer

The performance of this system can be evaluated by assuming that trailers have a capacity of 6 m^3 and that they are exchanged when full by an agricultural tractor. The tractor then takes the trailers to the disposal site. A tractor can travel at an average speed of 15 km/hr.

The number of trailers required for this type of service depends primarily upon population density. One trailer exchanged 6 times/day could support 40 collectors, serving a population of about 45,000. However, because of the limited operating range of a handcart, this 40-man unit must be kept within an area of about 1 km^2. Thus, in this example, if the population density is lower than 45,000 people/km^2, it is likely that more than one trailer transfer point will be required. Two transfer points, each having a trailer exchanged 3 times/day, would enable the tractor and 40 collectors to cover an area of 2 km^2, with a population density of 21,500 people/km^2.

In the first case, the theoretical trailer requirement would be two per tractor, one stationary (at the transfer point), and the other being towed. In the second case, the number of trailers would be three per tractor. One tractor would be located at each of the two transfer points and one would be towed. In practice, it usually is necessary to provide surge capacity at a transfer point, since the rates of handcart collection and trailer exchange are not continuously in balance. The number of trailers should be determined as follows: 1) optimum population density, 3 trailers/tractor, 2 at each transfer point; or 2) half optimum population density, 5 trailers/tractor, 2 at each transfer point.

The minimum population density for which handcarts could reasonably be used is on the order of 7,000 people/km^2. Each square kilometre would require six collectors and one trailer per transfer point. Surge capacity would not be necessary and, thus, the ratio of trailers to tractors would be 7:1 -- 6 trailers at transfer points and 1 being towed.

In general, the use of short-range transfer based on handcarts is applicable to the following conditions: low per capita generation of wastes, high-density wastes, high population density, and low wage rates. In situations where one or more of these conditions are absent, the principle of transfer may still be valid, but it may be necessary to employ vehicles of larger capacity.

J1.3. Primary collection by animal cart or motorised tricycle

The basic assumptions for evaluating the performance of these systems are given in Table IV-4. The data show that the productivity of a motorised tricycle is higher than that of an animal cart.

Table IV-4. Collection by animal cart or motorised tricycle[a]

Alternative					**Productivity**	
	Average Speed (km/hr)	**Travel Time (min)**	**Total Time/ Load**	**Quantity (kg/day)**	**Weight (kg/worker/ day)**	**Dwellings (No./worker/ day)**
Animal cart	3	40	5 hr, 12 min	875	437	219
Motorised tricycle	20	6	4 hr, 38 min	1,050	525	262

[a] Vehicle capacity is 700 kg (350 dwellings).
Time/load, 2 crew at 40 dwellings/worker/hr is 4 hr, 22 min.
Distance is 2 km; time to unload is 10 min.

J1.4. Secondary collection from transfer station

The main advantage provided by the use of animal carts or small, motorised vehicles in a solid waste management system is a wider range of operation than handcarts. The use of an animal cart is just as slow as that of a handcart, but the volumetric capacity of the vehicle is so much greater than that of the handcart that only two trips to transfer would be necessary, instead of four or more with a handcart. Thus, the animal cart would spend a higher proportion of the day in productive collection. The small motor vehicle has both greater capacity and higher speed.

The use of animal carts and small, motorised vehicles, instead of handcarts, enables transfer stations to be much more widely spaced, and to serve greater populations or areas having low-density populations. For animal carts, one transfer station per 5 km^2 would give a round trip distance of about 2 km. A much larger area could be served by motorised tricycles.

The process of transferring waste from an animal cart or a small motorised collection vehicle into a transfer trailer is much more complex than a process that employs the use of small handcart containers. The reason is that the process involves the manual emptying of a substantial volume of waste from a relatively large container (at least 2 m^3) into the transfer trailers.

J2. COMPARATIVE labour and vehicle productivity

The productivity of short-haul transfer equipment is presented in Table IV-5. It is important to point out that although the values in the table are based on actual experience, it is unlikely that the same values will be found in most situations, due to the wide variations that occur throughout the world in the determining factors. Some of the more important factors are:

- waste generation per capita and average family size,
- density of wastes at source,
- population density,
- labour rates,
- costs of animal carts and motor vehicles,
- fuel cost, and
- cost and availability of land for transfer stations.

Table IV-5. Productivity of short-haul transfer

Alternative	Productivity	
	Mg/Worker/Day	Mg/Vehicle/Day
Handcarts	0.40	14
Animal carts	0.44	25
Pedal tricycles	0.5 to 0.9	8 to 12
Motorised tricycles	0.53	25

J3. SHORT-HAUL transfer station facilities

Short-haul transfer stations fall into two main categories: 1) level sites, where transfer usually is carried out by manually emptying small containers of waste; and 2) split-level sites, where loads carried by small vehicles are unloaded directly into large vehicles by taking advantage of gravity.

Vehicles used for secondary collection at transfer stations fall into the following main groups:

- trailers (usually about 4 m^3), towed by an agricultural tractor;

- semi-trailers having capacities of 15 m^3 or greater;
- open-top vehicles with extended sides to provide capacities of at least 12 m^3;
- containers of 8 m^3 or greater capacity, carried by vehicles of 5-Mg capacity or more; and
- containers of 15 m^3 or higher capacity, carried by roll-on vehicles.

J4. LEVEL sites

In its simplest form, this type of transfer station consists of a parking space onto which a trailer or truck is placed. However, it is desirable to enclose the space for reasons of aesthetics, cleanliness, and security. When handcarts or tricycles are used for primary collection, their contents can be discharged at a height of 1 m or more into larger containers.

J5. COMBINED transfer stations and district depots

There are many advantages in building a combined transfer station and depot in areas where a transfer station serves a population in the range of 20,000 to 50,000. For a population in this range, there would probably be between 40 and 150 labourers employed for refuse collection, street cleansing, and ancillary services.

If a district depot is included in the system design, it should provide the following facilities: 1) sanitary facilities for workers (i.e., lockers, toilets, showers); 2) shops equipped with basic items such as brooms, shovels, cleaning materials, lubricants, and similar items; 3) parking facilities for hand trucks for sweepers and, if appropriate, refuse collectors; and 4) an office for a supervisor.

K. Large-scale transfer stations

In developing countries, the cost of solid waste collection typically is a disproportionate percentage of the revenue available to municipalities. Although labour rates in developing countries are relatively low, the cost of equipment and the cost of fuel usually are higher than in industrialised countries.

As background for this section, typical ranges of costs of collection are tabulated in Table IV-6 for countries categorised by level of economic development. Also shown in the table are quantities of solid waste and certain unit parameters (i.e., per capita) that are relevant to understanding and comparing the costs of collection around the world. The inordinately high cost of solid waste collection in developing countries is attributable primarily to the following conditions:

- poor supervision, labour management, and training in solid waste management;
- non-productive staff;
- inadequate education and discipline of the citizenry;
- inappropriate type and size of collection equipment;
- incorrect crew size and inappropriate shift duration;
- harsh driving conditions at the disposal sites;
- lack of sufficient numbers and of appropriate types of storage containers at collection points;
- inadequate maintenance of equipment;
- long distances to disposal sites (i.e., lack of transfer stations); and
- lack of systematic collection routes.

Table IV-6. Waste generation and cost of waste collection in regions with different levels of economic development (2003)

Parameter	Low Income	Middle Income	High Income
Waste generation (kg/cap/day)	0.3	0.5	2.0
Collection cost (US$/Mg)	15 to 40	25 to 75	75 to 150
Collection cost (US$/cap/yr)	2 to 4	5 to 14	55 to 110
Income (US$/cap/yr)[a]	500	3,000	25,000

[a] Average income based on selected world development indicators in Reference 7.

The period of time involved in transporting solid wastes over long distances, combined with the lack of transfer stations, can have a significant negative impact on the total cost of collection. In situations where 30 minutes or more are required to haul waste from the terminal point of the collection route to the disposal site, the total cost of collection and haul can be on the order of 30% to 50% higher than that of a system that incorporates one or more transfer stations into the system.

Long distances to the disposal site and the absence of transfer stations can also lead to negative environmental impacts. If the disposal site is located a long distance away from the point of generation, the waste management system is subject to inefficiency and to undesirable or illegal disposal of wastes by those frustrated by the great distance to the disposal site, i.e., wastes will be dumped at locations closer to the point of generation because of convenience.

Typically, the justification for a transfer station is that it will result in a reduction in the total cost of collection and haul and that it will offer convenience to the service area(s), i.e., the nearby station can be used directly by private citizens and businesses as a disposal location instead of the less attractive alternative of driving to a remote disposal site. The savings in total cost are due primarily to the shortened haul distance from the collection area to the disposal site (since a transfer station has been substituted for the disposal site) and the fact that collection vehicles (as opposed to transfer vehicles) are not suited for, nor are they technically or financially efficient in, long-haul, high-speed applications. Also, in some cases an increase in payload per vehicle, in-vehicle waste density, or both can be realised since transfer vehicle volumetric capacities can be several times that of collection vehicles and the wastes can be compacted at the transfer station using compaction equipment.

Despite the fact that the implementation of a transfer system offers potential cost savings over the long term, the system requires additional investments, such as the construction of a transfer station and materials handling equipment. The investment associated with these activities must be recovered, or monetary losses will be incurred as a consequence of the transfer operation.

The capital investments that are typically necessary to implement a transfer system include, but are not limited to: land, structures, utilities, and fixed and rolling equipment. In addition to the capital investments, the transfer system will have operational expenses, including maintenance, associated with the transfer station and also with the hauling of transferred waste to the disposal site.

In many developing countries, the prevalent situations for considering transfer stations are two. One situation is where a remote disposal site of large capacity exists, and the issue is whether or not the integration of a transfer station into the solid waste management system would result in lower overall collection and disposal costs. In this situation, the cost of the existing system of collection and haul is compared to that for the system modified to include a transfer station. The cost comparison is typically conducted on the basis of cost per unit weight of waste collected (e.g., US$/Mg), where the unit cost is composed of amortised capital component and of operating expenses. Due to the relatively large capital expense of a transfer station and to the sensitivity of the unit cost to haul distance, the unit cost (i.e., US$/Mg/km) of a transfer station operation is high when the hauling distance from the station to the disposal site is short. However, the unit cost decreases to an asymptotic (i.e., minimum) value as the distance between the transfer station and the disposal site increases. In the United States, the cost benefit of a transfer station is typically realised when the distance from the centroid of the wasteshed is in the range of 20 to 40 km from the disposal site. However, the reader is cautioned that a cost-benefit analysis of a transfer station in a developing country must be conducted using the local conditions, e.g., local labour rates, fuel prices, construction costs, etc., and must not use “rules of thumb” developed for different countries and circumstances.

The second situation regarding transfer stations that is relevant to developing countries concerns the siting of a new disposal facility and the use of a transfer station. Examples of this situation would be the use of a remote sanitary landfill to replace an open dump, or the need to use a remote disposal site because the existing and nearby site is reaching capacity. For either example, the boundary conditions listed below apply in many cases:

- The potential location of the transfer station is known with some degree of certainty.
- A level of acceptable solid waste collection service and of expense exists, and the siting of a new disposal facility requires the use a transfer station. However, the overall cost of the collection, haul, and disposal system cannot exceed the current cost of the waste management system.

For the analysis, the current (or future) cost of the existing collection and haul system is equated to the estimated cost of collection and haul for an alternative system that includes a transfer station. Haul distance serves as the key variable in determining the breakeven distance from the potential new transfer station to the remote disposal site. Several conditions must be specified in order to perform the analysis. They include the existing cost of collection and of haul, amortised capital cost, and operating cost of the new transfer station and hauling subsystem; the capacity and payload of the transfer vehicles; fuel usage and cost; driving speed; and quantities of waste collected and hauled. The results of the analysis are particularly sensitive to labour rates, cost of fuel, and vehicle speed. The latter parameter (speed) is a function of road conditions, speed limits, and traffic conditions.

If a transfer station is constructed and operated as part of a solid waste management system, it opens up the possibility of establishing a combined transfer station/resource recovery facility. The main objective of the resource recovery portion of the facility would be to recover materials that would be used near the facility (i.e., recyclable materials, organic matter, RDF). Therefore, only those materials that have no market or use would have to be transferred for long haul and disposal. The implementation of a system of this type could lead to additional cost savings since less waste would ultimately be hauled from the transfer station to the disposal site than in the case of no recovery of resources. However, an added layer of analysis is required in order to determine the type and degree of appropriate processing, as well as the overall arrangement and the cost of the combined facility.

L. Transfer station planning and design

The primary technical considerations for a transfer system include: site selection, design of structures (e.g., building enclosures), and transfer operations and plant layout. A discussion of each follows.

L1. SITE selection

Ideally, a transfer station should be located such that unit cost is minimised as a function of travel time of the collection vehicle to the transfer station and time required for the transfer vehicle to travel from the transfer station to the disposal site. In a large service area, such as that in Mexico City, this analysis may result in the need and selection of multiple sites for waste transfer points. This type of analysis can be conducted by means of mathematical models. Operations research techniques can be used to determine the optimum number and location of transfer stations. In practice, only a limited number of sites will be feasible, due to a number of factors such as access, topography, cost, and environmental acceptability.

Experience, however, has demonstrated that the siting of any solid waste facility cannot depend solely on technical and economic analyses, but must include public participation in the selection process.

L2. DESIGN of structures

The types of structures used to house a waste transfer operation range from none at all (open-air) to large, enclosed concrete and metal buildings. Open-air transfer stations work well in rural areas with dry climates. Rural areas with wet weather can utilise a small shelter over the unloading area, loading area, or both.

Most transfer station buildings in developing countries are fabricated of sheet metal, concrete, or brick. The specific type of design and landscaping is a function of location, i.e., locally available materials, available financial resources, and local preferences.

Transfer station buildings typically are equipped with water sprays and/or systems for controlling air emissions such as dust, motor vehicle exhaust, and doors. The building should include offices and facilities for the workers, e.g., restrooms, showers, etc. Designs of transfer stations in the United States incorporate viewing areas so that public education and public relations’ campaigns can be conducted from those areas.

The station should also be equipped with at least one truck scale for weighing inbound and outbound wastes. An inbound weigh scale is important for managing the operation and for levying disposal fees. Large, modern transfer stations also incorporate truck scales in the locations where the long-haul transfer vehicles are loaded. This design permits loading of the vehicles to their maximum allowable payloads, thus optimising the cost of transport of waste to the disposal site.

L3. TRANSFER operations and plant layout

The operation of a transfer station can be divided into the following phases: unloading, loading, transport, and discharge. The design concepts for transfer systems are described under each of the main phases.

L3.1. Unloading

This phase involves the unloading of collection vehicles and, if necessary, temporary storage of wastes. The following two basic alternatives can be utilised for the unloading phase: collection vehicles can either unload directly into containers, or into a storage area or pit. The wastes can then be loaded from the storage area into transfer vehicles, as described below.

L3.1.1 Direct unloading

A system that uses direct unloading involves the discharge of the wastes from the collection vehicles directly into transfer vehicles or the vehicle loading systems (e.g., compactors), i.e., the design does not incorporate a waste storage area as part of the system. Direct unloading requires a two-level arrangement. In this arrangement, the collection vehicles drive up a ramp to the upper level in order to discharge their contents through a chute into either a transfer vehicle or a loading system installed on the lower level, as shown in Figure IV-19. As an alternative to gravity loading, a direct loading system can also employ a wheeled loader to push the wastes directly into the transfer vehicles.

One of the basic requirements of the direct unloading system is that either the transfer vehicles in operation must keep pace with the frequency of arrival of collection vehicles at the transfer station, or extra transfer vehicles must be purchased for use as temporary storage. These operational alternatives support the efficient coordination of incoming and outgoing wastes and, thereby, avoid delays in the unloading of collection vehicles and the resultant delays in the collection operations. Such logistical coordination is difficult to achieve in a large-scale system (i.e., large processing capacity) where there is a steady flow of collection vehicles entering the transfer station and periods of high frequencies of unloading of delivered waste. Therefore, the direct unloading system generally is implemented only as a small-scale system, such as a neighbourhood transfer station in a small city, or a rural transfer station. In these situations, the quantity of waste handled at the transfer stations would be on the order of 200 to 300 Mg/day. If the transfer station is one of large processing capacity (i.e., greater than 200 to 300 Mg/day), provision should be made for a sufficient number of spare transfer vehicles to ensure that the delivering collection vehicles are not delayed unduly due to the inability of the transfer facility to load out the waste in a timely manner.

One of the main advantages of the direct unloading system is that it involves a small capital investment in terms of civil works. Since a pit to store the wastes is excluded in the direct loading system, in order to result in a simple facility and to save expense, the size of the building can be small. Furthermore, investment in specialised systems to control doors and insects under such conditions can usually also be small, since substantial doors and prevalence of insects generally are associated with storage of waste.

Courtesy: CalRecovery, Inc.

[a] Ramp to upper level shown in background to the right; hopper and loading system shown in the centre; transfer trailer shown in left foreground.

Figure IV-19. Two-level transfer station[a]

On the other hand, a major disadvantage associated with the direct unloading system is that it requires that the fleet size of transfer vehicles (and associated loading systems) be sufficiently large to keep pace with the unloading requirements of the collection fleet. Under most conditions, particularly in residential areas, collection vehicles operate by design, by regulation, or by policy during a limited timespan each day (usually early in the morning). Filling the collection vehicle can take from one to five hours, depending on capacity, route size, the method of loading from the collection points, and speed and distance from the disposal facility. In most cities, the majority of collection vehicles arrive at the transfer station within a 2- to 3-hr time period. This is demonstrated by the data presented in Figure IV-20 for a transfer station in Mexico City, Mexico. Therefore, the size of the transfer fleet, in a direct unloading system, would have to meet those peak periods of waste delivery.

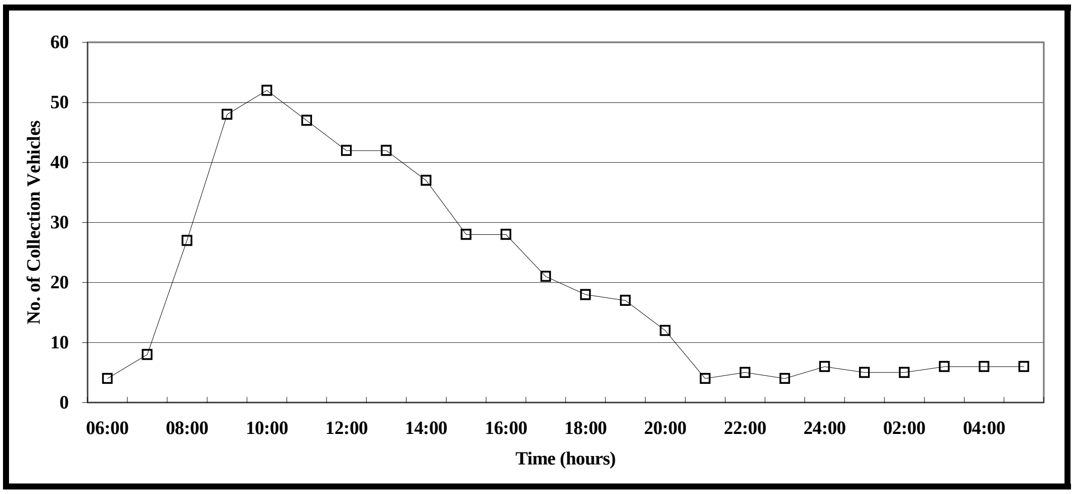
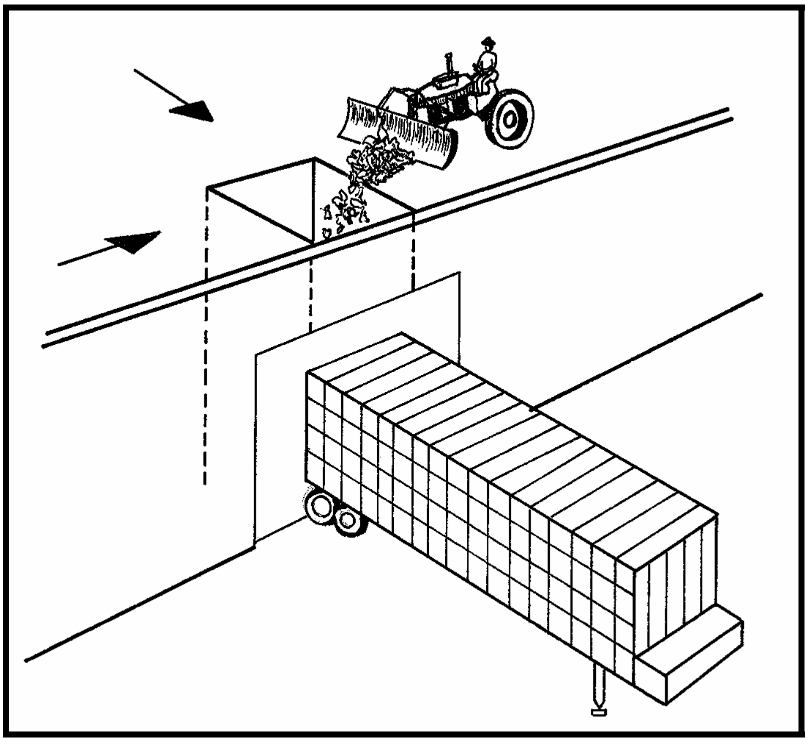


Figure IV-20. Frequency of arrival for collection vehicles at a transfer station

L3.1.2. Unloading to storage

As the phrase implies, a system that utilises unloading to storage involves collection vehicles discharging into a storage area. From the storage area, wastes are subsequently loaded into transfer vehicles. The storage area may consist of a platform located on the same level as that of the unloading area, in which case only a two-level design is required, as shown in Figure IV-21. If large processing rates of waste are required, the storage area may consist of a pit located below the unloading level and above the level on which the transfer vehicles are loaded. In this case, a three-level arrangement is required. The storage area is commonly designed to contain the highest (peak) quantity of waste generated in one day. An example of a three-level design is shown in Figure IV-22.



[a] In this type of transfer station, incoming solid waste is stockpiled on the floor during peak delivery periods and is then loaded into the stationary compactor hopper with a front-end loader.

Figure IV-21. Two-level transfer station design [a]

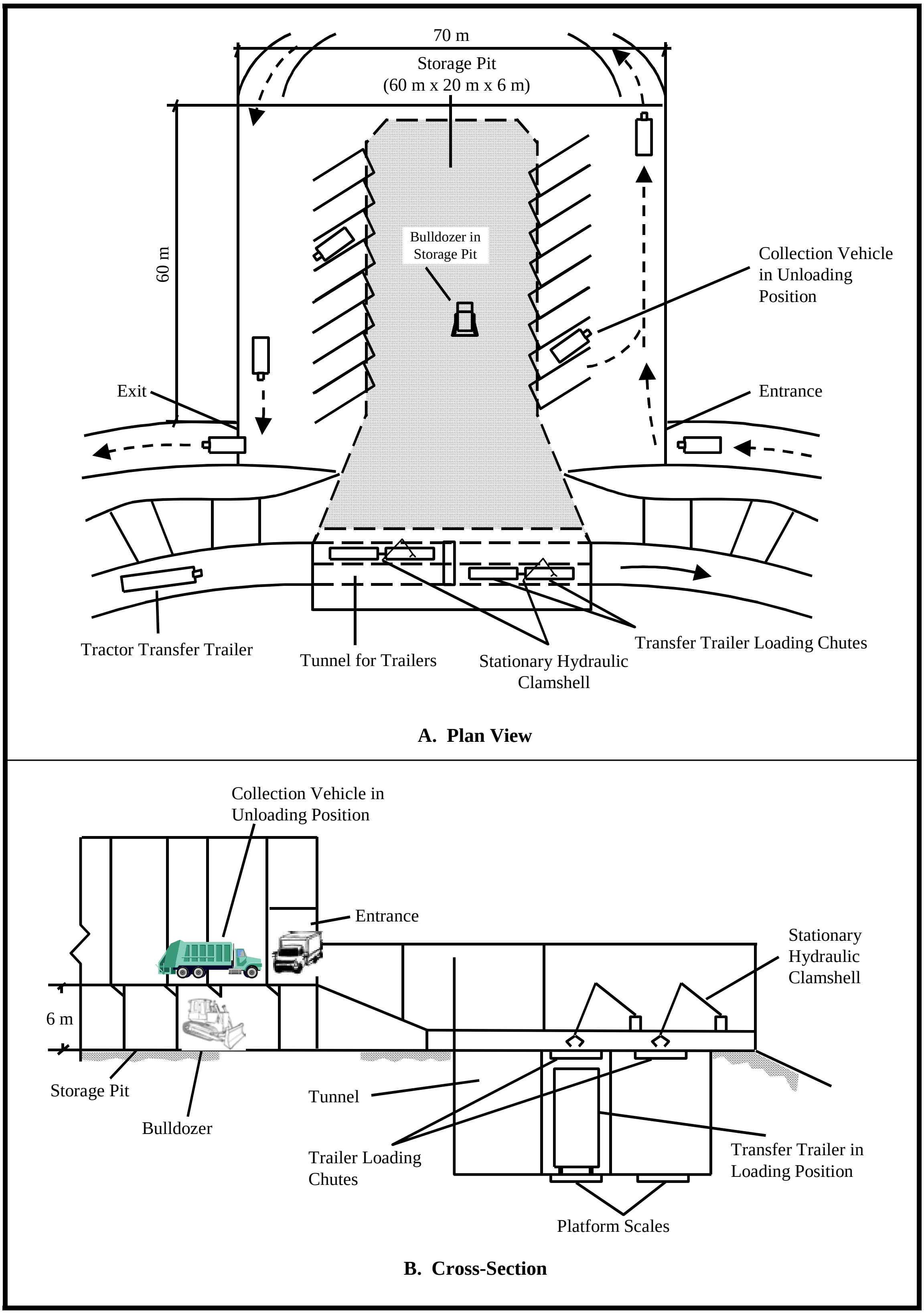


Figure IV-22. Enclosed large-capacity (2,000 Mg/day) storage-load transfer station

In another type of unload-to-storage system, the material is discharged from the collection vehicles, and is loaded into a hopper or onto a conveyor that transports the waste into a transfer vehicle situated at the same level (see Figure IV-23). If the waste is unloaded into a storage pit, the waste can be picked up and loaded into the transfer vehicles by an overhead crane or pushed into the vehicles by a bulldozer. The overhead crane generally is mounted on tracks over the storage pit and is provided with a clamshell or grapple bucket. The operator of the crane or of the bulldozer visually inspects the waste during operation to segregate any materials that are difficult to handle, potentially hazardous, or could damage the transfer vehicle during loading.

The use of an overhead crane for loading transfer vehicles should be carefully evaluated since it requires an adequate structural support. In addition, in the event that the crane breaks down and spare parts are not locally available, the station would essentially be shut down to operations if a contingency plan is not available. In developing countries, spare parts for a bulldozer and front-end loader are more likely to be readily available than those for an overhead crane.

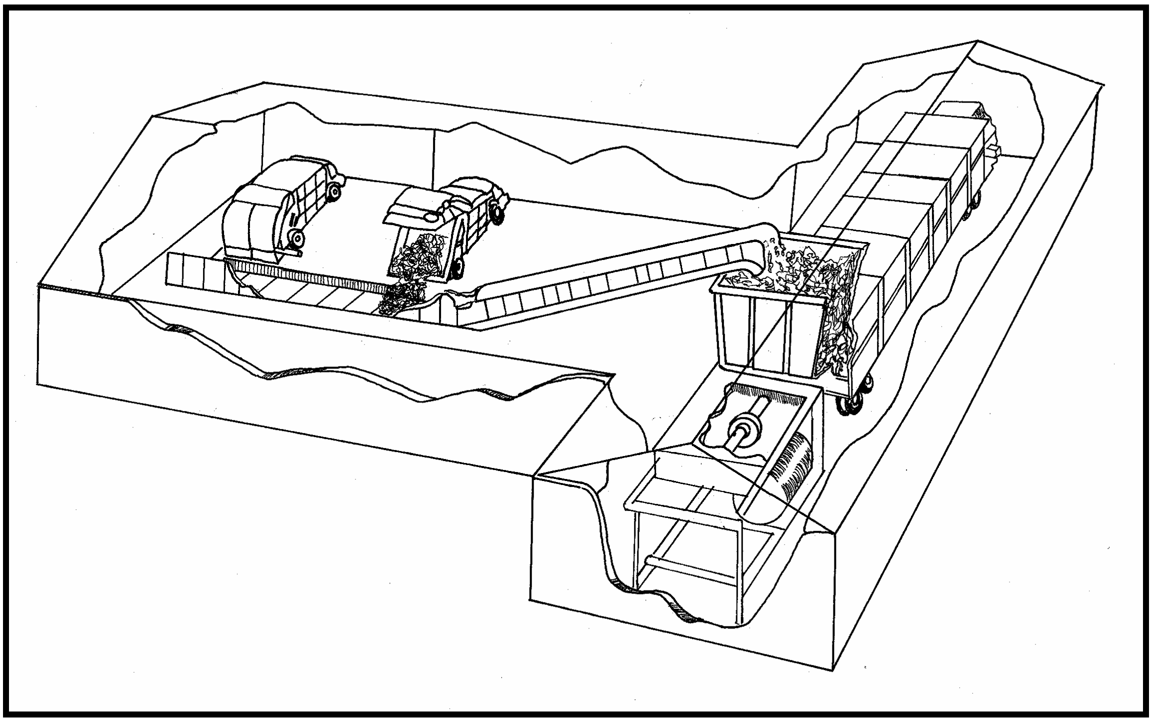


Figure IV-23. Single-level transfer station design in which an inclined conveyor is used to charge the stationary compactor hopper

A system that has provision for the storage of waste upon its delivery to a transfer station supports the optimal operation of the collection process. As previously indicated, waste collection typically is conducted in the morning, when ambient temperatures in many developing countries are relatively low and road traffic is light. The use of a storage system at a transfer station allows collection vehicles to discharge their contents during the morning periods, when waste collection is most likely to take place.

Similarly, the system of unloading to storage allows the transfer process to operate under conditions optimal to its nature. In this particular case, transfer operations can take place at night or at times when road traffic is relatively light. Furthermore, this system allows for a longer period of transfer operation than that of unloading directly from collection vehicles. For example, even though collection of waste commonly takes place between 6:00 am and 2:00 pm, and unloading of the collection vehicles at the transfer station generally occurs between 8:00 am and 4:00 pm, loading of the transfer vehicles and haul of the waste to the disposal facility can take place over a full 24-hr period. This advantage of the system of unloading to storage may result in improved collection service and lower costs than a transfer system that would employ a direct loading system and operate under similar conditions.

L3.2. Loading of transfer vehicles

This portion of the process involves the loading of waste into transfer vehicles. There are several systems that support this application. Some of the more common ones are described in the following paragraphs.

L3.2.1. Direct loading to transfer vehicle

In this particular system, the waste discharged from collection vehicles or from the storage area drops (by gravity) through a hopper directly into an open-top transfer vehicle. A crane may be mounted at the top of the hopper and used for distributing the load evenly within the transfer vehicle.

L3.2.2. Loading by stationary compactor

In this system, waste drops through a hopper into a stationary compactor. The compactor, mounted on the floor of the lower level of the transfer station, contains a hydraulically-driven ram. The ram pushes the waste from the compactor's receiving chamber into the storage chamber of the transfer vehicle. In this system, the chamber of the transfer vehicle must be adequately reinforced to withstand the pressure created by the compacted waste (see Figure IV-24).

Courtesy: CalRecovery, Inc.

Figure IV-24. Transfer trailer being loaded by a compactor

The primary purpose of the stationary compactor is to densify the waste for hauling. Achieving a high rate of compaction allows the use of fewer transfer vehicles than would be possible in the case of uncompacted waste, all other conditions being equal. However, the chamber of the transfer vehicle must be reinforced to withstand the high pressures created by the compaction of the waste. Thus, the net vehicle weight of transfer vehicle may be greater than would be the case for a transfer vehicle having a chamber designed for uncompacted waste. The upshot is that net payload of waste could be less in the case of using a compaction station than if wastes were transported in loose form.

L3.2.3. Loading by pre-load compactor

In this system, the waste drops through a hopper into a “pre-load” compactor. In this type of system, the pressure of compaction is applied in a chamber that is remote from the chamber of the transfer vehicle that ultimately will receive and haul the waste. The compactor is mounted on the floor of the lower level of the transfer station and contains a hydraulically-driven ram. The ram pushes the waste from the compactor's receiving chamber into a second chamber, i.e., the compaction chamber. The compaction chamber is reinforced to absorb the pressure exerted by the compacted waste and sized to form a compacted mass that fits within the chamber of the transfer vehicle. Once the compacted mass is fully formed, it is forced from the compaction chamber into the chamber of the transfer vehicle. Since the transfer vehicle does not receive compaction forces, it does not need to be heavily reinforced. Vehicles used with the pre-load compaction system are similar in design to those used with the systems that do not employ compaction (i.e., systems that employ either a bulldozer or crane). The main difference is that the vehicles, in the case of a pre-load compactor system, are loaded through the rear of the trailer, as opposed to loaded through the top.

L3.2.4. Direct loading to self-contained compaction vehicle

In this design, waste is discharged from the tipping area into a trailer that possesses its own compactor (i.e., a self-contained compaction vehicle). A ram, mounted at the front of the body of the trailer, pushes and compacts the waste toward the rear. The same ram used for compacting the waste also is used to discharge the material from the trailer at the disposal site. This system requires that the body of the trailer be suitably reinforced to take the full force applied by the ram.

The characteristics of the waste generated in the area must be carefully considered in the selection of a loading system. For instance, the feasibility of using any type of compaction is affected by the composition, bulk density, and moisture content of the incoming waste. As previously indicated, as a general rule, the lower the income level of a country, the higher the concentration of putrescible matter, moisture, ash, and dirt in the solid waste. Furthermore, the lower the level of income of the country, the less likely the possibility of finding low-density packaging materials. Therefore, in general, the lower the level of income, the higher the density of the waste. In low-income developing countries, loose (i.e., uncompacted) municipal wastes have a bulk density of about 300 to 600 kg/m^3. In middle-income developing countries, the density of loose waste is in the range of 200 to 300 kg/m^3. In industrialised countries, on the other hand, the density of loose waste is typically on the order of 100 to 150 kg/m^3.

Despite significant disparities in the density of loose waste between developing countries and industrialised countries, compaction mechanisms in collection vehicles and those installed at transfer stations produce compacted waste of similar density. The compacted densities achieved in low-income countries are slightly higher than those in industrialised countries (i.e., 550 kg/m^3, compared to 450 kg/m^3, respectively). This is probably due to the initial moisture content of the wastes, i.e., 30% to 70% in developing countries, compared to 25% to 35% in industrialised countries.

Load bearing limitations and maximum vehicle dimensions established by local and national design standards for roads and bridges are factors that influence the technology for loading at transfer stations. In the United States, design standards specified by the federal government for bridges built by the government limit gross vehicle weight to about 33 Mg and 5 axles. In addition, no axle may carry more than 7 Mg. However, some of the states allow higher vehicle weights on their roads and bridges.

Many developing countries have adopted standards for road and bridge design that are similar to those in the United States. Consequently, the standards in those countries limit gross vehicle weight to about 33 Mg on 5 axles, with no axle carrying more than 7 Mg. Early in the process of planning a transfer station, the designer should identify vehicle standards and determine whether or not bridges and roads along the proposed transportation route are designed to meet the standard.

If the largest volume transfer vehicle available or manufactured can be filled so as to achieve the allowable gross load limit without compaction of the waste, there is probably little economic justification for using smaller volume vehicles and compacting the waste. In the analysis of the potential benefits of compaction of waste, the capital and operating costs for large-volume transfer vehicles used for hauling uncompacted waste should be compared to the costs of small-volume vehicles transporting either compacted or loose waste. In addition, the incremental cost due to compaction should be added to the capital and operating costs of the fleet hauling compacted wastes.

The total costs associated with loading and transporting the wastes should be thoroughly analysed in order to select the most cost-effective alternative. Small differences in operating cost between the alternatives might prove to be significant if the travel time from transfer station to disposal site is substantial. Countries that are largely dependent on costly fuel (e.g., those dependent upon imported fuel) may achieve greater economy by compacting the loads of waste prior to haul. Similarly, in locations where the salaries of the drivers for transfer vehicles are relatively high, as is the case in most industrialised countries, there may be a greater need to maximise vehicle productivity by compacting loads.

The design or selection of the loading system must take into consideration the level of skill of the workforce. Generally, in comparison to simpler systems of loading that do not utilise compaction, loading systems that employ compaction require a higher level of skill to operate and maintain. Additionally, careful consideration must be given to the type and number of spare parts necessary to keep the equipment in operation. The need for spare parts can be a deciding factor in some developing countries, especially in locations where restrictions on imports exist due to limited foreign exchange.

Most transfer stations that incorporate storage areas into their designs provide for continuous inspection of the waste before loading. Inspection is necessary in order to prevent the loading of heavy items (such as engine blocks and large pieces of concrete) that might damage the floor of the transfer vehicle. Transfer stations that utilise stationary or pre-load compactors are the only systems in which waste is dropped into a receiving chamber rather than into a transfer vehicle. Therefore, these two types of transfer systems reduce the potential for damaging the floor of the transfer vehicles.

As the name implies, the self-contained compaction system incorporates the compaction unit on the transfer vehicle. Consequently, the weight of the transfer vehicle is greater than that of any of the other loading systems. Self-contained compaction units might be appropriate in waste management systems that utilise several small transfer stations served by a fleet of transfer vehicles. Self-contained compaction systems may also be used at small transfer stations that lack a source of power for operating a stationary ram compactor or a pre-load compactor. Similar to the other compaction systems, the operation and maintenance of the compactor mechanisms require special mechanical skills and adequate stocking of spare parts in order to maintain high levels of system availability.

In addition to cost, several other factors must be taken into consideration in order to determine the most feasible transfer system. Some of these factors include noise and dust generation, traffic, and aesthetics. These factors require that a certain amount of qualitative judgment be exercised in order to assign them a value relative to cost.

Selection of the most cost-effective transfer system generally requires an analysis of the disposal system as well a determination of the compatibility among the collection system, transfer system, and existing disposal system.

L3.3. Transport

In this section, the discussion is limited to transfer stations in which collection vehicles discharge their loads into large-capacity transfer vehicles. Small waste transfer systems, in which collection workers use pushcarts, tricycles, or animal carts to transfer waste into a motorised vehicle, are discussed elsewhere.

The vehicles discussed in this section are truck tractors used to pull trailers of various designs.

L3.3.1. Open-top trailers

As their name implies, these trailers are open at the top and are equipped with doors at the rear. Once full, the waste in the trailer is covered with a net or tarp to prevent spillage during transport. Open-top trailers are loaded from the top by gravity feed through a hopper or opening. The trailers can also be loaded from the rear by means of the pre-load compaction loading system (see Figure IV-25).

Courtesy: CalRecovery, Inc.

Figure IV-25. Typical open-top trailer used in Mexico City, Mexico

L3.3.2. Closed-top trailers

These trailers have a top, sidewalls, and doors at the rear. Closed-top trailers typically are loaded by pre-load compactors. The untied "bale" of waste is forced (extruded) from the compactor into the trailer.

L3.3.3. Compactor-compatible closed-top trailers

These trailers have a top, sidewalls, and doors at the rear. Closed-top trailers that are compatible with compactors are loaded by the system described above, and the top and siding of the unit are reinforced to be able to withstand the compaction forces.

L3.3.4. Self-contained compaction trailers

These trailers are closed at the top, except for an opening used to receive waste near the front. The trailers have sidewalls and doors at the rear. The movable bulkhead is mounted at the front of the trailer and pushes waste from the front toward the rear. The sidewalls, top, and rear doors are reinforced to be able to support the forces applied by the waste as it is compacted by the movable bulkhead. The bulkhead is also used for discharging the waste at the disposal site by pushing the waste out the rear of the unit.

As previously indicated, the allowable load limit used in the design of roads and bridges varies from country to country. Generally, the limit fluctuates between 32 and 42 Mg (gross vehicle weight). The most typical value used in developing countries is 33 Mg gross vehicle weight. The weight of an average truck tractor capable of pulling 33 Mg is about 6 Mg.

The weight of the trailer is a function of the material from which it is manufactured and of the extent of reinforcing provided. Most trailers used to transfer waste have vertical sidewall bracing. In the case of the design of trailers that will be subjected to the forces exerted by the waste as it is compacted, the spacing of the bracing may be closer than when the trailers are loaded by gravity with uncompacted waste. In addition, when the trailers are designed to withstand compaction forces, the areas that are prone to receiving the greatest force must be designed with horizontal sidewall bracing.

Trailers are commonly made of either steel or aluminium. The weight of aluminium trailers is generally 15% to 30% less than that of steel trailers with comparable volumetric capacity. For example, the weight of an empty 75 m^3 open-top aluminium trailer is about 5 Mg, and that of a steel trailer is about 6 Mg.

An empty, self-compacting steel trailer weighs significantly more than a compactor-compatible steel trailer of the same volume. For example, a 75 m^3 self-compacting steel trailer weighs about 13 Mg; whereas, a compactor-compatible steel trailer weighs about 8 Mg.

Aluminium trailers, since they are lighter, can carry a heavier payload than steel trailers of similar volume. However, the cost of aluminium trailers is 40% to 60% higher than that of steel trailers. Furthermore, aluminium trailers are more costly to repair than steel trailers because the welding of aluminium requires considerable skill, and welding materials are more costly. In addition, aluminium is more brittle and has a lower yield strength than steel; consequently, aluminium is more likely to crack or tear.

In order to determine whether or not aluminium trailers are more cost effective than steel, the incremental vehicle productivity of the aluminium trailers must be assessed versus their higher purchase price and potentially higher operation and maintenance costs. There are very few developing countries that have the capability of manufacturing aluminium trailers. On the other hand, there are several developing countries that have the capability of manufacturing steel trailers. Consequently, for these countries, a comparative cost analysis of aluminium versus steel trailers must take into consideration the foreign exchange component of purchasing aluminium, as well as any shipping and customs duty charges. In situations where locally manufactured trailers are not available, consideration should be given to local assembly of imported components in order to optimise trailer costs.

Transfer stations can also be designed to simply load containers (e.g., roll-off boxes) rather than to load trailers designed to be pulled by truck tractors. The containers can then be loaded onto a roll-on tilt frame chassis of a truck tractor, on flatbed freight cars, or on barges.

L3.4. Discharge

This phase involves the unloading of the wastes from transfer vehicles at the disposal site. A discharge system may either be self-contained (i.e., part of the transfer vehicle) or external (i.e., located at the disposal site). The discharge systems described in this section are self-contained, with the exception of an external system known as the mobile tipper. A description of each of the main types of discharge systems is presented in the following section.

L3.4.1 Push-blade

The push-blade discharge system consists of a single, tilted blade, sized to fit within the trailer body. The blade travels from the front of the vehicle toward the rear, in order to force the waste out of the vehicle. The blade is pushed by either one or two hydraulic cylinders mounted between the blade and the front of the trailer. In order to discharge its load, the transfer vehicle is driven onto the landfill area and backed up to the working face, the rear doors are opened, and the load is forced out by the blade. The push-blade system is compatible with closed-top trailers that have been loaded by stationary compactor or pre-load compactor systems.

L3.4.2. Live-floor

The live-floor discharge system consists of a series of longitudinal slats mounted on tracks in the floor of the trailer. The tracks move sequentially and alternately in a reciprocating motion to “walk” the load out of the trailer; thus, the use of the term “live-floor”. Hydraulic cylinders mounted below the floor induce the unloading motion. In order to discharge its load, the transfer vehicle is driven onto the landfill area and backed up to the working face, the rear doors are opened, and the load is discharged by the live-floor. The live-floor system is compatible with open- and closed-top trailers, as well as with the following loading systems: direct, stationary compactor, and pre-load compactor.

L3.4.3. Frame-mounted tipper

This system uses two hydraulic cylinders mounted on the frame of the trailer to tip the waste out of the vehicle. The cylinders lift the front of the trailer chamber such that the inclination of the body, combined with the weight of the load, causes the material under gravitational force to slide out the rear of the unit. In order to discharge its load, the transfer vehicle is backed up to the working face, the rear doors are opened, the trailer is tipped by means of the hydraulic system, and the load is discharged. The tipping system is compatible with open-top trailers that have been loaded by direct dumping from collection vehicles into the trailers and with closed-top trailers that have been loaded by pre-load compactor.

L3.4.4. Mobile tipper

Unlike the systems discussed in the previous paragraphs, the mobile tipper is not a self-contained (i.e., trailer mounted) discharge system. The mobile tipper is a machine mounted on a track. The track is located near the working face of the landfill and is used for tilting and emptying the transfer vehicles. Typically, the transfer vehicle is driven onto the mobile tipper and the vehicle's rear doors are opened. Hydraulic cylinders lift the front of the tipper's platform, along with the transfer vehicle. The weight of the load causes it to slide out through the rear opening of the trailer. A bulldozer, stationed near the rear of the mobile tipper, pushes the discharged load away, making sufficient room for discharging the next load. The mobile tipping system is compatible with open-top trailers, which have been loaded by direct dumping from collection vehicles, and with closed-top trailers, which have been loaded by pre-load compactor.

In general, the push-blade discharge system takes up more space within a trailer than a live-floor system. In a 75 m^3 trailer, a push-blade discharge system would occupy about 7.5 m^3, or about 10% of the trailer's space. On the other hand, a live-floor system would occupy less than 1.5 m^3 (about 2%) of the trailer's space.

The push-blade discharge system weighs more than the live-floor system. Push-blade systems are built from steel or aluminium. A steel push-blade, sized to fit a 75 m^3 trailer, weighs about 3 Mg; whereas an aluminium push-blade system of comparable performance weighs about 2 Mg. An aluminium live-floor system, sized to fit a 75 m^3 trailer, weighs about 1.5 Mg; a steel live-floor system weighs about 2 Mg.

There is little difference in unloading time between the push-blade and the live-floor ejection systems. Both systems unload within several minutes. The live-floor system has an advantage over the push-blade system in terms of minimising space occupied within the trailer and weight. This advantage makes the live-floor discharge system popular in North America. On the other hand, the push-blade system is easier to maintain and repair than the live-floor; this advantage results in the popularity of the push-blade discharge system in some developing countries. Several developing countries are capable of manufacturing push-blade trailer systems, whereas, to the knowledge of the authors, the live-floor system is not manufactured in any developing country at the present time.

The self-contained tipping system does not appreciably add weight to or consume space within the transfer vehicle. However, unless the ground conditions at the working face of the landfill are relatively dry, level, and compacted (a condition that seldom exists in most landfills in developing countries), the self-contained tipping system is potentially dangerous. The authors are aware of some cases in which large trucks with tipping systems have become unstable while elevating the loaded trailer or when the trailer is in an elevated position during the wet season when high winds, heavy rains, or muddy landfill conditions are present. Under similar site conditions, this stability problem and hazard is much less in the case of a mobile tipper discharge system. The mobile tipper system consists of a track-mounted, relatively strong and stable lifting structure that incorporates outriggers at both ends of the platform to provide additional stability to the tipping system.

The mobile tipper allows a transfer vehicle to transport maximum payloads since the vehicle does not have to accommodate the weight and space of a self-contained discharge system. In terms of an analysis of costs and benefits of a mobile tipping system versus a self-contained system, the capability of transporting more waste per vehicle must be compared with the total cost of owning and operating the mobile tipper. Mobile tippers appear to be economically justifiable in situations where the travel time to the landfill is high (well over an hour each way) and where the load limits of the roads and bridges are low and strictly enforced.

For any potential cost effectiveness of the mobile tipper discharge system to be assured, there must not be any queuing of transfer vehicles at the disposal site waiting for emptying by the mobile tipper. It takes an average cycle time of 6 minutes for a trailer to be driven onto the mobile tipper, have its contents discharged, and be driven off the tipper. Therefore, a mobile tipper typically can discharge about 10 transfer trailers per hour.

One way to avoid any queuing of transfer vehicles is to put into effect a shuttle system. In a shuttle system, the tractor truck leaves a fully loaded trailer at the disposal site and takes an empty trailer. The loaded trailers usually are connected to an off-highway tractor (also called a yard goat) to be shuttled to the mobile tipper for discharge of the loads. An analysis of the cost of operating the mobile tipper would need to take into consideration the additional cost of owning and operating the off-highway tractors, as well as the cost of acquiring some spare trailers. The spare trailers are necessary in order to make sure that empty trailers are always waiting for incoming truck tractors.

There does not seem to be a substantial difference in the operation and maintenance requirements of the various discharge systems. All systems utilise moving parts that either tip, push, or walk (via reciprocation) the load of wastes out of the trailer. Generally, the moving parts are driven by the power take-off, and hydraulic pumps and cylinders.

L4. CONCLUSIONS

The main objective for the implementation of a transfer system is to establish efficient collection, transport, and disposal systems and, thus, conserve resources. Transfer stations should only be implemented when the cost of direct haul in collection vehicles is higher than the combined cost of supplemental haul in large transfer vehicles and the cost of the supporting infrastructure necessary at both the transfer station and the disposal site.

In a developing country, a typical collection vehicle carries a load of 2 to 5 Mg and has a crew of 1 driver and 2 or 3 workers. On the other hand, a transfer vehicle carries a load of 20 to 25 Mg and has a crew of only 1 driver. Consequently, the unit cost per kilometre (US$/Mg/km) for bulk transport should be substantially less than that for direct haul. The type and degree of savings in collection and transportation costs due to the implementation of a transfer station depend not only on the costs of transportation, but also on all of the costs associated with the operation of the transfer system, e.g., unloading, storage, loading at the transfer location, and discharge of transferred wastes at the disposal site.

Every aspect of the transfer station must be designed such that optimal savings can be attained. Local conditions will play a dominant role in the determination of which type of transfer system(s) will be more cost effective. The composition, density, and moisture content of the wastes will affect the decision regarding the need for a loading system that provides compaction of the wastes. The available area for the transfer station and the frequency of arrival of collection vehicles will be major determinants in the assessment of the need for a waste storage system at the station. The distance to the disposal facility, the cost of fuel, weight limits, and wages for transfer vehicle drivers are some of the more important local factors that will govern the decision of whether or not to make the greater capital investment in systems that yield maximum waste payloads.

In summary, before a final decision is made with regard to the implementation of a transfer system, the conduct of a thorough analysis of costs is essential, including the costs associated with owning and operating alternative types of transfer station systems. The various costs of alternative systems for unloading, loading, transport, and discharge must be normalised in terms of unit cost (i.e., US$/Mg) in order to determine the optimum system under local conditions. Although unrelated to costs, but intimately related to overall feasibility of a transfer system, the site selection process should include the participation of members of the public.

M. Costs of solid waste collection

Collection of solid waste is a key element of any modern solid waste management system, and its importance is also reflected by the fact that collection generally is the costliest subsystem of a waste management system. Consequently, a good understanding of the actual costs involved in providing collection service is very important in the planning and implementation of the service. Furthermore, an accurate determination of collection costs allows: 1) selection of the least cost option, 2) adequate budgeting, and 3) determination of tariffs or user fees. The major components of waste collection are those associated with vehicles and labour. Therefore, the total cost of collection is affected by the degree of mechanisation, the ratio of imported equipment to that manufactured locally, and the degree of labour intensity required for the types of storage containers and vehicles employed in the system.

During the initial stages in the design of a collection system, it is necessary to establish the criteria to be used for selecting the system. The criteria should allow for an objective comparison between alternatives. Until recently, selection of the most cost-effective alternative was based solely on financial analyses. Financial analyses do not reflect the relative amounts of the resources that are used in a waste collection system. Financial analyses include price distortions due to government policies concerning or affecting interest rates, loan maturities, and subsidies. For example, many developing countries are severely affected by the availability of foreign exchange. Financial analyses do not take into consideration the quantity of foreign exchange available to the country. Consequently, the authors recommend that economic analyses be conducted, rather than financial analyses, to determine the “true” least-cost collection option. In the following section, a description is provided of: 1) the major cost elements that must be considered in determining the overall costs of the collection system, 2) the use of economic analysis for purposes of determining the least-cost option, and 3) the use of financial analysis for the establishment of user fees.

M1. SYSTEM costs

The costs associated with waste collection consist of the following major components: 1) planning and design, 2) labour and equipment, and 3) garage and supporting facilities (e.g., transfer stations). Each of these components is discussed in the following sections.

M1.1. Planning and design

Planning and design of waste collection systems must be carried out by professionals who are knowledgeable in waste management practices. These professionals should be assisted by other professionals such as economists, mechanical and civil engineers, and sociologists. In addition, these individuals should obtain technical support for the collection of data on quantity and composition of the wastes, as well as on physical, chemical, and other properties of the waste stream. In general, however, the cost of planning and design should be moderate and should be on the order of 1% to 5% of the overall capital cost. The cost of design of civil works for garage and other facilities, in general, should not exceed 8% of the capital cost of the facilities.

M1.2. Labour and equipment

The type of equipment used in the collection process includes vehicles and storage containers (for residential, commercial, and industrial wastes). Operating costs for the collection process include: labour (both skilled and unskilled); fuel, oil, and other fluids; maintenance of vehicles and containers; management and administrative overheads; debt service; and insurance and tax for the vehicles. The cost of labour should include fringe benefits. Fringe benefits usually are on the order of 20% to 40% of basic wages (i.e., salaries). Overhead for management and administration varies widely from one municipality to another. A list of the major cost elements involved in the purchase and operation of waste collection equipment is presented in Table IV-7.

M1.3. Garage and auxiliary civil works

The costs associated with the construction and operation of a garage and auxiliary civil works include the following components: land and civil works, tools and equipment, and operation and maintenance costs for the facilities and equipment. A listing of the major cost elements associated with owning and operating garage facilities and auxiliary civil works is presented in Table IV-8.

Table IV-7. Major capital and operating cost items for collection equipment

Item
Collection vehicles
• Primary
• Secondary
• Other
Vehicles for supervisors
Trailers
Containers
Bins
Labour
• Skilled
• Unskilled
Fringe benefits
Repair and maintenance
• Vehicles (about 15% to 20% of purchase price per year)
• Trailers (about 8% to 10% of purchase price per year)
• Bins (about 5% to 10% of purchase price per year)
Depreciation (over 5 years)
Interest
Administrative overhead (about 15% of direct labour costs)
Tax, insurance, licenses

Table IV-8. Major capital and operating cost items for garage and auxiliary civil works

Item
Land
Site preparation
Civil works
Utilities
Engineering (about 2% to 5% of construction costs)
Contingencies (about 5% to 10% of construction costs)
Labour
• Skilled
• Unskilled
Overhead
Operation and maintenance
Insurance
Utilities
Fuel
Supplies and outside services
Tools and equipment

M2. COLLECTION from communal containers

In most developing countries, the size of waste collection crews is generally two to eight workers. In this section, we discuss key factors that determine optimum crew size and, therefore, optimum cost.

In many situations in developing countries, enclosures for the storage of solid wastes are located at ground level and contain between 500 and 1,500 kg of wastes. Typically, the wastes are transferred into the vehicles by means of shovels, rakes, and baskets. In this method of collection, the limit on crew size is determined by the maximum number of labourers that can collectively empty a basket into the vehicle. Within that limitation, every additional crew member adds an equal amount of productivity. Crews in this instance typically consist of six workers. Generally, the enclosures are located several hundreds of meters apart. Furthermore, the process requires that the workers be transported between sites. In practice, therefore, available space on the vehicle for transport of the crew could be the limiting factor on crew size.

In those cases where cylindrical concrete bins for waste storage are located alongside the road, the number of workers that can simultaneously transfer wastes from the bins to smaller containers used to load the collection vehicle is constrained by the diameter of the bin. Typically, only one or two workers can work within the bin at the same time. Therefore, considering the amount of work involved in filling and carrying the baskets, the largest number of workers that can be effectively employed is between three and six.

If single, 200-L drums for waste storage are placed at certain intervals on the road or street, the maximum practical crew size is two. The number of crew members would have to be increased by one or two if the collection vehicle is of the type having an open top with very high sidewalls. The additional crew members would be stationed in the body of the vehicle to assist in lifting and emptying the containers handed to them by the workers at the street level.

In block collection of solid wastes, it is rarely necessary to use a crew of more than two, since the crew’s only task is to stand at the rear of the vehicle and empty containers handed to them by the residents.

M3. KERBSIDE and door-to-door collection

In the case of the analysis of kerbside and of door-to-door collection systems, the process of determining the most cost-effective crew size is more complex than that for collection systems that utilise communal container storage. For door-to-door collection in a residential area of single-family dwellings, the basic work elements for a two-person crew, working both sides of the road, are as follows: 1) walk into the backyard and pick up the full container, 2) carry the container to the collection vehicle and empty it, 3) return the empty container to its original location, 4) walk back to the road, and 5) walk to the next house on the same side of the road.

In the case of a crew using four workers (two workers for each side of the road), the time required to walk to the next house to be serviced is essentially doubled, since both workers on one side of the road must walk the frontage distance of two houses, instead of one.

A second factor that impacts selection of this type of collection system is that the greater the crew size, the longer the distance over which the crew is spread at any one time while the vehicle remains stationary. Thus, the larger the crew, the more time that will be spent either walking toward the vehicle or waiting with the container for the vehicle to come within a reasonable walking distance.

Collection from only one side of the street sometimes is necessary when traffic is heavy or the street is extremely wide. In fact, there are some operators of waste collection systems in industrialised countries that do not collect on both sides of the street due to safety factors. When collection is carried out from only one side of the street, every worker increment above a single collector causes a disproportionate increase in labour time in terms of waste collection productivity, with the result that productivity per labour unit decreases and labour cost per container emptied increases.

In the case of kerbside collection, the frontage walked constitutes a much greater proportion of total work content and, thus, the incremental reduction in labour productivity is more rapid than in the case of door-to-door collection. Vehicle productivity, however, follows the opposite pattern; the greater the crew size, the larger the number of containers that can be emptied per unit time and, therefore, the larger quantity of wastes that can be collected per unit time.

Thus, for every situation there is an optimum crew size that achieves the lowest total cost of collection. There are several factors that determine optimum crew size. Some of these factors include: physical layout of the collection area, distance to be walked for the various activities of the collection process, the type of system used (door-to-door or kerbside), traffic and parking patterns and conditions, local wages, and cost of vehicles.

In most cities, it is possible to define different types of collection areas (e.g., areas with wide streets and those with narrow streets), each of which would require a particular number of collection crew members in order to optimise productivity and cost. Typically, in a particular city, the costs of collection vehicles and labour wages are constant. However, these costs may vary within a country and from one country to another. For these reasons, it is generally advisable to carry out time-and-motion studies in every city under consideration for a new or improved collection system in order to determine, within a reasonable level of accuracy, optimum crew size for collection areas defined within a certain set of conditions, e.g., narrow, winding streets with hilly terrain and wide, straight streets with flat terrain.

The route or portion of a route selected for time-and-motion studies should be sufficiently long to provide work between one and two hours. In addition, during each test, the crew should be accompanied by a supervisor who will record the total number of containers emptied and the elapsed time between the starting and finishing points. In the case of routes designed for working a single side of the street, crews of 1, 2, 3, and 4 personnel should be used on successive occasions for the purpose of determining the optimum crew size. For routes designed for working on both sides of the street, crews of 2, 4, and 6 should be used in the test. It is also recommended that each test be repeated at least four times; each time the members of the crew should be different in order to account for and balance out individual worker characteristics.

In order to determine the optimum crew size, the unit costs for collection labour and for collection vehicles must be examined as part of the analysis. To demonstrate this type of analysis, a hypothetical example for a collection system using bins and typical productivities for crew and vehicles is given in Table IV-9. The data shown in the table illustrate the important influence of the ratio of cost of labour to operating cost of collection vehicles on the determination and optimisation of collection costs.

Table IV-9. Impact of cost ratio of labour to vehicle on collection cost (units of national currency)

No. of Crew	Productivity		Low Wage Rate[a] Cost/Bin			High Wage Rate[b] Cost/Bin		
	Bins/ Person-hr	Bins/ Vehicle-hr	Labour	Vehicle	Total	Labour	Vehicle	Total
2	30	60	0.66	1.60	2.26	3.32	1.60	4.92
4	25	100	0.80	1.00	1.80	4.00	1.00	5.00
6	20	120	1.00	0.77	1.77	5.00	0.77	5.77

[a] Low Wage Rate: 1 person-hr = 20, 1 vehicle-hr = 100.
[b] High Wage Rate: 1 person-hr = 50, 1 vehicle-hr = 100.

In Table IV-9, a breakdown of the unit costs of collection (i.e., cost/bin) is shown for two categories of wage rates (low and high, respectively). The results shown within each category are based on a low and high wage rate of 20 and 50 currency units, respectively. The hourly cost of the collection vehicle is normalised to 100 currency units. These relative rates are fairly typical for several developing countries.

A curious effect of a high ratio of wage cost to vehicle cost is observed in some locations in the United States, where one person-day may cost 140% of one vehicle-day. The result of this high ratio is that in some cities, the optimum crew size using a 15 m^3 compactor vehicle is one crew member (i.e., the driver).

M4. OPERATION of collection vehicles in relay

In some situations, it may be advisable to consider the use of more than one vehicle per collection crew. This situation can occur if the vehicle is very slow, as in the case of an animal cart, and if the disposal site is remote from the collection location.

When the time required to deliver a load to the disposal site and to return to the collection area is approximately equal to the time required to load a vehicle, then a 2:1 relay system (i.e., two vehicles to one crew) enables the crew to be continuously employed throughout the workday. If only one vehicle is used, the crew would be employed for only about half the time. A 2:1 relay system requires staggered starting times for the drivers of the vehicles.

Working in relays in the situation described above achieves maximum labour productivity. However, some of this advantage is lost due to a reduction in output toward the end of the day, as a result of fatigue of the collection crews. Crews working in a single vehicle system benefit from the periods of rest observed during the trip to and from the disposal site. The result is a higher average rate of productivity during the lesser number of hours during which they are effectively collecting wastes, when compared to crews operating in a relay system when all other conditions are similar.

One advantage of relay systems is that they help to maintain reliability of service. In the event of a breakdown of one vehicle, work can proceed and the day's task can be completed by using a single vehicle and by working longer hours.

Since a relay must be operated to a precise timetable if it is to achieve its aim of continuous productive employment for the collectors, it requires high standards of supervision and of discipline.

M5. OPTIMISATION of vehicle routes

A large number of municipalities in developing countries do not have specific routes for waste collection. Typically, collection vehicles are assigned general areas and the specific routes to be followed are left to the discretion of the drivers. This manner of operation often results in routing that is convenient to the collection crew but not optimum in terms of technical and financial efficiency of collection. There are several approaches available for designing collection routes, depending on the complexity of the situation. Some of these approaches include: 1) heuristic, 2) deterministic, and 3) heuristic-deterministic. In the heuristic method, the system of assigning routes simply is based on experience of the service supplier and, therefore, the solution obtained will be reasonable but may not be optimum. In the deterministic method, a model is developed and by using a computer, an optimum solution for the routing is calculated. In the heuristic-deterministic method, a number of possible alternatives are first identified and then, for a set of defined constraints, the optimum solution is determined.

M6. COSTS of alternative systems

In this section, we present the results of the type of analysis that should be carried out in order to compare the feasibility of implementing a particular type of collection system. The results are given in Tables IV-10 and IV-11 for refuse collection service using a 10-Mg diesel truck and a farm tractor, respectively. The values shown in the tables are, of course, based on a number of assumptions. The assumptions used in the analyses are also shown in the tables. Although the assumptions used are fairly typical and realistic for many situations, the values of the parameters can fluctuate widely from country to country. It is important to note that, in many municipalities, the amount of time spent by administrators, supervisors, and mechanics on the operation and maintenance of a particular type or piece of equipment is not known and, consequently, judgments must be made, or the necessary data collected in order to produce accurate estimates.

As shown in Tables IV-10 and IV-11, the results of the analyses ultimately are normalised to a unit cost (i.e., US$/Mg). The results of this particular set of analyses indicate that, for the specific conditions given in this evaluation, the unit cost for collection is between US$27 and US$49/Mg, depending upon the type of collection service. In this analysis, the alternative that results in the lowest cost is the system that uses a 10-Mg diesel truck. As previously indicated, factors other than unit cost also influence the final selection of the specific type of collection system.

The unit cost and productivity of collection systems vary widely around the world, and the variation illustrates the impact of site-specific conditions on collection. An example of the variation is given in Table IV-12. The data presented in the table can be used as one basis of comparison once costs and productivities are estimated for a given location.

Table IV-10. Example of cost analysis for refuse collection using a 10-Mg diesel truck (2003, US$/yr)

Operation and Maintenance		**Assumption**		**Annual Cost**
Capacity (m^3)		10		
Useful life (years)		10		
Interest rate (%/yr)		15		
Capital cost ($)		76,000		
Spares (15% of capital cost in $)		11,000		
Total capital investment ($)		87,000		
No. of shifts/day		1		
Operating schedule (hr/yr)		2,080		
No. of trips (trips/shift)		4		
No. of loads (loads/shift)		3.6		
Density of refuse (Mg/m^3)		0.3		
Vehicle productivity (Mg/day)		10.8		
Amortisation (interest, useful life)			17,000	
Maintenance (9% of capital cost)			7,800	
Taxes, registration, insurance (3% of capital cost)			2,600	
Subtotal Operation and Maintenance				27,400
Personnel		**Rate**		**Annual Cost**
No.	**Type**			
1	Drivers	5,300	5,300	
2	Collectors	4,000	8,000	
3	Helpers	2,500	7,500	
0.3	Mechanics	6,000	1,800	
0.3	Supervisors	6,600	2,000	
	Subtotal		24,600	
	Fringe benefits (15% of salaries)		3,690	
	Administration (20% of salaries)		4,920	
	Subtotal Personnel			33,210
Total Operation and Maintenance				60,610
Quantity Collected (Mg/yr)				2,246
Unit Cost (average US$/Mg)				27

Table IV-11. Example of cost analysis for refuse collection using a 50-kW farm tractor (2003, US$/yr)

Operation and Maintenance		**Assumption**	**Annual Cost**	
Capacity (m^3)		8		
Useful life (years)		15		
Interest rate (%/yr)		15		
Capital cost ($)		100,000		
Spares (15% of capital cost in $)		15,000		
Total capital investment ($)		115,000		
No. of shifts/day		1		
Operating schedule (hr/yr)		2,080		
No. of trips (trips/shift)		3.5		
No. of loads (loads/shift)		3.15		
Density of refuse (Mg/m^3)		0.3		
Vehicle productivity (Mg/day)		7.56		
Amortisation (interest, useful life)			19,300	
Maintenance (9% of capital cost)			10,400	
Taxes, registration, insurance (3% of capital cost)			3,500	
Subtotal Operation and Maintenance				33,200
Personnel		**Rate**	**Annual Cost**	
No.	**Type**			
1	Drivers	5,300	5,300	
2	Collectors	4,000	8,000	
6	Helpers	2,500	15,000	
0.3	Mechanics	6,000	1,800	
0.3	Supervisors	6,600	2,000	
	Subtotal		32,100	
	Fringe benefits (15% of salaries)		4,800	
	Administration (20% of salaries)		6,400	
	Subtotal Personnel			43,300
Total Operation and Maintenance				76,500
Quantity Collected (Mg/yr)				1,572
Unit Cost (average US$/Mg)				49

Table IV-12. Unit cost and productivity of collection in various countries

Economic Status	Geographical Region	Urban Population	Collection Cost (US$/Mg)	Mg/ Vehicle
Developing	Latin America, Turkey, Nigeria	> 1,500,000	10 to 30	10 to 15
	Tunisia, Turkey, Western Pacific	< 250,000	20 to 35	4 to 5
	Spain	50,000 to 250,000	60 to 80	6 to 15
Industrialised	Denmark, United States	50,000 to 1,000,000	100 to 130	6 to 8

Sources: Reference 6 and CalRecovery, Inc.

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