1. SOURCES AND TYPES OF SOLID WASTES

1.1 INTRODUCTION

Due to rapid increase in the production and consumption processes, societies generate as well as reject solid materials regularly from various sectors– agricultural, commercial, domestic, industrial and institutional. The considerable volume of wastes thus generated and rejected is called solid wastes. In other words, solid wastes are the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted. This inevitably places an enormous strain on natural resources and seriously undermines efficient and sustainable development.

1.2 OBJECTIVES

- Classify solid wastes;
- Explain the functional elements of SWM
- Solid waste disposal acts

1.3 Solid Waste

Solid waste refers to non-soluble material such as agricultural refuse, industrial waste, mining residues, demolition waste, municipal garbage or even sewage sludge. Most of these kind of wastes cannot be recycled or rehabilitated for further use.

1.4 Solid Waste Management

Solid waste management is the entire process involved in the recycling process. Solid waste management starts with the trucks picking up recyclables, delivering them to the recycling.

Solid waste management (SWM) is associated with the control of waste generation, its storage, collection, transfer and transport, processing and disposal in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, publically attitude and other environmental considerations.

Put differently, the SWM processes differ depending on factors such as economic status (e.g., the ratio of wealth created by the production of primary products to that derived from manufactured goods, per capital income, etc.), degree of industrialisation, social development (e.g., education, literacy, healthcare, etc.) and quality of life of a location. In addition, regional, seasonal and economic differences influence the SWM processes.

1.5 CLASSIFICATION OF SOLID WASTES

Solid wastes are the organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc., produced in a society, which do not generally carry any value to the first user(s). Solid wastes, thus, encompass both a heterogeneous mass of wastes from the urban community as well as a more homogeneous accumulation of agricultural, industrial and mineral wastes. While wastes have little or no value in one setting or to the one who wants to dispose them, the discharged wastes may gain significant value in another setting. Knowledge of the sources and types of solid wastes as well as the information on composition and the rate at which wastes are generated/ disposed is, therefore, essential for the design and operation of the functional elements associated with the management of solid wastes.

1.5.1 Source-based classification

(i) Residential: This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.

(ii) Commercial: This refers to wastes consisting of leftover food, glasses, metals, ashes, etc., nerated from stores, restaurants, markets, hotels, motels, auto-repair shops, medical facilities, etc.

(iii) Institutional: This mainly consists of paper, plastic, glasses, etc., generated from educational, administrative and public buildings such as schools, colleges, offices, prisons, etc.

(iv) Municipal: This includes dust, leafy matter, building debris, treatment plant residual sludge, etc., generated from various municipal activities like construction and demolition, street cleaning, landscaping, etc.

(v) Industrial: This mainly consists of process wastes, ashes, demolition and construction wastes, hazardous wastes, etc., due to industrial activities.

(vi) Agricultural: This mainly consists of spoiled food grains and vegetables, agricultural remains, litter, etc., generated from fields, orchards, vineyards, farms, etc.

(vii) Open areas: this includes wastes from areas such as Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.

1.5.2 Type-based classification

Classification of wastes based on types, i.e., physical, chemical, and biological characteristics of wastes, is as follows.

(i) **Garbage:** This refers to animal and vegetable wastes resulting from the handling, sale, storage, preparation, cooking and serving of food. Garbage comprising these wastes contains putrescible (rotting) organic matter, which produces an obnoxious odour and attracts rats and other vermin. It, therefore, requires special attention in storage, handling and disposal.

(ii) **Ashes and residues:** These are substances remaining from the burning of wood, coal, charcoal, coke and other combustible materials for cooking and

heating in houses, institutions and small industrial establishments. When produced in large quantities, as in power-generation plants and factories, these are classified as industrial wastes. Ashes consist of fine powdery residue, cinders and clinker often mixed with small pieces of metal and glass. Since ashes and residues are almost entirely inorganic, they are valuable in landfills.

(iii) **Combustible and non-combustible wastes:** These consist of wastes generated from households, institutions, commercial activities, etc., excluding food wastes and other highly putrescible material. Typically, while combustible material consists of paper, cardboard, textile, rubber, garden trimmings, etc., non-combustible material consists of such items as glass, crockery, tin and aluminium cans, ferrous and non-ferrous material and dirt.

(iv) **Bulky wastes:** These include large household appliances such as refrigerators, washing machines, furniture, crates, vehicle parts, tyres, wood, trees and branches. Since these household wastes cannot be accommodated in normal storage containers, they require a special collection mechanism.

(v) **Street wastes:** These refer to wastes that are collected from streets, walkways, alleys, parks and vacant plots, and include paper, cardboard, plastics, dirt, leaves and other vegetable matter. Littering in public places is indeed a widespread and acute problem in many countries including India, and a solid waste management system must address this menace appropriately.

(vi) **Biodegradable and non-biodegradable wastes:** Biodegradable wastes mainly refer to substances consisting of organic matter such as leftover food, vegetable and fruit peels, paper, textile, wood, etc., generated from various household and industrial activities. Because of the action of micro-organisms, these wastes are degraded from complex to simpler compounds. Non-biodegradable wastes consist of inorganic and recyclable materials such as plastic, glass, cans, metals, etc.

(vii) **Dead animals:** With regard to municipal wastes, dead animals are those that die naturally or are accidentally killed on the road. Note that this category does not include carcasses and animal parts from slaughter-houses, which are regarded as industrial wastes. Dead animals are divided into two groups – large and small. Among the large animals are horses, cows, goats, sheep, pigs, etc., and among the small ones are dogs, cats, rabbits, rats, etc. The reason for this differentiation is that large animals require special equipment for lifting and handling when they are removed. If not collected promptly, dead animals pose a threat to public health since they attract flies and other vermin as they decay. Their presence in public places is particularly offensive from the aesthetic point of view as well.

(viii) **Abandoned vehicles:** This category includes automobiles, trucks and trailers that are abandoned on streets and other public places. However, abandoned vehicles have significant scrap value for their metal, and their value to collectors is highly variable.

(ix) **Construction and demolition wastes:** These are wastes generated as a result of construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. They consist mainly of earth, stones, concrete, bricks, lumber, roofing and plumbing materials, heating systems and electrical wires and parts of the general municipal waste stream.

(x) **Farm Wastes:** These wastes result from diverse agricultural activities such as planting, harvesting, production of milk, rearing of animals for slaughter and the operation of feedlots. In many areas, the disposal of animal waste has become a critical problem, especially from feedlots, poultry farms and dairies.

(xi) **Hazardous wastes:** Hazardous wastes are those defined as wastes of industrial, institutional or consumer origin that are potentially dangerous either immediately or over a period of time to human beings and the environment. This is due to their physical, chemical and biological or radioactive characteristics like ignitability, corrosivity, reactivity and toxicity. Note that in some cases, the active agents may be liquid or gaseous hazardous wastes. These are, nevertheless, classified as solid wastes as they are confined in solid containers. Typical examples of hazardous wastes are empty containers of solvents, paints and pesticides, which are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous wastes may cause explosions in incinerators and fires at landfill sites. Others such as pathological wastes from hospitals and radioactive wastes also require special handling. Effective management practices should ensure that hazardous wastes are stored, collected, transported and disposed of separately, preferably after suitable treatment to render them harmless.

(xii) **Sewage wastes:** The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and derived from the treatment of organic sludge separated from both raw and treated sewages. The inorganic fraction of raw sewage such as grit and eggshells is separated at the preliminary stage of treatment, as it may entrain putrescible organic matter with pathogens and must be buried without delay. The bulk of treated, dewatered sludge is useful as a soil conditioner but is invariably uneconomical. Solid sludge, therefore, enters the stream of municipal wastes, unless special arrangements are made for its disposal.

1.6 SWM system

A SWM system refers to a combination of various functional elements associated with the management of solid wastes. The system, when put in place, facilitates the collection and disposal of solid wastes in the community at minimal costs, while preserving public health and ensuring little or minimal adverse impact on the environment. The functional elements that constitute the system are:

(i) **Waste generation:** Wastes are generated at the start of any process, and thereafter, at every stage as raw materials are converted into goods for consumption. For example, wastes are generated from households, commercial areas, industries, institutions, street cleaning and other municipal services. The most important aspect of this part of the SWM system is the identification of waste.

(ii) **Waste storage:** Storage is a key functional element because collection of wastes never takes place at the source or at the time of their generation. The heterogeneous wastes generated in residential areas must be removed within 8 days due to shortage of storage space and presence of biodegradable material. Onsite storage is of primary importance due to aesthetic consideration, public health and economics involved. Some of the options for storage are plastic containers, conventional dustbins (of households), used oil drums, large storage bins (for institutions and commercial areas or servicing depots), etc.

(iii) **Waste collection:** This includes gathering of wastes and hauling them to the location, where the collection vehicle is emptied, which may be a transfer station (i.e., intermediate station where wastes from smaller vehicles are transferred to larger ones and also segregated), a processing plant or a disposal site. Collection depends on the number of containers, frequency of collection, types of collection services and routes. Typically, collection is provided under various management arrangements, ranging from municipal services to franchised services, and under various forms of contracts.

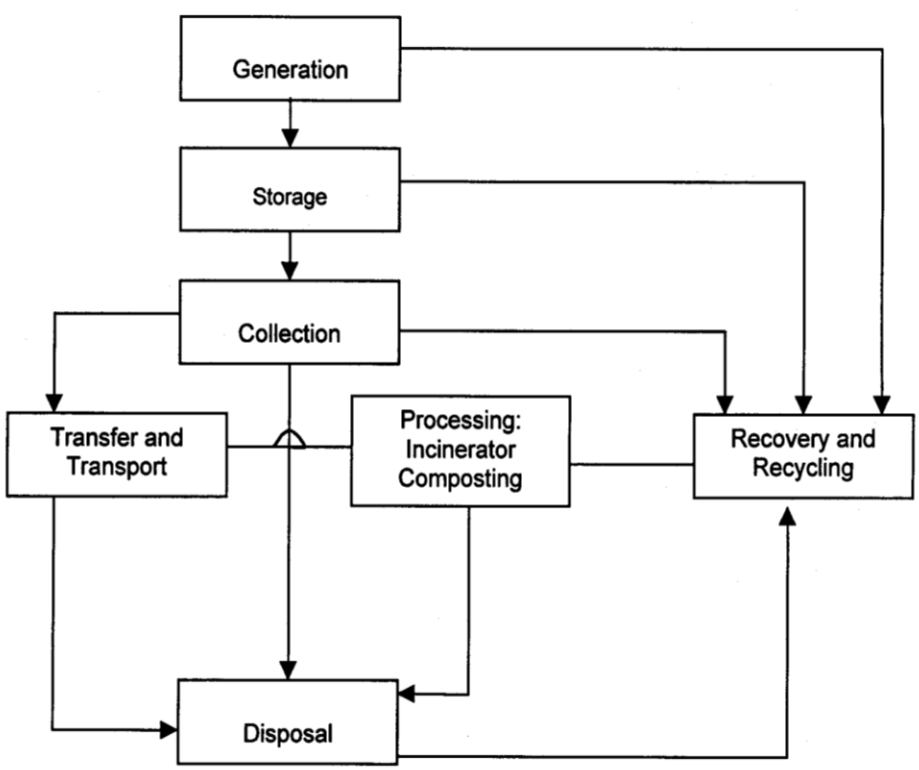
(iv) Transfer and transport: This functional element involves: The transfer of wastes from smaller collection vehicles, where necessary to overcome the problem of narrow access lanes, to larger ones at transfer stations.The subsequent transport of the wastes, usually over long distances, to disposal sites. The factors that contribute to the designing of a transfer station include the type of transfer operation, capacity, equipment, accessories and environmental requirements.

(v) **Processing:** Processing is required to alter the physical and chemical characteristics of wastes for energy and resource recovery and recycling. The important processing techniques include compaction, thermal volume reduction, manual separation of waste components, incineration and composting.

(vi) Recovery and recycling: This includes various techniques, equipment and facilities used to improve both the efficiency of disposal system and recovery of usable material and energy. Recovery involves the separation of valuable resources from the mixed solid wastes, delivered at transfer stations or processing plants. It also involves size reduction and density separation by air classifier, magnetic device for iron and screens for glass. The selection of any recovery process is a function of economics, i.e., costs of separation versus the recovered-material products. Certain recovered materials like glass, plastics, paper, etc., can be recycled as they have economic value.

(vii) Waste disposal: Disposal is the ultimate fate of all solid wastes, be they residential wastes, semi-solid wastes from municipal and industrial treatment plants, incinerator residues, composts or other substances that have no further use to the society. Thus, land use planning becomes a primary determinant in the selection, design and operation of landfill operations. A modern sanitary landfill is a method of disposing solid waste without creating a nuisance and hazard to public health. Generally, engineering principles are followed to confine the wastes to the smallest possible area, reduce them to the lowest particle volume by compaction at the site and cover them after each day's operation to reduce exposure to vermin. One of the most important functional elements of SWM, therefore, relates to the final use of the reclaimed land.

Typical SWM System: Functional Elements



1.7 Factors affecting SWM system

(i) Quantities and characteristics of wastes: The quantities of wastes generated generally depend on the income level of a family, as higher income category tends to generate larger quantity of wastes, compared to low-income category. The quantity ranges from about 0.25 to about 2.3 kg per person per day, indicating a strong correlation between waste production and per capita income. One of the measures of waste composition (and characteristics) is density, which ranges from 150 kg/m^3 to 600 kg/m^3. Proportion of paper and packaging materials in the waste largely account for the differences. When this proportion is high, the density is low and vice versa. The wastes of high density reflect a relatively high proportion of organic matter and moisture and lower levels of recycling.

(ii) Climate and seasonal variations: There are regions in extreme north (> 70 N Latitude) and south (> 60 S Latitude), where temperatures are very low for much of the year. In cold climates, drifting snow and frozen ground interfere with landfill operations, and therefore, trenches must be dug in summer and cover material stockpiled for winter use. Tropical climates, on the other hand, are subject to sharp seasonal variations from wet to dry season, which cause significant changes in the moisture content of solid waste, varying from less than 50% in dry season to greater than 65% in wet months. Collection and disposal of wastes in the wet months are often problematic.

High temperatures and humidity cause solid wastes to decompose far more rapidly than they do in colder climates. The frequency of waste collection in high temperature and humid climates should, therefore, be higher than that in cold climates. In sub-tropical or desert climate, there is no significant variation in moisture content of wastes (due to low rainfall) and low production of leachate from sanitary landfill. High winds and wind blown sand and dust, however, cause special problems at landfill sites. While temperature inversions can cause airborne pollutants to be trapped near ground level, landfill sites can affect groundwater by altering the thermal properties of the soil.

(iii) Physical characteristics of an urban area: In urban areas (i.e., towns and cities), where the layout of streets and houses is such that accessby vehicles is possible and door-to-door collection of solid wastes is the accepted norm either by large compaction vehicle or smaller vehicle. The picture is, however, quite different in the inner and older city areas where narrow lanes make service by vehicles difficult and often impossible. Added to this is the problem of urban sprawl in the outskirts (of the cities) where population is growing at an alarming rate. Access ways are narrow, unpaved and tortuous, and therefore, not accessible to collection vehicles. Problems of solid waste storage and collection are most acute in such areas.

(iv) Financial and foreign exchange constraints: Solid waste management accounts for sizeable proportions of the budgets of municipal corporations. This is allocated for capital resources, which go towards the purchase of equipments, vehicles, and fuel and labour costs. Typically, 10% to 40% of the revenues of municipalities are allocated to solid waste management. In regions where wage rates are low, the aim is to optimise vehicle productivity. The unfavourable financial situation of some countries hinders purchase of equipment and vehicles, and this situation is further worsened by the acute shortage of foreign exchange. This means that the balance between the degree of mechanisation and the size of the labour force becomes a critical issue in arriving at the most cost-effective solution.

(v) Cultural constraints: In some regions, long-standing traditions preclude the intrusion of waste collection on the precincts of households, and therefore, influence the collection system. In others, where the tradition of caste persists, recruits to the labour force for street cleaning and handling of waste must be drawn from certain sections of the population, while others will not consent to placing storage bins in their immediate vicinity. Social norms of a community more often than not over-ride what many may consider rational solutions. Waste management should, therefore, be sensitive to such local patterns of living and consider these factors in planning, design and operation.

(vi) Management and technical resources: Solid waste management, to be successful, requires a wide spectrum of workforce in keeping with the demands of the system.

1.8 PHYSICAL CHARACTERISTICS

Density:

It is expressed as mass per unit volume (kg/m³). This parameter is required for designing a solid waste management program. A reduction in volume by 75% is achieved through normal compaction equipment, so that an initial density of 100kg/m³ may readily be increased to 400 kg/m³. Significant changes in the density occur as waste moves from sources to disposal site, as a result of scavenging, handling, wetting, and drying by the weather and vibration during transport. Density is critical in the design of sanitary landfill as well as for storage, collection and transport of wastes. Efficient operation of landfill requires compaction of wastes to optimum density.

Moisture Content

Values greater than 40% are also not common. Moisture increases the weight of the solid wastes and therefore the cost of collection and transport increases. Consequently waste should be insulated from rain or other extraneous water source. Moisture content is critical determinant in the economic feasibility of waste treatment by incineration. During incineration energy must be supplied for evaporation of water and raising the temperature of vapour.

1.5 CHEMICAL CHARACTERISTICS

Information of chemical characteristics is important in evaluating alternative processing and recovery options. Typically waste is considered as combination of combustible and noncombustible components. If solid waste is to be used as a fuel or for any other use we should know its chemical components.

Lipids

These are included in the class of fats, oils and grease. The principal sources of lipids in the garbage are cooking oil and fats. Lipids have high heating values about 38,000 Kj/Kg (kilojoules/kilograms), which makes the waste with high lipid content suitable for energy recovery. Since lipids become liquids at temperature slightly above ambient they add to the liquid content during waste decomposition. They are biodegradable, but they have low solubility in water and hence the rate of biodegradation is slow.

Carbohydrates

These are primarily originated from the food sources rich in starch and celluloses. These readily biodegrade into carbon dioxide, water and methane. Decomposition of carbohydrates attracts the flies and rats and hence should not be left exposed for long duration

Proteins

These are the compounds containing carbon, hydrogen, nitrogen and oxygen and organic acid with amino groups. They are primarily found in food and garden wastes, but their partial decomposition result in the production of amines, which impart unpleasant odors.

Natural Fibers

These are the natural products contain cellulose and lignins that are relatively resistant to biodegradation. These are found in paper products, food and yard wastes. Paper is almost 100% cellulose, cotton over 95% and wood products over 40-50%. These are highly combustible products most suitable for incineration. The calorific value of oven dried paper products are in the range 12000-18000 kj/kg.

Synthetic Organic Materials

In the recent years plastics have become a significant components of solid waste, accounting for 1-10%. They are highly resistant to the biodegradation; hence their presence in the waste is objectionable. Currently much attention is given to reduce this component at disposal sites. Plastics have a high heating value, about 32000 kj/kg, which makes them very suitable for incineration. However, among the plastics Polyvinyl chloride (PVC) when burnt produces dioxin and acid gas. The trace gases produced during the burning of plastic are proved to be carcinogenic.

2. ONSITE STORAGE & PROCESSING

2.1 Hauled and Stationary containers

The design of an efficient waste collection system requires careful consideration of the type, size and location of containers at the point of generation for storage of wastes until they are collected. While single-family households generally use small containers, residential units, commercial units, institutions and industries require large containers. Smaller containers are usually handled manually whereas the larger, heavier ones require mechanical handling. The containers may fall under either of the following two categories:

(i) Stationary containers: These are used for contents to be transferred to collection vehicles at the site of storage.

(ii) Hauled containers: These are used for contents to be directly transferred to a processing plant, transfer station or disposal site for emptying before being returned to the storage site.

The desirable characteristics of a well-designed container are low cost, size, weight, shape, resistance to corrosion, water tightness, strength and durability (Phelps, et al., 1995). For example, a container for manual handling by one person should not weigh more than 20 kg, lest it may lead to occupational health hazards such as muscular strain, etc. Containers that weigh more than 20 kg, when full, require two or more crew members to manually load and unload the wastes, and which result in low collection efficiency.

Containers should not have rough or sharp edges, and preferably have a handle and a wheel to facilitate mobility. They should be covered to prevent rainwater from entering (which increases the weight and rate of decomposition of organic materials) into the solid wastes. The container body must be strong enough to resist and discourage stray animals and scavengers from ripping it as well as withstand rough handling by the collection crew and mechanical loading equipment.

Containers should be provided with a lifting bar, compatible with the hoisting mechanism of the vehicle. The material used should be light, recyclable, easily moulded and the surface must be smooth and resistant to corrosion. On the one hand, steel and ferrous containers are heavy and subject to corrosion; the rust peels off exposing sharp edges, which could be hazardous to the collection crew. On the other, wooden containers (e.g., bamboo, rattan and wooden baskets) readily absorb and retain moisture and their surfaces are generally rough, irregular and difficult to clean.

2.2 Waste processing technique

The processing of wastes helps in achieving the best possible benefit from every functional element of the solid waste management (SWM) system and, therefore, requires proper selection of techniques and equipment for every element. Accordingly, the wastes that are considered suitable for further use need to be paid special attention in terms of processing, in order that we could derive maximum economical value from them.

(i) **Improving efficiency of SWM system:** Various processing techniques are available to improve the efficiency of SWM system. For example, before waste papers are reused, they are usually baled to reduce transporting and storage volume requirements. In some cases, wastes are baled to reduce the haul costs at disposal site, where solid wastes are compacted to use the available land effectively. If solid wastes are to be transported hydraulically and pneumatically, some form of shredding is also required. Shredding is also used to improve the efficiency of the disposal site.

(ii) **Recovering material for reuse:** Usually, materials having a market, when present in wastes in sufficient quantity to justify their separation are most amenable to recovery and recycling. Materials that can be recovered from solid wastes include paper, cardboard, plastic, glass, ferrous metal, aluminium and other residual metals.

(iii) **Recovering conversion products and energy:** Combustible organic materials can be converted to intermediate products and ultimately to usable energy. This can be done either through incineration, pyrolysis, composting or bio-digestion. Initially, the combustible organic matter is separated from the other solid waste components. Once separated, further processing like shredding and drying is necessary before the waste material can be used for power generation.

2.3 Waste evaluation options in India

The problem of municipal solid waste management has acquired alarming dimensions in India especially over the last decade, before which waste management was hardly considered an issue of concern as the waste could be easily disposed of in an environmentally safe manner.

The physical and chemical characteristics of Indian city refuse, nonetheless, show that about 80% of it is compostable and ideal for biogas generation due to adequate nutrients (NPK), moisture content of 50-55% and a carbon-to-nitrogen ratio of 25-40:1. Therefore, the development of appropriate technologies for utilisation of wastes is essential to minimise adverse health and environmental consequences.

Against this backdrop, let us discuss below the quantum of wastes generated in India, their composition, disposal methods, recycling aspects, and health and environment impacts:

(i) **Waste quantum:** The per capita waste generation rate is about 500 g/day. This along with increased population has contributed to higher total waste generation quantum.

(ii) **Waste composition:** Studies reveal that the percentage of the organic matter has remained almost static at 41% in the past 3 decades, but the recyclables have increased from 9.56% to 17.18%.

Garbage in Indian cities is estimated to contain about 45-75% biodegradable waste (as against 25% of US city-garbage) with 50-55% moisture; 35-45% being fruits, vegetable and food biomass; and 8-15% non organic materials like plastic, metal, glass, stones, etc. Refuse from Indian cities also contains high organic and low combustible matter, if the studies carried out in six cities are of any indication.

(iii) **Waste disposal methods:** Waste disposal is the final stage of the waste management cycle. About 90% of the municipal waste collected by the civic authorities in India is dumped in low-lying areas outside the city/town limits, which have no provision of leachate collection and treatment, and landfill gas collection and use.

(iv) **Recycling:** This involves collection of recyclables from various sources, which ultimately reach recycling units. It is estimated that about 40-80% of plastic waste gets recycled in India, as compared to 10-15% in the developed nations of the world. However, due to lack of suitable government policies, incentives, subsidies, regulations, standards, etc., related to recycling, this industry is still far behind its western counterparts in terms of technology and quality of manufactured goods. Nevertheless, recycling in India is a highly organised and profit-making venture, though informal in nature.

(v) **Health impacts:** Due to the absence of standards and norms for handling municipal wastes, municipal workers suffer occupational health hazards of waste handling. At the dumpsites in the city of Mumbai, for example, 95 workers were examined and it was found that about 80% of them had eye problems, 73% respiratory ailments, 51% gastro intestinal ailments and 27% skin lesions. Also, municipal workers and rag pickers who operate informally for long hours rummaging through waste also suffer from similar occupational health diseases ranging from respiratory illnesses (from ingesting particulates and bio-aerosols), infections (direct contact with contaminated material), puncture wounds (leading to tetanus, hepatitis and HIV infection) to headaches and nausea, etc. Studies among the 180 rag pickers at open dumps of Kolkata city reveal that average quarterly incidence of diarrhoea was 85%, fever 72% and cough and cold 63%.

(vi) Environmental impacts: In addition to occupational health, injury issues and environmental health also need to be mentioned in the context of waste management. Contaminated leachate and surface run-off from land disposal facilities affects ground and surface water quality. Volatile organic compounds and dioxins in air-emissions are attributed to increasing cancer incidence and psychological stress for those living near incinerators or land disposal facilities. Drain clogging due to uncollected wastes leading to stagnant waters and subsequent mosquito vector breeding is a few of the environmental health issues, which affect the waste workers as well as the public.

2.4 Vehicle storage method

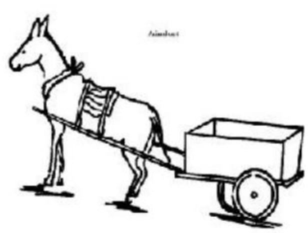
2.4.1 Collection vehicles

Almost all collections are based on collector and collection crew, which move through the collection service area with a vehicle for collecting the waste material. The collection vehicle selected must be appropriate to the terrain, type and density of waste generation points, the way it travels and type and kind of material (UNEP, 1996). It also depends upon strength, stature and capability of the crew that will work with it.

collection vehicle may be small and simple (e.g., two-wheeled cart pulled by an individual) or large, complex and energy intensive (e.g., rear loading compactor truck). The most commonly used collection vehicle is the dump truck fitted with a hydraulic lifting mechanism. A description of some vehicle types follows:

(i) **Small-scale collection and muscle -powered vehicles:** These are common vehicles used for waste collection in many countries and are generally used in rural hilly areas. As Figure 3.3 illustrates, these can be small rickshaws, carts or wagons pulled by people or animals, and are less expensive, easier to build and maintain compared to other vehicles:

Small-scale Collection Vehicles: An Illustration



They are suitable for densely populated areas with narrow lanes, and squatter settlements, where there is relatively low volume of waste generated. Some drawbacks of these collection vehicles include limited travel range of the vehicles and weather exposure that affect humans and animals.

(ii) **Non-compactor trucks:** Non-compactor trucks are efficient and cost effective in small cities and in areas where wastes tend to be very dense and have little potential for compaction.

Non-compactor Trucks

When these trucks are used for waste collection, they need a dumping system to easily discharge the waste. It is generally required to cover the trucks in order to prevent residue flying off or rain soaking the wastes. Trucks with capacities of 10 – 12 m^3 are effective, if the distance between the disposal site and the collection area is less than 15 km. If the distance is longer, a potential transfer station closer than 10 km from the collection area is required. Non-compact trucks are generally used, when labour cost is high. Controlling and operating cost is a deciding factor, when collection routes are long and relatively sparsely populated.

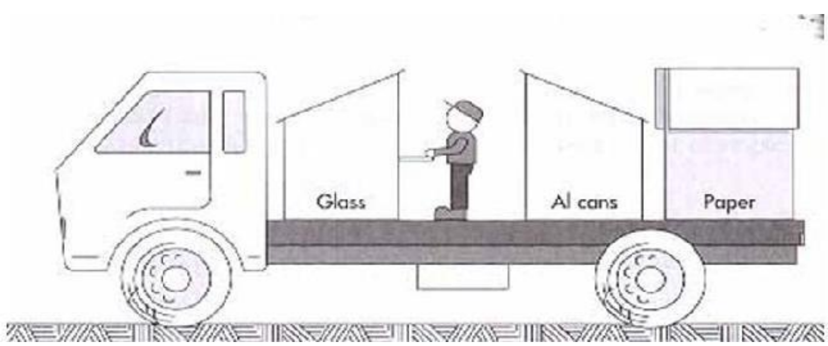
2.4.2 Compactor truck:

Compaction vehicles are more common these days, generally having capacities of 12 – 15 m^3 due to limitations imposed by narrow roads. Although the capacity of a compaction vehicle, illustrated in Figure 3.4, is similar to that of a dump truck, the weight of solid wastes collected per trip is 2 to 2.5 times larger since the wastes are hydraulically compacted:

Figure 3.5

Compactor Truck

The success of waste management depends on the level of segregation at source.



A compactor truck allows waste containers to be emptied into the vehicle from the rear, front or sides and inhibits vectors (of disease) from reaching the waste during collection and transport. It works poorly when waste stream is very dense, wet, collected materials are gritty or abrasive, or when the roads are dusty. The advantages of the compactor collection vehicle include the following:

- ✓ Containers are uniform, large, covered and relatively visually inoffensive;
- ✓ Waste is set out in containers so that the crew can pick them up quick ly;

- ✓ Health risk to the collectors and odour on the streets are minimized, waste is relatively inaccessible to the waste pickers.

2.5 Factors affects the waste collection

(i) Finalising and implementing the system management plan:

For proper implementation of collection and transfer system, it is necessary to have clear organisational structures and management plans. The organisational structure should be simple, with a minimum of administrative and management layers between collection crews and top management. All workers in the department should clearly understand the department's mission and their roles. Through training, incentives and reinforcement by management, workers should be encouraged to be customer-oriented and team contributors. Feedback mechanisms must be introduced to help the crew review their performance and help managers monitoring the performance of crews, equipment, etc. It is also important to periodically review the management plans and structures, as implementation of collection services continues.

(ii) **Purchasing and managing equipment:** For purchasing equipment, most municipalities issue bid specifications. Detailed specifications include exact requirements for equipment sizes and capacities, power ratings, etc. Performance specifications often request that equipment be equivalent to certain available models and meet standards for capacity, speed, etc. Municipalities may either perform equipment maintenance themselves; contract with a local garage, or in some cases, contract with the vehicle vendor at the time of purchase. As part of the preventive maintenance programme, the collection crew should check the vehicle chassis, tyres and body daily and rep ort any problems to maintenance managers. In addition, each vehicle should have an individual maintenance record that includes the following items:

- ✓ Preventive maintenance schedule;
- ✓ Current list of specific engine;
- ✓ A description of repairs and a list containing information on the repair date, mechanic, cost, type an d manufacturer of repair parts
- ✓ The length of time the truck was out of service, for each maintenance event.

(iii) **Hiring and training personnel:** As in all organisations, good personnel management is essential to an efficient, high-quality waste collection system. Authorities responsible for SWM should, therefore, strive to hire and keep well-qualified personnel. The recruitment programme should assess applicants' abilities to perform the types of physical labour required for the collection, equipment and methods used. To retain employees, management should provide a safe working environment that emphasises career advancement, participatory problem solving and worker incentives. Worker incentives should be developed to recognise and reward outstanding performance by employees. Ways to accomplish motivation include merit-based compensation, awards programme and a work structure. Feedback on employee performance should be regular and frequent.

Safety is especially important because waste collection employees encounter many hazards during each workday. As a result of poor safety records, insurance costs for many collection services are high. To minimise injuries, haulers should have an ongoing safety programme. This programme should outline safety procedures and ensure that all personnel are properly trained on safety issues. Haulers should develop an employee-training programme that helps employees improve and broaden the range of their job-related skills. Education should address such subjects as driving skills, first aid, safe lifting methods, identification of household hazardous wastes, avoidance of substance abuse and stress management.

(iv) **Providing public information:** Maintaining good communication with the public is important to a well-run collection system. Residents can greatly influence the performance of the collection system by co-operating in separation requirements, and by keeping undesirable materials from entering the collected waste stream. Commonly used methods of communicating information include brochures, articles in community newsletters, newspaper articles, announcements, and advertisements on radio and television, information attachments to utility bills (either printed or given separately) and school handouts. Communication materials should be used to help residents understand the community waste management challenges and the progress in meeting them. Residents should also be kept informed about issues such as the availability and costs of landfill capacity so that they develop an understanding of the issues and a desire to help meet their waste management needs.

(v) **Monitoring system cost and performance:** Collection and transfer facilities should develop and maintain an effective system for cost and performance reporting. Each collection crew should complete a daily report containing the following information:

- ✓ Total quantity hauled.
- ✓ Total distance and travel times to and from the disposal site.
- ✓ Amounts delivered to ea ch disposal, transfer, or processing facility. Waiting time at sites.
- ✓ Number of loads hauled.
- ✓ Vehicle or operational problems needing attention.

Collected data should be used to forecast workloads, truck costs, identify changes in the generation of wastes and recyclables; trace the origin of problematic was materials and evaluates crew performance. Just as the goals of a collection programme set its overall directions, a monitoring system provides the short-term feedback necessary to identify the corrections needed to achieve those goals.

3. COLLECTION AND TRANSFER

3.1 COLLECTION COMPONENTS

(i) **Collection points:** These affect such collection system components as crew size and storage, which ultimately control the cost of collection. Note that the collection points depend on locality and may be residential, commercial or industrial.

(ii) **Collection frequency:** Climatic conditions and requirements of a locality as well as containers and costs determine the collection frequency. In hot and humid climates, for example, solid wastes must be collected at least twice a week, as the decomposing solid wastes produce bad odour and leachate. And, as residential wastes usually contain food wastes and other putrescible (rotting) material, frequent collection is desirable for health and aesthetic reasons. Besides climates, the quality of solid waste containers on site also determines the collection frequency. For instance, while sealed or closed containers allow collection frequency up to three days, open and unsealed containers may require daily collection. Collection efficiency largely depends on the demography of the area (such as income groups, community, etc.), where collection takes place. Cost, e.g., optimal collection frequency reduces the cost as it involves fewer trucks, employees and reduction in total route distance; storage space, e.g., less frequent collection may require more storage space in the locality; sanitation, e.g., frequent collection reduces concerns about health, safety and nuisance associated with stored refuse.

(iii) **Storage containers:** Proper container selection can save collection energy, increase the speed of collection and reduce crew size. Most importantly, containers should be functional for the amount and type of materials and collection vehicles used. Containers should also be durable, easy to handle, and economical, as well as resistant to corrosion, weather and animals. In residential areas, where refuse is collected manually, standardised metal or plastic containers are typically required for waste storage. When mechanised collection systems are used, containers are specifically designed to fit the truck-mounted loading mechanisms efficiency, i.e., the containers should help maximise the overall collection efficiency.

- Convenience, i.e., the containers must be easily manageable both for residents and collection crew.
- Compatibility, i.e., the containers must be compatible with collection equipment.
- Public health and safety, i.e., the containers should be securely covered and stored.
- Ownership, i.e., the municipal ownership must guarantee compatibility with collection equipment.

(iv) **Collection crew** (see also Subsection 3.3.1)**:** The optimum crew size for a community depends on labour and equipment costs, collection methods and route characteristics. The size of the collection crew also depends on the size and type of collection vehicle used, space between the houses, waste generation rate and collection frequency. For example, increase in waste generation rate and quantity of wastes collected per stop due to less frequent collection result in a bigger crew size. Note also that the collection vehicle could be a motorised vehicle, a pushcart or a trailer towed by a suitable prime mover (tractor, etc.). It is possible to adjust the ratio of collectors to collection vehicles such that the crew idle time is minimised. However, it is not easy to implement this measure, as it may result in an overlap in the crew collection and truck idle time. An effective collection crew size and proper workforce management can influence the productivity of the collection system. The crew size, in essence, can have a great effect on overall collection costs. However, with increase in collection costs, the trend in recent years is towards:

- ✓ Decrease in the frequency of collection;
- ✓ Increase in the dependence on residents to sort waste materials;
- ✓ This trend has, in fact, contributed to smaller crews in municipalities.

(v) **Collection route:** The collection programme must consider the route that is efficient for collection. An efficient routing of collection vehicles helps decrease costs by reducing the labour expended for collection. Proper planning of collection route also helps conserve energy and minimise working hours and vehicle fuel consumption. It is necessary therefore to develop detailed route configurations and collection schedules for the selected collection system. The size of each route, however, depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad, embankments, rivers and roads with heavy traffic, can be considered to divide route territories. Routing (network) analyses and planning can:

- increase the likelihood of all streets being serviced equally and consistently;
- help supervisors locate or track crews quickly;
- provide optimal routes that can be tested against driver judgement and experience.

(vi) **Transfer station:** A transfer station is an intermediate station between final disposal option and collection point in order to increase the efficiency of the system, as collection vehicles and crew remain closer to routes. If the disposal site is far from the collection area, it is justifiable to have a transfer station, where smaller collection vehicles transfer their loads to larger vehicles, which then haul the waste long distances. In some instances, the transfer station serves as a pre- processing point, where wastes are dewatered, scooped or compressed. A centralised sorting and recovery of recyclable materials are also carried out at transfer stations (EPA, 1989). The unit cost of hauling solid wastes from a collection area to a transfer station and then to a disposal site decreases, as the size of the collection vehicles increases.

3.2 STORAGE: CONTAINERS/COLLECTION VEHICLES

3.2.1 Containers/storage bins

The design of an efficient waste collection system requires careful consideration of the type, size and location of containers at the point of generation for storage of wastes until they are collected. While single-family households generally use small containers, residential units, commercial units, institution and industries require large containers. Smaller containers are usually handled manually whereas the larger, heavier ones require mechanical handling. The containers may fall under either of the following two categories:

(i) Stationary containers: These are used for contents to be transferred to collection vehicles at the site of storage.

(ii) Hauled containers: These are used for contents to be directly transferred to a processing plant, transfer station or disposal site for emptying before being returned to the storage site.

The desirable characteristics of a well-designed container are low cost, size, weight, shape, resistance to corrosion, water tightness, strength and durability (Phelps, et al., 1995). For example, a container for manual handling by one person should not weigh more than 20 kg, lest it may lead to occupational health hazards such as muscular strain, etc. Containers that weigh more than 20 kg, when full, require two or more crew members to manually load and unload the wastes, and which result in low collection efficiency.

Containers should not have rough or sharp edges, and preferably have a handle and a wheel to facilitate mobility. They should be covered to prevent rainwater from entering (which increases the eight and rate of decomposition of organic materials) into the solid wastes. The container body must be strong enough to resist and discourage stray animals and scavengers from ripping it as well as withstand rough handling by the collection crew and mechanical loading equipment. Containers should be provided with a lifting bar, compatible with the hoisting mechanism of the vehicle. The material used should be light, recyclable, easily moulded and the surface must be smooth and resistant to corrosion. On the one hand, steel and ferrous containers are heavy and subject to corrosion; the rust peels off exposing sharp edges, which could be hazardous to the collection crew.

Communal *containers*

TYPICAL COMMUNAL CONTAINER

The use of communal containers is largely dependent on local culture, tradition and attitudes towards waste. Communal containers may be fixed on the ground (stationary) or movable (hauled). Movable containers are provided with hoists and tails compatible with lifting mechanism of collection vehicles and such containers have capacities of 1 – 4 m^3. The waste management authority must monitor, maintain and upgrade the communal containers. Note that in residential and commercial areas in India, the communal containers are often made of concrete.

In areas with very high waste generation rates, i.e., rates exceeding two truckloads daily, such as wet markets, large commercial centres and large business establishments, roll-on-roll or hoisted communal containers with capacities of 12 – 20 m^3 and a strong superstructure with wheels are used.

Normally, the collection vehicle keeps an empty container as a replacement before it hauls the filled container. When a truck is used as a collection vehicle, the use of communal containers may be appropriate.

This means that the farthest distance the householder will have to walk is 50 meters. However, in narrow streets with low traffic, where the house owner can readily cross the street, a longer distance is advisable. If the collection vehic le has to stop frequently, say, at every 50 m or so, fuel consumption increases, and this must be avoided.

Disadvantages

The major disadvantage of communal containers is the potential lack of maintenance and upgrading. The residuals and scattered solid wastes emit foul odours, which discourage residents from using the containers properly. In addition, if fixed containers are built below the vehicle level, the collection crew may be held responsible for sweeping and loading the solid wastes into transfer containers before being loaded into the collection vehicle. Sweeping and cleaning the communal containers of residuals obviously impinge on the time of the crew members and take a longer time than if the wastes are placed in smaller containers. As fixed communal containers have higher rates of failure, their use is not advisable.

To overcome the problem of maintaining communal containers, individual residents should maintain their own containers and locate them in designated areas. The communal area must have water and drains to facilitate the cleaning of the containers. This practice has the advantage of reducing the number of collection stops and at the same time maintaining the householder's responsibility for cleaning them. The residents must also be properly educated on the importance of good housekeeping as the containers in the communal area are subject to vandalism. In the main, if communal containers are to be successful, the design of the containers, loading and unloading areas, and collection vehicle accessories should be co-ordinated.

3.3 COLLECTION OPERATION

3.3.1Movement of collection crew

In cultures such as India, Bangladesh, etc., solid waste collection is assigned to the lowest social group. More often, the collection crew member accepts the job as a temporary position or stopgap arrangement, while looking for other jobs that are considered more respectable.

Apart from this cultural problem, the attitude of some SWM authorities affects collection operation. For example, some authorities still think that the collection of solid waste is mechanical, and therefore, the collection crew does not need any training to acquire special skills. As a result, when a new waste collector starts working, he or she is sent to the field without firm instruction concerning his or her duties, responsibilities and required skills. For an effective collection operation, the collection team must properly be trained. The collection crew and the driver of the collection vehicle must, for example, work as a team, and this is important to maintain the team morale and a sense of social responsibility among these workers.

The difference may be one or two minutes per collection stop, but it matters with the number of stops the crew will take in a working shift. Multiplying the minutes by the total number of crew working and labour cost depicts the amount of labour hours lost in terms of monetary value.

Generally, familiarity of the crew with the collection area improves efficiency. For example, the driver becomes familiar with the traffic jams, potholes and other obstructions that he or she must avoid. The crew is aware of the location of the containers and the vehicle stops. It is, therefore, important to assign each crew specific areas of responsibility. Working together also establishes an understanding of the strong and weak points of the team members and efficient work sequences. The collection operation must also observe a strict time schedule. Testing of new routes, new gadgets and vehicles is best carried out first in the laboratory and later in a pilot area. Testing of a new sequence using the whole service area could result in disorder and breakdown of the solid waste collection system. Studies show that it takes two hours to recover for every hour of a failed system.

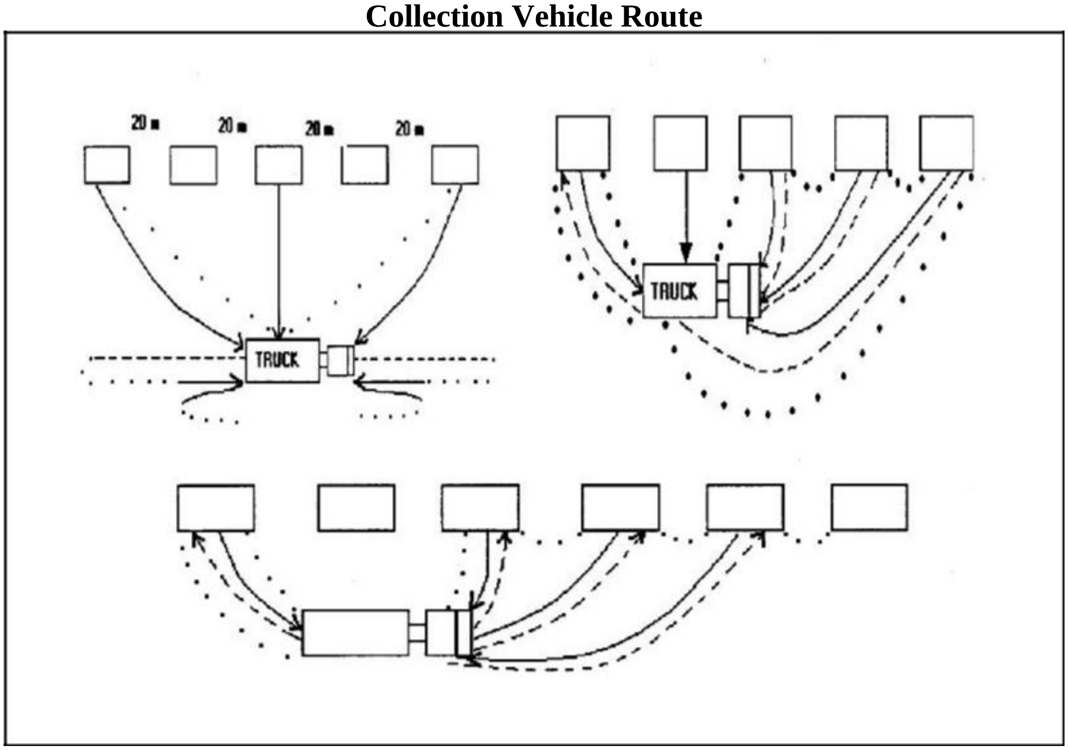
3.3.2 Collection vehicle routing

Efficient routing and re-routing of solid waste collection vehicles can help decrease costs by reducing the labour expended for collection. Routing procedures usually consist of the following two separate components:

(i) **Macro-routing:** Macro-routing, also referred to as route-balancing, consists of dividing the total collection area into routes, sized in such a way as to represent a day's collection for each crew. The size of each route depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad embankments, rivers and roads with heavy competing traffic, can be used to divide route territories. As much as possible, the size and shape of route areas should be balanced within the limits imposed by such barriers.

(ii) **Micro-routing:** Using the results of the macro-routing analysis, micro- routing can define the specific path that each crew and collection vehicle will take each collection day. Results of micro-routing analyses can then be used to readjust macro-routing decisions. Micro-routing analyses should also include input and review from experienced collection drivers.

Collection Vehicle Route



3.4 TRANSFER STATION

Transfer station

The transfer of waste is frequently accompanied by removal, separation or handling of waste. In areas, where wastes are not already dense, they may be compacted at a transfer station. The technical limitations of smaller collection vehicles and the low hauling cost of solid waste, using larger vehicles, make a transfer station viable. Also, the use of transfer station proves reasonable, when there is a need for vehicles servicing a collection route to travel shorter distances, unload and return quickly to their primary task of collecting the waste.

Limitations in hauling solid wastes are the main factors to be considered, while evaluating the use of transfer stations. These include the additional capital costs of purchasing trailers, building transfer stations and the extra time, labour and energy required for transferring wastes from collection truck to transfer trailer.

3.4.1 Types

Depending on the size, transfer stations can be either of the following two types:

(i) **Small to medium transfer stations:** These are direct-discharge stations that provide no intermediate waste storage area. The capacities are generally small (less than 100 tonnes/day) and medium (100 to 500 tonnes/day). Depending on weather, site aesthetics and environmental concerns, transfer operations of this size may be located either indoor or outdoor. More complex small transfer stations are usually attended during hours of operation and may include some simple waste and materials processing facilities. For example, it includes a recyclable material separation and processing centre. The required overall station capacity (i.e., the number and size of containers) depends on the size and population density of the area served and the frequency of collection.

(ii) **Large transfer stations:** These are designed for heavy commercial use by private and municipal collection vehicles. The typical operational procedure for a larger station is as follows:

- when collection vehicles arrive at the site, they are checked in for billing, weighed and directed to the appropriate dumping area;
- collection vehicles travel to the dumping area and empty the wastes into a waiting trailer, a pit or a platform;
- after unloading, the collection vehicle leaves the site, and there is no need to weigh the departing vehicle, if its weight (empty) is known;
- Transfer vehicles are weighed either during or after loading. If weighed during loading, trailers can be more consistently loaded to just under maximum legal weights and this maximises payloads and minimises weight violations.