

**University of Asia Pacific**  
**Department of Civil Engineering**  
**Course Lecture Plan (Tentative)**

**Course Code: CE 431      Credit Hour: 2.0**  
**Course Title: Environmental Engineering III (Solid Waste Management)**  
**Course Teacher: Kazi Shamima Akter, Assistant Professor**

<b>Topics</b>	<b>No. of Classes</b>
<b>1. Introduction to Solid Waste Management</b>	<b>2</b>
Definition of solid waste Background of solid waste management Composition of solid waste Management of solid waste	
<b>2. Sources and Characteristics of Solid Waste</b>	<b>4</b>
Classification of solid waste Generation rates Physical properties Chemical properties Proximate analysis Methods of sampling and measurement Variations in quantity and composition of solid waste Forecasting future quantities	
<b>3. Source Reduction, On-Site Processing and Storage of Solid Waste</b>	<b>2</b>
Source Reduction On-site processing and collection of waste Implementation of source reduction and on-site processing Calculation of source reduction On-site storage	
<b>4. Collection and Transfer of Solid Wastes</b>	<b>5</b>
Classification of collection system Point of collection Frequency of waste collection Street cleansing Transfer stations Collection vehicles	
<b>5. Recycling and Reuse</b>	<b>2</b>
Significance Present practices Recycling processes Resource recovery options Material recovery facilities	

	Full stream processing facilities	
<b>6.</b>	<b>Anaerobic Digestion</b>	<b>2</b>
	The mechanism of anaerobic digestion	
	Environmental factors affecting anaerobic digestion	
	Anaerobic treatment processes and present practices	
	Biogas technologies	
	Environmental aspects	
<b>7.</b>	<b>Composting</b>	<b>1</b>
	Introduction	
	Composting process	
	Composting methods	
<b>8.</b>	<b>Thermal Treatment</b>	<b>1</b>
	Incineration	
	Processes of thermal treatment	
	Pyrolysis	
	Thermal gasification	
<b>9.</b>	<b>Land Disposal</b>	<b>4</b>
	Landfill classification	
	Stages of decomposition in a typical landfill	
	Planning, design and operation of sanitary landfills	
	Groundwater monitoring and corrective action	
	Landfill completion	
<b>10.</b>	<b>Hazardous waste treatment</b>	<b>2</b>
	Definition of hazardous waste	
	Hazardous waste management	
	Treatment of hazardous waste	

**References:**

1. Solid and Hazardous Waste Management - M.Habibur Rahman and Abdullah Al-Muyeed
2. Environmental Engineering-Howard S. Peavy, Donald R. Rowe and George Tchobanoglous
3. Class Notes

**Grading Policy:**

Class Assessment & Attendance	10%
Class Tests	20%
Mid Term Exam	20%
Final Exam	50%

**Note:** 2 out of 3 class tests will be counted.

CE 431  
Solid Waste Management  
(Credit 2.0, Class Period 2 hours/week)

What is WASTE?

- According to [United Nations Statistics Division](#) (UNSD):  
"Wastes are **materials** that are **not prime products** (that is products produced for the market) for which the generator has **no further use** in terms of his/her own purposes of **production, transformation or consumption**, and of which he/she **wants to dispose**. Wastes may be **generated** during the **extraction** of raw materials, the **processing** of raw materials into intermediate and final products, the **consumption** of final products and other **human activities**. Residuals recycled or reused at the place of generation are excluded."

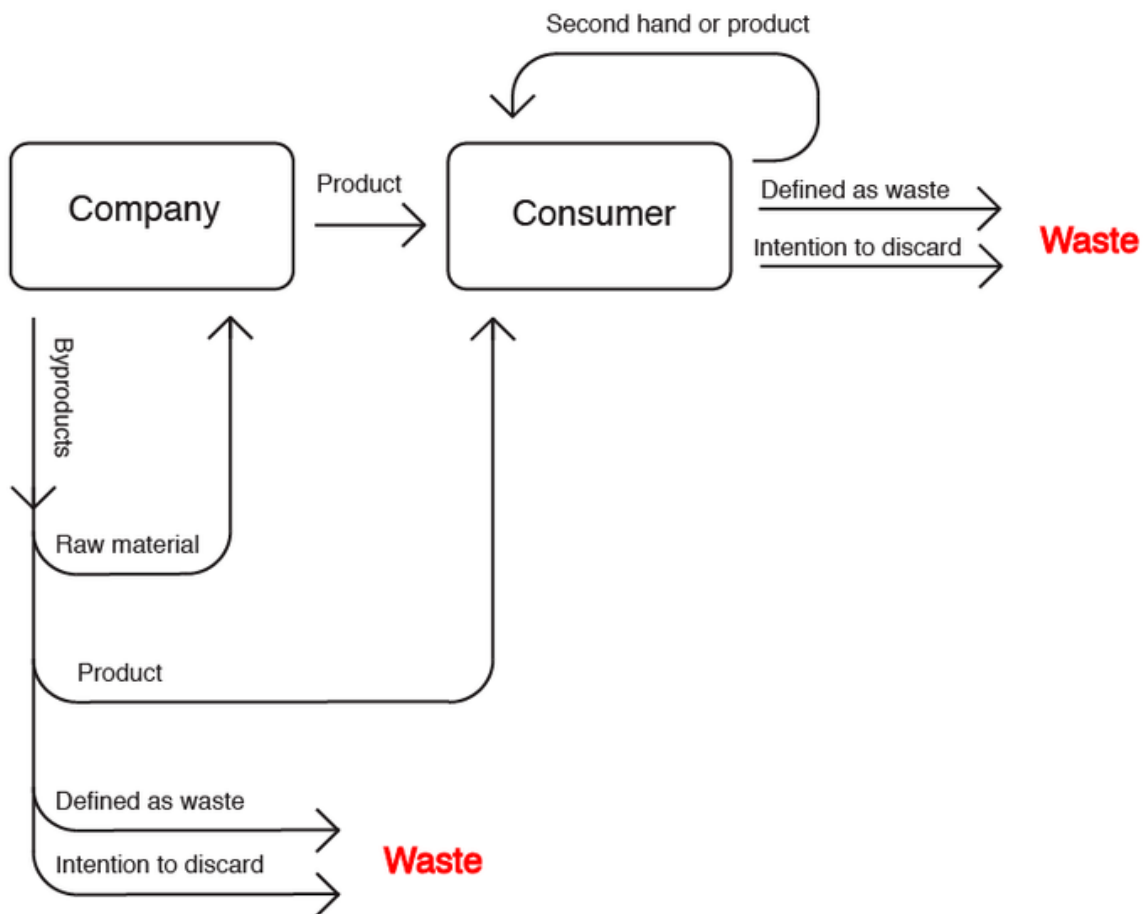


Figure: Schematic Illustration of the EU Legal Definition of Waste

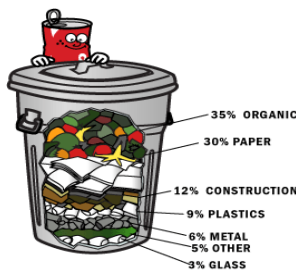
## SOLID WASTE-

Solid waste means any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded materials including solid, liquid, semi-solid, or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations, and from community activities.

### Categories of Solid Waste-

There are many types of wastes defined by modern systems of waste management:

- [municipal solid waste](#)(MSW)
- [construction waste](#)and [demolition waste](#)(C&D)
- institutional waste, [commercial waste](#), and [industrial waste](#) (IC&I)
- [medical waste](#)(also known as clinical waste)
- [hazardous waste](#), [radioactive waste](#), and [electronic waste](#)
- [biodegradable waste](#)



### Examples of Solid Waste-

- waste tires
- septage

- scrap metal
- latex paints
- furniture and toys
- domestic refuse (garbage)
- discarded appliances and vehicles
- uncontaminated used oil and anti-freeze
- empty aerosol cans, paint cans and compressed gas cylinders
- construction and demolition debris, asbestos

### **Waste Dumping Sites in Developing Countries**



**Comparative Scenario**

Developed country	Developing country
Waste management includes reduction, reuse, recycling, composting, and land filling.	Waste management means waste dumping at a site and composting naturally.
Landfill is designed from engineering and environmentally point of view.	Waste is disposed to Low lying area and it will be developed in future. In Dhaka at Matuail, recently semi-aerobic landfill have been developed there.
Area available for developing Landfill.	Densely populated, area is limited.
Recyclable materials such as plastic, rubber, paper, metal, wood etc. have no salvage value. Government allocates fund and taking various steps for collection of recyclable material before sent to landfill.	Since, recyclable materials have good sale value, unemployed poor people make their living by collecting and selling them.
Labor rate high, shortage of manpower, that's why many cases reproduce from recyclable materials bears more cost, to some extent it's more expensive.	Cheap labors, product from recyclable materials are less costly.

**Solid Waste Generation Scenario of DHAKA city( in 2004)**

Features:

- Population and growth rate: 6.61 million (5.52%)
- Water and sanitation 80% and 44%
- Solid waste management:
  - Generation about 5000 t/d
  - Collection 50%
  - Dumping 2600 t/d
  - Illegal dumping 2400 t/d

Recycling	140 t/d (at source) + 290 t/d (scavenger)
Composting	2 t/d by Waste done by (NGO)

### **Objectives of Management of Solid Waste**

Proper planning is needed to manage solid waste for its effective final disposal to prevent reintroduction into the environment. The main objective of waste management is to achieve adequate control over different stages of waste management and it should be compatible with the following achievable principles:

- Public health- decrease in disease
- Environmental well-being- to ensure more hygienic and pollution free living conditions
- Effective use of technologies- adaption to cost- effective and environmentally clean technology.
- Responsiveness of stakeholders- It involves proper integration of multidisciplinary stakeholders and functions (legal, planning, administrative, political, engineering, financial as well as waste generators). An effective plan can only be made if all groups involved in the management system are fully motivated and they clearly understand the problems.
- Costs- optimization of resources

### **Effects of Poor Solid Waste Management**

#### **Environmental Concern**

Society now demands the solid waste management should consider both short-term and long- term effects on the environment (including conservation of resources and prevention of pollution) and the system should be reliable and environmentally compatible.

#### **Risks associated with poor management of solid waste:**

- Breeding ground for diseases carriers.
- Spread of disease by animals and other vectors, and food.
- Spread of diseases by direct contact.
- Air pollution
- Contaminated water.

- Fire risk - piles of waste and gas generated by these present a fire risk.
- Connection to other services.
- Environmental pollution.

**Financial Effects**

- The management of solid waste absorbs a huge amount of the municipal budget and the cost of public cleansing, transportation, and transfer is much higher in low-and middle-income countries compared with that of industrialized countries.
- Indirect financial loss involving the costs associated with the environmental damage and overall waste mgt. expenditures.
- The optimization of the productivity of collection vehicles and workers involved in public cleansing & collection services can improve the situation to achieve greater efficiency and cutting the cost of solid waste mgt. systems.

**The table below (by Cointreau-Levine – 1994) estimated the municipal solid waste management costs:  
Costs in US\$/capita/yr (as % of income)**

	Low-income country	Middle-income country	Industrialized country
Collection	3 to 6 (0.9 to 1.7)	9 to 21 (0.5 to 1.1)	42 to 72 (0.2 to 0.4)
Public cleansing	0.6 to 1.2 (0.2 to 0.3)	1.8 to 4.2 (0.1 to 0.2)	4.2 to 7.2 (0.02 to 0.04)
Transfer	0.62 to 1.0 (0.2 to 0.3)	1.5 to 4.5 (0.1 to 0.2)	9.0 to 12.0 (0.05 to 0.07)
Disposal	0.2 to 0.6 (0.05 to 0.2)	0.9 to 3.3 (0.05 to 0.2)	9.0 to 30.0 (0.05 to 0.2)

---

**Composition of Solid Waste**

The composition of solid waste depends on a number of factors:

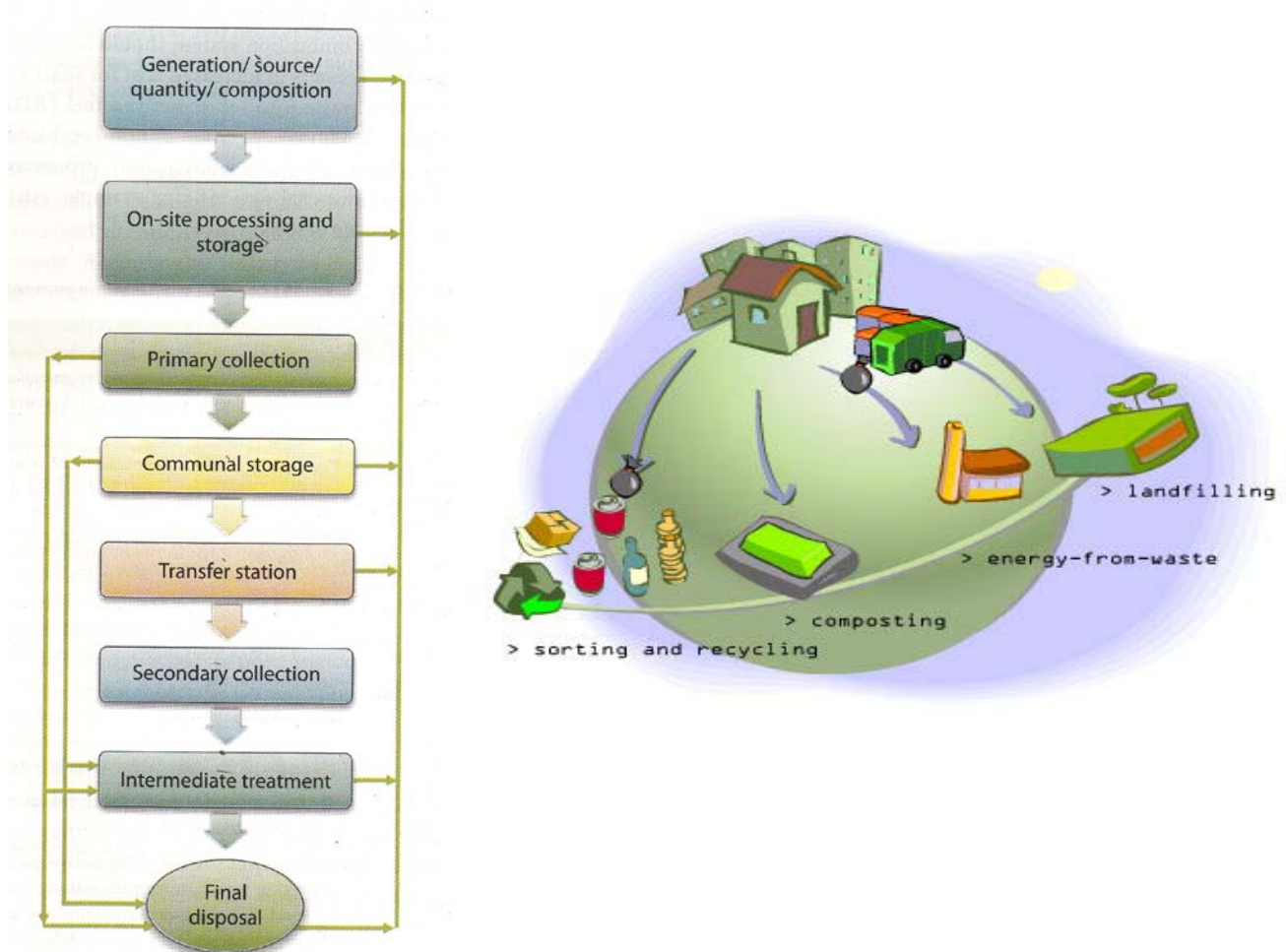
- Living standards, lifestyle, culture, and religious habits of people, availability of resources, geographic location, season of the year, climatic condition, and the like.
- Both industrialized countries and developing countries contain a huge amount of putrescible materials (from the preparation & consumption of foods, papers, paperboard, garden waste and similar materials which decomposes rapidly).
- Industrialized countries contain 55% of putrescible materials of total MSW whereas in developing countries it is 90%.
- Industrialized countries contains higher% of papers than in developing countries.

**Selected material composition (%) of solid waste in industrialized and developing countries:**

City/country	Putrescible including paper	Paper	metal	glass	Plastic,rubber	textiles	Miscellaneous
Bangladesh	66.0-90.0	1.0-7.0	---	---	1.0-4.0	1.0-7.0	7.0-19.0
India,Banglore	76.7	1.5	0.1	0.2	0.9	3.1	19.0
United States	61.6	38.5	7.7	5.5	9.9	6.8	6.0
United Kingdom	53.0	32.0	8.0	9.0	11.0	2.0	8.6

### Functional Elements Included in Solid Waste Management System

- Waste generation/ source
- On-site processing and storage
- Primary collection.
- Communal storage
- Transfer station
- Secondary collection
- Intermediate treatment, recycling, and resource recovery
- Final disposal



**Waste Generation/ Source:**

- Waste generation encompasses activities in which materials are identified as no longer being of value and are either thrown out or gathered together for disposal.

**On-processing and storage Primary collection:**

- Processing (includes separation of waste components and resource/ energy recovery) and storage at or near the point of generation.

**Communal Storage:**

- Picking up of waste from sources by external bodies and transport to transfer station (if any) or closely located disposal sites.
- Collection of waste by community organizations/voluntary organizations from source and transport to communal bins/collected points.

**Transfer Station:**

- Common in low-income countries (for all categories of waste), storage at communal bins, containers or designated places for picking up of solid waste by external organizations.

**Secondary Collection:**

- This element involves two steps:
  - i) The transfer of wastes from the smaller collection vehicle to the larger transport equipment.
  - ii) The subsequent transport of the wastes, usually over long distances, to a processing or disposal site.

**Recycling, processing, resource recovery:**

- Picking up of waste from secondary storage sites ( communal collection points or transfer station) and
- Transport to final disposal sites.
- Includes separation of waste components and resource/ energy recovery at different stages beyond the source of generation.

**Final disposal:**

Treatment plant and /or final destination of waste:

- Landfill is generally considered to be final disposal of wastes (land spreading of all solid wastes, wastes collected and transported directly to a landfill site mostly in developing countries).

- It also receives residual materials from materials recovery facilities (MRFs), residue from the combustion of solid waste (e.g. ash), compost or other substances from various solid waste processing facilities.

### **The waste collection system in Dhaka city**

Dhaka, the capital city of Bangladesh, is the primate city of the country. According to Dhaka City Corporation (DCC) Ordinance, DCC is allowed to provide dustbins or other receptacles at suitable places and to require residents to bring their waste to the dustbins or receptacles. DCC is responsible for secondary waste collection to remove waste from its dustbins/containers and to transport the waste to final disposal sites. Residents are responsible for bringing their waste to DCC's waste collection points where dustbins/containers are located, as shown in Figure 4.3.

When dustbins/containers are placed at far locations, households usually throw their garbage at any convenient point such as roads, ditches, ponds, lakes or surface drains which degrade the environment severely. Therefore, the present system of solid waste management by DCC has been regarded as inadequate and inefficient, especially as its primary collection system is insufficient to collect the total generated waste by the householders.

In order to tackle the waste disposal problem, a house-to-house collection of domestic waste was initiated locally by the community in a private sector. At present, about 150 private organisations are providing house-to-house waste collection services. Usually they use different tricycles/vans (three-wheelers) to collect waste (Figure 4.4). With the help of local people and community participation, these vans collect waste from houses and deposit it at containers. As a result, the overall environmental condition in the local area has improved a lot. However, only some dwellers of the community who can afford to pay for this primary waste collection system benefit directly from this informal system. Therefore, incorporation of local government authority is very important in order to transform this informal system into a formal one so that people from the society can be benefited. Here, it is mentioned that strengthening of local government authority and proper empowerment with transparency is the key to success with this formal primary waste collection system.

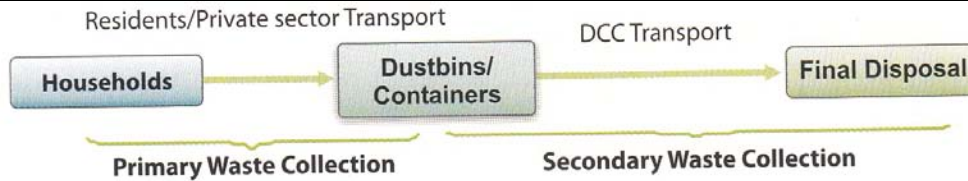


Fig: Waste collection system in Dhaka city

## Energy Generation

Energy can be generated from solid waste in 2 different ways :

- Waste-to-Energy Plants (Incineration or biochemical processing ) :This type of generator burns trash (that would otherwise go to the landfill) to create energy.
- Landfill Gas to Energy (LFGTE): This type of plant gets energy from the gas emitted by the landfill.

Several technologies have been developed that make the processing of MSW for energy generation cleaner and more economical than ever before, including landfill gas capture, combustion, pyrolysis, gasification and plasma arc gasification.

The huge amount of putrescible solid waste can be converted to useful products or energy through combustion or biochemical processing particularly-anaerobic digestion and composting. Biogas originates from biogenic material and is a type of **biofuel**. Biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manures, sewage, municipal waste, green waste, and plant material and energy crops.

In Bangladesh the best possible use of the organic portion of solid waste through biogas generation can supply clean cooking energy for about 50% of total population (Rahman, 1994 and Rahman, 1997).

Composting is nature's way of recycling & is relatively simple to manage. Since approximately 45 - 55% of the waste stream is organic matter, composting can play a significant role in diverting waste from landfills thereby conserving landfill space and reducing the production of leachate and methane gas. In addition, an effective composting program can produce a high quality soil amendment with a variety of end uses.

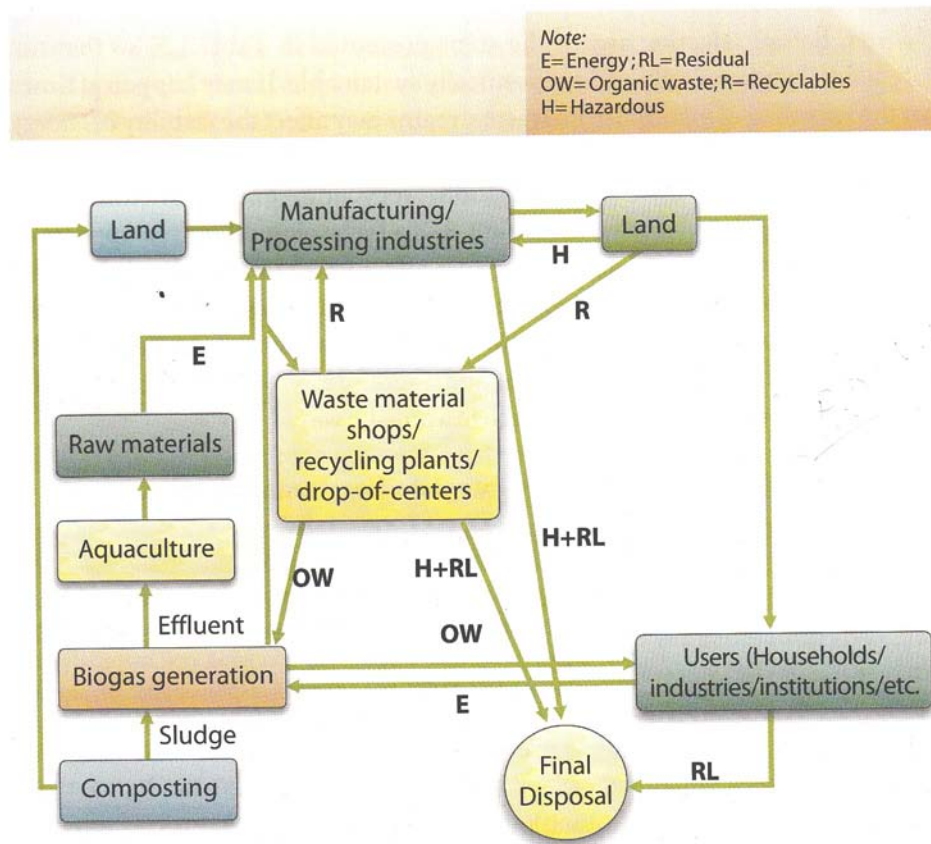


Fig: Proposed recycling and resource recovery system in urban centers

**Rational steps in integrated waste management:**

- Minimize waste and hazard
- Maximize waste recycling and reuse
- Recover energy
- Promote environmentally clean and economically feasible technologies – attempt for cost effectiveness.
- Expand collection and disposal services

**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

**Types of Waste Materials**

Biodegradable materials:

- Degraded easily by microorganisms (either aerobic or anaerobic), into their basic elements.
- Most organic solid wastes are biodegradable.

Putrescible materials:

- Decompose rapidly, particularly in warm weather, and unless carefully controlled, develop objectionable odours.

Non-putrescible material:

- Decompose very slowly.
- Plastic and polythene bags for shopping are classed under this category.

Refuse materials:

- Putrescible and non-putrescible materials wastes that is discarded or rejected including, but not limited to , garbage, rubbish, incinerator residue, street cleaning, dead animals etc.

Leachate :

- Comprises liquids seeping from solid waste as it degrades and decomposes. It generally contains decomposed waste, water and microorganisms.
- In landfills, leachate percolates through soils, causing surface and groundwater pollution.

**Categories of Solid Waste**

- Household-residential
- Commercial/trade

- Institutional
- Treatment plants
- Municipal
- Hazardous
- Healthcare
- And so on.

### **Quantity of Solid Waste**

- The quantity of waste is required to know before attempting to identify appropriate types of collection, waste collection routes and vehicles, material recycling and recovery facilities, and waste treatment and /or disposal facilities.
- The quantity of waste by source of generation is important in establishing collection design and financial strategies.
- The figures on collected waste are more reliable than the figures on waste generation.

### **Rate of Generation**

- The generation of waste calculated as the total collected waste divided by the population.
- The rates of generation are low in low-income countries or communities when compared to the rates of generation in industrialized countries or wealthier communities.
- It changes along its flow path from the generating source to final disposal depending on how much material /resources are recycled or recovered at different stages of the solid waste mgt.

### **Factors affecting the generation rates:**

- Status of development of the country
- Socio-economic conditions
- Availability of resources

- Geographic location
- Attitude of waste generators and / or manufactures.
- Availability and enforcement of laws to regulate waste, and promote recycling and resources recovery.
- Culture
- Season of the year
- Level of technological advancement.

**Table 3.1: Suggested rates of generation of municipal solid waste**

(where reliable data is not available, especially for developing countries)

Source	MSW generation rate (kg/capita/day)
Residential	0.3 – 0.6
Commercial	0.1 – 0.2
Street sweeping	0.05 – 0.2
Institutional	0.05 – 0.2
Industrial	0.1 – 1.0

(Source: Contreau-Levine, 1982)

### Composition of Solid Wastes

Nature and composition of solid waste is essential in selecting:

- Method of storage
- Method and frequency of collection
- Equipment used for collection
- Size of workforce
- Potential for resource recovery
- Choice of method of disposal
- Environmental impact

**Table 3.2: Composition of solid waste in different cities of Bangladesh**

Constituent	% by dry weight	
	Range	Typical
Food waste	65 – 88	78
Paper	1 – 7	3
Plastic, rubber	1 – 4	1.5
Textiles	1 – 7	2.5
Glass, metals, ceramics, grass, other construction material	7 – 19	15

(Source: Rahman and Muyeed, 2010)

- In order to design an effective material recovery and recycle system, knowledge of the individual materials present in the waste stream is as important as the general trend in the quantity.
- To meet this objective, more detailed compositional analyses have been undertaken in some countries. In United States sample data sheet developed for detailed compositional studies.
- Physical, mechanical, chemical and biological properties are important in addition to the composition of waste (presented in sample data sheet) , when organizing effective waste management programs.

**Physical properties:**

1) Density

- Density is the mass occupied by a unit volume of material.
- A high-density volume waste capture system can reduce the volume in a solid waste mgt. significantly reduces the cost of: collection, transportation and final disposal.
- Density plays an important role of choosing the size and nature of collection vehicle, capacity of treatment and disposal facilities (area required for a certain tonnage of storage).

- The densities of waste in countries with low per capita income are high (because they contain a higher proportion of organic material, ashes, soil and relatively small particle) compared to that in industrialized countries.
- Compacting equipment is not required on collection vehicles handling waste from low-income communities where the density of the waste is often high whereas this equipment is essential to reduce the volume of waste in industrialized communities where relatively low-density waste is found.
- The composition of materials and the variations in their shape and size, play an important role in changing the density of a waste stream.
- The bulk density (kg per cubic meter) of waste is generally determined by dividing the total weight of the waste found in the collection container (compacted or uncompacted) by its volume.

#### 2) Moisture content

- The ratio of the amount of water present to the total weight of waste material for a given waste stream. The percentage of moisture content in solid waste is generally determined by one of the following equations:
- Moisture content (wet weight method) =  $100(W_w - W_d)/W_w$
- Moisture content (dry weight method) =  $100(W_w - W_d)/W_d$
- Where,  $W_w$  = wet weight of sample

$W_d$  = dry weight of sample.

#### 3) Size distribution

- Waste is composed of many discrete objects of different sizes. The size of objects may influence the collection and disposal system used, such as diameter of the storage bins.
- Size distribution is important in designing the collection vehicles and mechanical recovery system, and in designing biological treatment methods.
- Size distribution can be measured using manually-manipulated screens and reported as size distribution curves (which represent cumulative percentages of matter passing through increasing screen size.)

## Chemical properties

### 1) Ultimate analysis

- It is an analysis used to ascertain the percentage of each element present in a waste sample.
- It frequently involves the % of the five primary elements shown below:

**Table 3.3: Ultimate analysis of solid waste (percent by weight in dry basis)**

Component	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulphur (S)	Ash (A)
Food waste	49.1	6.6	37.6	1.7	0.2	4.8
Paper (mixed)	43.4	5.8	44.3	0.3	0.2	6.1
Newsprint	49.1	6.1	43.0	0.1	0.2	1.5
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Rubber	77.8	10.4	-	-	2.0	9.8
Plastics	60.0	7.0	23.0	-	-	10.0
PVC	45.2	5.6	1.6	0.1	0.1	47.4
Leather shoes	42.0	5.3	22.8	6.0	1.0	22.9
Textiles	55.0	6.5	31.2	4.5	0.2	2.6
Yard waste	48.7	6.3	37.9	3.0	0.3	3.8
Wood	50.5	6.0	42.4	0.2	0.1	0.8

Source: adapted in part from Kaiser (1978)

- An ultimate analysis comprises a mass balance analysis of chemical and thermal processes. It is apparent that the four elements carbon, hydrogen, oxygen and nitrogen make up the bulk mass of the materials listed and ash contains both residues from the combustion of the organic matter in the waste and in many situations, a percentage of inorganic material.

### 2) Proximate analysis

- Proximate analysis is used to evaluate the combustion properties of solid waste and to determine the possibility of its use in combustion system.
- It frequently involves the determination of moisture content, volatile combustible matter, fixed carbon and ash content.

**Table 3.4: Proximate analysis and calorific value of solid waste**

Component	Proximate analysis, % of weight				Calorific value, kJ/kg		
	Moisture content	Volatiles	Fixed carbon	Ash	As collected	Dry	Moisture/ash free
Paper (mixed)	10.2	76.0	8.4	5.4	15,750	17,530	18,650
News print	6.0	81.1	11.5	1.4	18,550	19,720	20,000
Food waste	78.3	17.1	3.6	1.0	4,170	19,230	20,230
Meat waste	37.7	56.3	1.8	4.2	17,730	28,940	30,490
Grass	75.2	18.6	4.5	1.7	4,760	19,250	20,610
Green logs	50.0	42.2	7.3	0.5	4,870	9,740	9,840
Plants	54.0	35.6	8.1	2.3	8,560	18,580	19,590
Rubber	1.2	84.0	5.0	9.8	25,930	26,230	29,180
Leather shoes	7.5	57.1	14.3	21.1	16,770	18,120	23,500
PVC	0.2	86.9	10.9	2.0	22,590	22,640	23,160

Source: Kaiser (1978)

### 3) Fusing point of ash

- This is the temperature at which the ash resulting from the burning of waste will form a solid clinker by fusion and agglomeration.
- The typical fusion temperatures for the formation of clinker from solid waste range between 1100°C and 1200°C (Tchobanoglous et al., 1993).

### 4) Energy content

- It is essential of an organic fraction of solid waste for evaluating its potential for use as a fuel in a combustion system.
- Determined using bomb calorimeter and estimated by Dulong formula:

$$\text{Energy content (kJ/kg)} = 338.2C + 1430(H - 1/8 O) + 95.4S$$

**PROBLEMS TO SOLVE**

**Example 1:** Determine the energy content/value of a typical sample of municipal solid waste (MSW) of 100 kg with the average composition shown as in the table (3.5) below.

**Table 3.5:** Physical constituents of a typical municipal solid waste sample

Component	Weight (%)
Food waste	32.5
Paper (mixed)	35
News print	5
Cardboard	4
Rubber	0.5
Plastics	3
PVC	0.5
Leathershoe	0.5
Textiles	3
Yard waste	13
Wood	3

**Solution:**

1. Determine the energy value for each of the constituent of MSW using the following equation

$$\text{Energy content (kJ/kg)} = 338.2C + 1430(H - 1/8 O) + 95.4S$$

And the data in Table 3.3, mentioned before.

**Table 3.6:** Energy value for each of the constituents of MSW

Constituent	Energy (kJ/kg)
Food waste	19,342
Paper (mixed)	15,072
News print	17,661
Cardboard	15,365
Rubber	41,375
Plastics	26,191
PVC	23,018
Leathershoe	17,803
Textiles	22,338
Yard waste	18,733
Wood	18,090

2. Determine energy values using a computation table

**Table 3.7:** Computation of energy content for MSW

Constituent	Solid Wastes, (kg)	Energy, (kJ/kg)	Total Energy, (kJ)
Food waste	32.5	19,342	628,615
Paper (mixed)	35	15,072	527,520
Newsprint	5	17,661	88,305
Cardboard	4	15,365	61,460
Rubber	0.5	41,375	20,688
Plastics	3	26,191	78,573
PVC	0.5	23,018	11,509
Leather shoe	0.5	17,803	8,902
Textiles	3	22,338	67,014
Yard waste	13	18,733	243,529
Wood	3	18,090	54,270
<b>Total</b>	<b>100</b>		<b>1,790,385</b>

Now, the energy content for the given MSW sample =  $1790385/100 = 17904$  kJ/kg

**Example 2:** Determine the energy content/value of 100 kg of a typical MSW sample as given in the following table (3.8).

**Table 3.8:** Physical constituents of a typical municipal solid waste sample

Component	Wet mass (kg)	Composition (kg)					
		C	H	O	N	S	Ash
Food wastes	45	13	0.5	2.5	0.5	0.03	1.47
Paper	22	5.5	1.3	6.4	0.71	0.09	1.0
Cardboard	8	3.1	0.31	3.2	0.06	0.03	0.8
Plastics	5	3.3	0.35	1.1	—	—	0.15
Garden trimming	15	1.7	0.65	1.85	0.25	0.01	0.54
Wood	5	2.1	0.21	1.35	0.2	—	0.14
<b>Totals</b>	<b>100</b>	<b>28.7</b>	<b>3.32</b>	<b>16.4</b>	<b>1.72</b>	<b>0.16</b>	<b>4.1</b>

**Solution:**

1. Prepare a summary table of the data provided.

Mass of constituents =  $28.7 + 3.32 + 16.4 + 1.72 + 0.6 + 4.1 = 54.4$  kg

Therefore, moisture content =  $100 - 54.4 = 45.6$  kg

Component	Mass, kg
Moisture	45.6
Carbon	28.7
Hydrogen	3.32
Oxygen	16.4
Nitrogen	1.72
Sulphur	0.16
Ash	4.1

2. Convert the moisture content in step 1 to Hydrogen and Oxygen mass

a. Hydrogen =  $2/18 * 45.6 = 5.06$  kg

b. Oxygen =  $16/18 * 45.6 = 40.53$  kg

3. Prepare a revised summary table computing percentage of the chemical constituents of MSW

Component	Mass, kg	Per cent by mass
Carbon	28.7	28.7
Hydrogen	8.38	8.38
Oxygen	56.93	56.94
Nitrogen	1.72	1.72
Sulphur	0.16	0.16
Ash	4.1	4.1
<b>Total</b>	<b>99.99</b>	<b>100</b>

4. Estimate the energy content of the waste using the following equation and the data from step 3

$$\begin{aligned}\text{Energy content (kJ/kg)} &= 338.2C + 1430(H - 1/8 O) + 95.4S \\ &= 338.2 \times 28.7 + 1430(8.38 - 1/8 \times 56.93) + 95.4 \times 0.16 \\ &= 11,527\end{aligned}$$

### **Methods of Sampling and Measurement**

#### **Factors to be considered choosing sampling points:**

- Proper selection of sampling points and collection of representative samples are both essential in quantifying and characterizing solid wastes.
- Before sampling one should clearly understand the objectives of the analysis (e.g. whether this data will be used to optimize collection vehicles or to plan a disposal system).
- In high-income countries there is, in general, an insignificant change in the quantity and quality of waste in their flow cycle from source to final disposal site. (unless there are intermediate formal recycling or recovery processes). Moreover, it is easy to identify the no. of households served by a particular collection system.
- In low-income and/or middle income countries, due to extensive informal recycling, quantities and characteristics of solid waste vary widely. Often it is difficult to identify the no. of waste generators and the origin of the waste (household, industrial, commercial, etc). Even municipal cleaners (involved in street cleaning) are observed to dispose of their collected waste into communal waste storage bins or storage points.
- The moisture content of waste collected from open storage bins may not be representative, and will depend on the prevailing weather conditions.

#### **Methods used in determining the quantity, the composition & the physico-chemical properties of solid waste are:**

1. household survey methods
2. load-count methods

### 3. material balance methods

#### Variations in quantity & composition of solid waste

- The quantity of waste generated varies from country to country, city to city and even from generator to generator.
- The quantity and composition of household waste varies with population density as well as with the people's living standards.
- The amount of commercial waste varies with the nature of local commerce.

The UK Institute of waste mgt (c.1992) reported the significant changes with time in the quantities and composition of solid waste in UK (table below)

**Table 3.9: Composition of household waste in UK**

Composition	% by weight		
	1933	1967	1992
Fines including ash	56.9	21.9	3.9
Putrescible	13.7	17.6	32.0
Paper/cardboard	14.3	36.9	29.0
Metals	4.0	8.9	6.2
Textiles	1.9	2.4	3.0
Glass	3.4	9.1	7.3
Plastic	nil	1.1	10.1
Miscellaneous	5.8	2.1	8.5

#### Forecasting future waste quantities

- An assessment of probable quantities and composition of waste to be handled is essential when planning, designing, financing, and regulatory decision -making of a waste mgt. system.
- To provide an accurate estimate of future waste quantities, the planner or designer should consider the changes over time for a wide range of factors including:

- ❖ Rate of population growth
  - ❖ Waste generation rate
  - ❖ Waste characteristics
  - ❖ Degree of commercial and industrial development
  - ❖ per capita consumption
  - ❖ Future policy directives and their effect on waste mgt. practices
- 
- There are many models for estimating the quantity and characteristics of waste in industrialized countries as for example mathematical models.
  - In developing countries due to lack of such data, they commonly used to extrapolate the per capita daily waste generation rates into the future.
  - More recently the macro-economic factors that cause, or drive, changes in waste generation have been used as a basis for predicting the quantity of waste that is likely to be generated in the future. The factors are:
    - ❖ Population and the waste generation per capita
    - ❖ Income
    - ❖ Gross national product (GNP)
    - ❖ Personal consumption expenditure (PCE)

**Reference book:**

Solid and Hazardous Waste Management – M. Habibur Rahman and Abdullah Al-Muyeed

**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

**Functional Elements of Integrated Solid Waste Management**

- (1) Waste minimization and hazard reduction
- (2) On-site processing and storage

**(1) Source Reduction:**

- Source reduction means reducing the amount and /or toxicity of waste before it enters the municipal waste management system or is discharged into the environment.
- At the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, (Agenda 21) an agreement among the participating nations emphasized that reducing waste and maximizing environmentally sound waste, recycling and reuse should be the first step in waste management.
- The term “**Source Reduction**” is used to describe waste minimization, waste utilization and hazard reduction at source.
- **Waste minimization** refers to waste avoidance through the actions of the waste generators to avoid generating solid waste.
- **Waste utilization** comprises actions that make the waste a useful product or raw material for other processes, eliminating the need for disposal.
- **Hazard reduction** means finding ways to reduce the toxicity of waste.

**Significance of Source Reduction:**

Source reduction has a significant impact on a waste management system, as it reduces both the quantity and the toxicity of the waste. It helps to promote the efficient use of discarded products and resources, as they have not been contaminated by the toxic or contaminated waste removed at source. This saves the cost of construction, operation and maintenance of centralized waste treatment and disposal options.

**It has other beneficial consequences in relation to climate change issues:**

1. It reduces the consumption of energy through reuse of goods by consumers and use of minimum quantities of materials in industry. This leads to the production of fewer

products, which ultimately saves the energy required to collect raw materials, to produce the products, and to transport them to the consumers.

2. Emissions at treatment and disposal sites are reduced.
3. Pressure on vegetative cover and trees are decreased as source reduction minimizes the demand for raw materials for new products.

**Advantages of source reduction and on-site processing-**

- Generation of clean recyclable material
- Removal of hazardous material from general waste streams in order to minimize health risks to the general population, particularly the waste handlers
- Improved working condition within waste recycling plants
- Improved efficiency of energy recovery processes. It helps to operate the waste treatment system cost-effectively
- Improved quality of end-products
- Minimization of overall waste management cost

**Main strategic options to minimize waste as well as reduce hazards at source:**

- Decreasing consumption of products
- Resource recovery
- Reduction of toxicity
- Awareness development

**Table 4.1:** Main strategic options for waste minimization and hazard reduction at source

Option	Examples
Decreased consumption of products	<ul style="list-style-type: none"> <li>• reducing the amount of materials required per unit service or process</li> <li>• packaging of product with minimum quantity of materials</li> <li>• choosing recyclable products</li> <li>• buying in bulk</li> <li>• buying concentrated products (e.g. liquids and foodstuffs) to reduce the number of containers</li> <li>• using re-usable (long-life) products such as shopping bags</li> <li>• reducing use of disposable goods such as lunch packs, disposable razors, pens, etc.</li> <li>• maintaining and repairing appliances</li> <li>• borrowing, renting or sharing items not required frequently</li> <li>• selling or donating reusable goods</li> </ul>
Resource recovery	<ul style="list-style-type: none"> <li>• Reducing the amount of materials required per unit process or for packaging of a product in industry, saves virgin raw materials or other goods in that it saves energy and the resources required to collect and mobilise them</li> <li>• managing organic wastes at source, and recovering the energy and nutrients, through home composting, anaerobic digestion, etc.</li> <li>• using products made from recycled materials</li> </ul>
Reduction of toxicity	<ul style="list-style-type: none"> <li>• buying materials with less toxic content</li> <li>• in industry, manufacturing and packaging products with materials of less toxic content</li> </ul>
Awareness	<ul style="list-style-type: none"> <li>• Educating the public to make people fully aware of the importance of source reduction and ways in which they can do it</li> </ul>

**(2) On-site Processing:**

On-site processing includes separation of components and treatment of solid wastes at or near the source of generation. The key concepts around on-site processing are:

- Resource recovery to generate less waste
- Hazard reduction
- Separation of different fraction of waste

**Significance of On-site Processing:**

- On site processing is one of the most effective and sustainable ways to achieve resource recovery.
- It reduces hazards and diverts different fractions of material present in the waste stream to locations for appropriate treatment in the solid waste mgt.
- It reduces the quantity of general waste and minimizes the toxicity of the general waste stream (if hazardous materials are diverted).
- It minimizes the cost of the operation and reduces maintenance problems of biological - treatment and recycling technologies. The economic viability of most biological treatment options largely depends on separation of waste materials at source.
- Without sorting at source, expensive pre-sorting and final refining technologies are required in central treatment plants to process mixed wastes.
- Within an industrial setting, on-site processing reduces waste treatment costs, minimizes the regulatory burden and maximizes production economics.

**Source Separation and Collection System in Developed Countries Vs Developing Countries:**

- Most developed cities or countries (North America, Australia, Japan, Korea etc) have adopted municipally – sponsored source separation and collection system. In some cases, separation of post-consumer materials by waste generators has been made mandatory (IETC, 1996).
- For example, in Japan and Australia, cities have implemented laws and regulations governing disposal that bans substances such as batteries, tires, waste oil, CFC gases, etc. In Japan, to ensure that separation of waste is carried out properly; households are required to use transparent plastic bags for waste disposal, so that collection crews can easily identify the contents.
- In many developing countries a large number of people who are involved in informal waste trading, resource recovery and waste processing are exposed to severe health risks. They often lack of technological and financial resources needed to improve their traditional systems.
- In many instances, the most common problem in the poorer parts of the developing world is that there is a considerable overlap between administrative and enforcement authorities concerning environmental control, particularly in the field of waste mgt.

---

**Collection Systems Based on Common Practices:**

**Mixed (commingled) materials:**

- ❖ The most traditional system, involves collection of all (non- separated) wastes from residential and commercial establishments as well as from industrial enterprises.
- ❖ External actors either collect mixed waste from the source of generation, or the waste generators are responsible for bringing their waste to communal collection points or containers.

**Source separated materials:**

- ❖ Waste material that have been separated at source are collected and transported to recycling and resource recovery facilities which generally done by formal sectors in industrialized countries and
- ❖ This task is often done by the informal sectors in poorer parts of the developing countries or by the waste generators who are responsible for bringing their waste to communal collection points or containers designated for different fractions of the waste.
- ❖ A common practice in industrialized countries is for the generators to be responsible for delivering selected separated materials and bulky waste (furniture, garden waste etc) to drop-off centers and buy-back centers.
- ❖ If external factors involved in the collection system, then color coded bags, bins or roll-out containers are given to the waste generators for sorting appropriate fractions of waste for collection by external actors.

**Waste collection containers and box:**



**Communal bin:**



**Processing and collection methods for some of the commonly on-site recyclable and recoverable materials:**

**(1) Dry recyclable materials**

- ❖ Collection of dry recyclable (paper, glass, metal, and plastic) is common both in industrialized and developing countries. In industrialized countries, a single –material or mono-material bank is one of the most popular forms of material recovery process. In Europe using this method high levels of glass recovery have been achieved. Similar examples can be seen in Bangladesh that customers are required to pay a deposit for the bottles when buying beverages. They get back the money when the empty bottles are returned (Rahman, 1993).
- ❖ Collection of mixed dry recyclables either from communal collection points (particularly from high rise buildings) or from the other sources of waste generation, is practiced in some countries which leads further expensive sorting at material recovery facilities.

**(2) Biodegradable materials:**

- ❖ In industrialized and developing countries a substantial parts of wastes is biodegradable organic wastes .The digestion of these waste, particularly at landfills, produces a very strong leachate and greenhouse gases and become a great threat to the environment but represent a significant source of renewable energy.

- ❖ In waste treatment technologies based on establishing a natural eco-balance, composting and fermentation should be the main routes for the treatment of waste containing organic matter. The organic fraction of solid waste can be used for biogas generation, aquaculture and / or composting and these techniques can be applied near or at the source of generation (e.g, anaerobic digestion, home composting). If this waste is not treated on –site, it can be treated at a central treatment unit.
- ❖ In the UK, the community Composting Network (CCN) is actively involved in popularizing home composting of source-separated biodegradable material, using a home composting bin for kitchen waste.



**Fig.** Green bin used in home composting

### **(3) Hazardous materials:**

- ❖ Hazardous waste contains materials which are difficult to dispose of or which put human health or environment at risk because of their chemical or biological nature.
- ❖ It includes tubes, batteries, bulbs, lubricating oil, coatings, decorative paints, tires, pharmaceutical, refrigerants etc.
- ❖ These wastes are found in relatively small quantities compared to the total volume of household waste, their presence significantly influences the available treatment options and the market for end products. It is therefore very important to handle the hazardous wastes separately.
- ❖ In developing countries a large fraction of hazardous substances (like batteries, tyres, paints, pharmaceuticals etc) escape the waste stream, mostly because of their waste

trading. Whereas in Industrialized countries attention has been given to separate these materials.

- ❖ Hazardous wastes from other sources such as commercial or trade premises, civic amenity services, treatment plants and construction and demolition sites contain materials similar to those found in household hazardous waste. These fractions of wastes are small but potentially highly polluted for human and environment whose separation at source can minimize the costs of waste treatment. If these wastes are not treated on-site, can be treated on at a central treatment unit, but increase the overall waste mgt. costs.

### PROBLEMS TO SOLVE

**Example 1: Effect of home recovery on energy content of collected solid wastes**

Using the typical percentage distribution data given in **Table 3.5 (Lecture 2)**, estimate the energy content of the remaining solid wastes if 80% of the cardboard, 70% of the paper and 90% of the wood is recovered by the homeowner.

**Solution:**

From Lecture 2 (Example 1) -

**Table 3.7:** Computation of energy content for MSW

Constituent	Solid Wastes, (kg)	Energy, (kJ/kg)	Total Energy, (kJ)
Food waste	32.5	19,342	628,615
Paper (mixed)	35	15,072	527,520
Newsprint	5	17,661	88,305
Cardboard	4	15,365	61,460
Rubber	0.5	41,375	20,688
Plastics	3	26,191	78,573
PVC	0.5	23,018	11,509
Leather shoe	0.5	17,803	8,902
Textiles	3	22,338	67,014
Yard waste	13	18,733	243,529
Wood	3	18,090	54,270
<b>Total</b>	<b>100</b>		<b>1,790,385</b>

Now, the energy content for the given MSW sample of 100 kg = 1790385 kJ

Energy content by 80% cardboard =  $0.8 \times 61460 = 49168$  kJ

Weight of 80% cardboard =  $0.8 \times 4 = 3.2$  kg

Energy content by 70% paper =  $0.7 \times 527520 = 369264$  kJ

Weight of 70% paper =  $0.7 \times 35 = 24.5$  kg

Energy content by 90% wood =  $0.9 \times 54270 = 48843$  kJ

Weight of 90% wood =  $0.9 \times 3 = 2.7$  kg

Now, the total energy after recovery =  $1790385 - 49168 - 369264 - 48843$   
= 1323110 kJ

Total weight after salvage =  $100 - 3.2 - 24.5 - 2.7 = 69.6$  kg

Energy content per kg after recovery =  $1323110 / 69.6 = \mathbf{19010}$  kJ/kg

### **Implementation of source reduction and on-site processing:**

Source reduction and on-site processing can be effectively implemented by raising public awareness (through education programs, legislation, etc) to change the behavior of consumers and industries, and to place the responsibility for certain products on manufactures (product-stewardship) throughout the products entire life cycle including its disposal.

**The success of source reduction and on-site processing depends primarily on:**

1. Competence of waste generators
2. Motivation of waste generators
3. Economic incentives
4. Convenience
5. Environmental education
6. Legislation

**1. Competence (Ability) of waste generators:**

- Home composting and biological treatment of organic waste is promoted in some communities to reduce the quantity of waste.
- It is evident from Forrest et al.(1990) that households in Leeds, UK are able to sort their waste into six different categories with a 96.5% success rate. A survey was conducted on 43 municipalities in Italy where the dominant (paper & compostable organic waste) were separated at source and excellent quality of material was collected (97% to 99% compostable).
- This eliminated the need for expensive pre-sorting and final refining technologies in central composting plants (Warmer, 2000e).

**2. Motivation of waste generators:**

- It is apparent from the waste prevention and minimization study undertaken for the European Commission's Environment Directorate that many industrial sectors independently initiate voluntary measures to reduce the hazardous nature or quality of the waste they generate (Warmer, 2000d).As a part of solid waste minimization schemes (White et al., 1996), production improvement as well as product changes have been introduced by many companies. These measures include internal recycling of materials & on-site energy recovery.

**3. Economic incentives:**

- Warmer (2000e) has shown that economic incentives reduce garbage collection quantities, and simultaneously increase ways in which waste is used. Informal recycling, in poorer parts of developing world, is very effective because of waste trading.

**4. Convenience:**

- It is evident from Lardinios and Furedy(1999) that daily collection of separated organic wastes was considered more important in Hanoi than incentive such as bins or even payments.

**5. Environmental education:**

- Effective public education & participatory programs always improve public involvement and motivate waste generators to cooperate with waste mgt. policies and services.

- They may also change traditional waste disposal habits, encourage source reduction and on-site processing and thus increase waste mgt. efficiency.

#### **6. Legislation:**

- Legislation action (with proper enforcement) can be used to improve waste mgt. practices. For example, legislation in Italy provided a strong impetus to overhaul waste mgt. systems.

#### **Calculation of Source Reduction:**

- Source reduction for a given period of time involves the following formula:

***Source reduction=(projected waste generation at a given time) – ( actual waste generation at that time)***

- For a small community, this can be measured by conducting a survey at the source of waste generation for a given period of time.
- For nationwide information, the estimate generally involves the calculation of the difference between the amount of waste generated during a given period and the actual amount of waste generated during the period.

#### **On-site storage:**

- On-site storage is essential to contain waste prior to their collection. Solid waste may be generated at source on a continuous basis throughout the day and night.
- The effectiveness and efficiency of a particular collection system largely depends on the method of storage of solid waste at the point of collection.
- It is generally collected by external actors once a week (particularly in cold climate) or at some other appropriate interval depending on the quantity and type of waste and also the climate.

#### **On-site storage of solid waste is influenced by a number of factors including:**

- Type of storage containers used
- Location of storage containers

- Public health and aesthetics
- Availability of resources for waste mgt.
- Available methods for waste collection & further transportation.

**Storage at source or near source of generation may be broadly classified as:**

1) Individual storage on premises – in high income and low-density areas, individual closed storage containers placed on the premises may be a more feasible option for storing waste materials.

2) Communal storage – in high-density areas, communal (large) container storage may be a more realistic option. These containers can be split into compartments to accommodate different fractions of waste.

**Present practices of on-site storage:**

- ❖ At present both standardized (more common in industrialized countries) and non-standardized (more common in poorer parts in developing countries) storage containers are used to store waste materials at or near the source of generation.
- ❖ In industrialized countries, for single family residential sources, materials are collected from the household in paper or plastic bags (sacks), or from paper or plastic bags placed in a plastic or metal dustbin. Sometimes a paper or plastic is used within a metal or wooden frame.
- ❖ The size and location of storage containers depends on the type of available collection services. Rollout containers (wheeled containers) are used. Sizes of containers vary from 20 gallons to 50 gallons. The special rollout containers of 75 gallons to 120 gallons capacities are used as a part of a mechanized collection system. A wide range of container volume varying from  $0.4\text{m}^3$  to  $30\text{m}^3$  is used.
- ❖ For recyclable materials, special containers, such as “blue boxes” or large wheeled blue or green bins are used to store waste materials at or near the source of generation.
- ❖ In many developing countries communal storage facilities are common; they are used to store domestic, commercial, and industrial waste.

- ❖ They include containers or enclosures ( both fixed or movable) made of concrete , brick, metal, and wood and have capacities from 0.5 m<sup>3</sup> to 10.0 m<sup>3</sup>. Empty oil drums and sections of wide-bore pipes are used in certain localities.
- ❖ Small storage containers can be made from truck tyres and plastic and galvanized steel bins. They have capacities ranges from 7.5 gallons to 50 gallons.
- ❖ Plastic buckets, boxes, clay pots, concrete or brick vats, temporary containers are used also; they have capacities from 2 to 5 gallons.
- ❖ In many places in the poorer parts of the developing world, waste materials are simply heaped on the street or on the ground because of the dearth or cost of containers.

**Design of Storage Containers:**

General considerations:

- ❖ Nature of waste
- ❖ Capacity margin
- ❖ Compatibility
- ❖ Standardization
- ❖ Efficiency
- ❖ Convenience
- ❖ Public health
- ❖ Social
- ❖ Cost
- ❖ Ownership

**Capacity margin:**

The design and selection of containers requires that an allowance that 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. As for example:

holidays and short periods after them usually give rise to significant surges in waste generation.

**Size of storage containers:**

- Size of storage containers ( $m^3$ ) =  $(N * G * F) / D$  + capacity margin

Where,

N=number of population served (nos, cap)

G=average rate of waste generation (kg/cap/day)

F=weekly frequency of collection(=7 days/ numbers of collection trip)

D=density ( $kg/m^3$ )

**Table 4.2:** Capacity margin of storage container

Collection per week	Excess capacity required (%)		
	Individual	Communal	
		Attended	Unattended
6	66	66	100
7	33	33	50

**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

**Mathematical Problems on Physical Properties of MSW**

Table 10-3 Typical composition of municipal solid wastes

Component	Percent by mass			
	Range	Typical	Davis California*	Merida, Venezuela†
Food wastes	6-26	14	8.3	27.4
Paper	15-45	34	35.8	15.5
Cardboard	3-15	7	10.9	13.0
Plastics	2-8	5	6.9	4.6
Textiles	0-4	2	2.5	2.3
Rubber	0-2	0.5	2.5	0.4
Leather	0-2	0.5	0.7	1.3
Garden trimmings	0-20	12	10.8	5.8
Wood	1-4	2	1.9	3.6
Misc. organics	0-5	2	2.0	0.6
Glass	4-16	8	7.5	10.3
Tin cans	2-8	6	5.1	8.3
Nonferrous metals	0-1	1	1.6	0.1
Ferrous metals	1-4	2	2.2	1.2
Dirt, ashes, brick, etc.	0-10	4	1.3	5.6

\* Based on measurements made during the month of October over a 5-year period (1978 through 1982).

† Based on measurements made during the month of July over a 3-year period (1978 through 1980).

Table 10-4 Typical data on moisture content of municipal solid waste components

Component	Moisture, percent	
	Range	Typical
Food wastes	50-80	70
Paper	4-10	6
Cardboard	4-8	5
Plastics	1-4	2
Textiles	6-15	10
Rubber	1-4	2
Leather	8-12	10
Garden trimmings	30-80	60
Wood	15-40	20
Misc. organics	10-60	25
Glass	1-4	2
Tin cans	2-4	3
Nonferrous metals	2-4	2
Ferrous metals	2-6	3
Dirt, ashes, brick, etc.	6-12	8
Municipal solid wastes	15-40	20

Source: From Tchobanoglous et al. [10-5]

**Moisture Content of MSW**

$$\text{Moisture content (\%)} = \left( \frac{a-b}{a} \right) \times 100 \dots\dots\dots (5.1)$$

Where, a = initial mass of sample a delivered = wet mass

b = mass of sample after drying = dry mass

**Example 5.1:** Estimate the moisture content of a solid waste sample with the following composition

Component	Percent by mass
Food wastes	15
Paper	45
Cardboard	10
Plastics	10
Garden trimmings	10
Wood	5
Tin cans	5

**Solution:**

(1) Calculating dry mass

Component	Percent by mass	Moisture content, %	Dry mass,* kg
Food waste	15	70	4.5
Paper	45	6	42.3
Cardboard	10	5	9.5
Plastics	10	2	9.8
Garden trimmings	10	60	4.0
Wood	5	20	4.0
Tin cans	5	3	4.9
			79.0

\* Based on 100-kg sample of waste.

**Note:**

- The moisture contents (%) are taken from typical moisture content values in **Table 10-4**, mentioned before.
- Dry masses are calculated using **equation 5.1**, mentioned before. For example – for food waste,

$$\text{Dry mass} = 15 - \frac{70 \times 15}{100} = 4.5 \text{ kg}$$

(2) Determining moisture content

$$\text{Moisture content} = \left( \frac{100 - 79}{100} \right) \times 100 = \mathbf{21\%}$$

**Density of MSW**

Table 10-5 Typical densities for solid wastes components and mixtures

Item	Density, kg/m <sup>3</sup>	
	Range	Typical
<b>Component*</b>		
Food wastes	120-480	290
Paper	30-130	85
Cardboard	30-80	50
Plastics	30-130	65
Textiles	30-100	65
Rubber	90-200	130
Leather	90-260	160
Garden trimmings	60-225	105
Wood	120-320	240
Misc. organics	90-360	240
Glass	160-480	195
Tin cans	45-160	90
Nonferrous metals	60-240	160
Ferrous metals	120-1200	320
Dirt, ashes, brick, etc.	320-960	480
<b>Municipal solid wastes</b>		
Uncompacted	90-180	130
Compacted	180-450	300
(in compactor truck)		
In landfill	350-550	475
(compacted normally)		
In landfill	600-750	600
(well-compacted)		

\* Data for components is on an as-discarded basis.

**Example 5.2:** Estimate the “as-discarded density” (without compaction) of a solid waste sample with the following composition

Component	Percent by mass
Food wastes	15
Paper	45
Cardboard	10
Plastics	10
Garden trimmings	10
Wood	5
Tin cans	5

**Solution:**

Components	Percent by mass	Mass (kg)	Typical density (kg/m <sup>3</sup> )	Volume * (m <sup>3</sup> )
Food waste	15	150	290	0.52
Paper	45	450	85	5.29
Cardboard	10	100	50	2.00
Plastic	10	100	65	1.54
Garden trimmings	10	100	105	0.95
Wood	5	50	240	0.21
Tin cans	5	50	90	0.56
				11.07

\*Based on a 1000 kg sample of waste

Density of the sample =  $1000/11.07 = 90.33 \text{ kg/m}^3$

**Mathematical Problems on Chemical Composition of MSW**

**Energy content (dry basis)**

$$\text{kJ/kg (dry basis)} = \text{kJ/kg (as discarded)} \frac{100}{100 - \% \text{moisture}} \dots\dots\dots (5.2)$$

**Energy content (ash-free dry basis)**

$$\text{kJ/kg (ash-free dry basis)} = \text{kJ/kg (as discarded)} \frac{100}{100 - \% \text{ash} - \% \text{moisture}} \dots\dots\dots (5.3)$$

**Table 10-6 Proximate and ultimate chemical analysis of municipal solid waste**

	Value, percent*	
	Range	Typical
Proximate analysis		
Moisture	15-40	20
Volatile matter	40-60	53
Fixed carbon	5-12	7
Noncombustibles	15-30	20
Ultimate analysis (combustible components)		
Carbon	40-60	47.0
Hydrogen	4-8	6.0
Oxygen	30-50	40.0
Nitrogen	0.2-1.0	0.8
Sulfur	0.05-0.3	0.2
Ash	1-10	6.0
Heating value†		
Organic fraction, kJ/kg	12,000-16,000	14,000
Total, kJ/kg	8,000-12,000	10,500

\* By mass.  
† As-discarded basis.

Table 10-7 Typical data on inert residue and energy content of municipal solid wastes

Component	Inert residue,* percent		Energy, † kJ/kg	
	Range	Typical	Range	Typical
Food wastes	2-8	5	3,500-7,000	4,650
Paper	4-8	6	11,600-18,600	16,750
Cardboard	3-6	5	13,950-17,450	16,300
Plastics	6-20	10	27,900-37,200	32,600
Textiles	2-4	2.5	15,100-18,600	17,450
Rubber	8-20	10	20,900-27,900	23,250
Leather	8-20	10	15,100-19,800	17,450
Garden trimmings	2-6	4.5	2,300-18,600	6,500
Wood	0.6-2	1.5	17,450-19,800	18,600
Misc. organics	2-8	6	11,000-26,000	18,000
Glass	96-99†	98	100-250	150
Tin cans	96-99+	98	250-1,200	700
Nonferrous metals	90-99+	96		
Ferrous metals	94-99+	98	250-1,200	700
Dirt, ashes, brick, etc.	60-80	70	2,300-11,650	7,000
Municipal solid wastes			9,300-12,800	10,500

\* After combustion.

† As-discarded basis.

**Example 5.3:** Estimate the energy content of a solid waste sample with the following composition. What is the content on a dry basis and on an ash-free dry basis?

Component	Percent by mass
Food wastes	15
Paper	45
Cardboard	10
Plastics	10
Garden trimmings	10
Wood	5
Tin cans	5

**Solution:**

(i) Total as-discarded energy content

Component	Percent by mass	Energy,* kJ/kg	Total energy,† kJ
Food waste	15	4,650	69,750
Paper	45	16,750	753,750
Cardboard	10	16,300	163,000
Plastics	10	32,600	326,000
Garden trimmings	10	6,500	65,000
Wood	5	18,600	93,000
Tin cans	5	700	3,500
			1,474,000

\* From Table 10-7, as-discarded basis.

† Based on 100-kg sample of waste.

(ii) Energy content on a dry basis

Moisture content of the sample = 21 % (From **Example 5.1**)

$$\text{Energy content on a dry basis} = 14740 \frac{100}{100 - 21} = 18658 \text{ kJ/kg}$$

(iii) Energy content on an ash-free dry basis

Let, ash content = 5%

$$\text{Energy content on ash-free dry basis} = 14740 \frac{100}{100 - 5 - 21} = 19919 \text{ kJ/kg}$$

**Chemical Content**

Modified Dulong Formula:

$$\text{Energy Content (kJ/kg)} = 337C + 428\left(H - \frac{O}{8}\right) + 95S \dots\dots\dots (5.4)$$

Where, C = carbon content

H = hydrogen content

O= oxygen content

S = sulfur content

**Table 10-8 Typical data on ultimate analysis of the combustible components in municipal solid wastes**

Component	Percent by mass (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastic	60.0	7.2	22.8	—	—	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	—	2.0	—	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Garden trimmings	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Misc. organics	48.5	6.5	37.5	2.2	0.3	5.0
Dirt, ashes, brick, etc.	26.3	3.0	2.0	0.5	0.2	68.0

*Source:* From Tchobanoglous et al. [10-5]

**Example 5.4:** Derive an approximate formula for the organic portion of a solid waste sample with the composition given below

Component	Percent by mass
Food wastes	15
Paper	45
Cardboard	10
Plastics	10
Garden trimmings	10
Wood	5
Tin cans	5

**Solution:**

Step (1) Computation of the chemical composition of the waste sample

Component	Wet mass, kg	Dry mass, kg	Composition, kg					
			C	H	O	N	S	Ash
Food wastes	15	4.5	2.16	0.29	1.69	0.12	0.02	0.23
Paper	45	42.3	18.40	2.54	18.61	0.13	0.08	2.54
Cardboard	10	9.5	4.18	0.56	4.24	0.03	0.02	0.48
Plastics	10	9.8	5.88	0.71	2.23	—	—	0.98
Garden trimmings	10	4.0	1.91	0.24	1.52	0.14	0.01	0.18
Wood	5	4.0	1.98	0.24	1.71	0.01	—	0.06
Totals	95	74.1	34.51	4.58	30.00	0.43	0.13	4.47

Step (2) Summary of mass data

Component	Mass, kg
Moisture	20.9*
Carbon	34.51
Hydrogen	4.58
Oxygen	30.00
Nitrogen	0.43
Sulfur	0.13
Ash	4.47

\* (95.0 – 74.1).

**Step (3) Converting the moisture content to hydrogen and oxygen**

Hydrogen =  $(2/18) \times 20.9 = 2.32 \text{ kg}$

Oxygen =  $(6/18) \times 20.9 = 18.58 \text{ kg}$

**Step (4) Revised mass data summary**

Component	Mass, kg	Percent by mass
Carbon	34.51	36.3
Hydrogen	6.90	7.3
Oxygen	48.58	51.1
Nitrogen	0.43	0.5
Sulfur	0.13	0.1
Ash	4.47	4.7
Total	95.02	100.0

**Step (5) Computing molar composition of elements**

Element	Mass, kg	kg/mol	Moles
Carbon	34.51	12.01	2.873
Hydrogen	6.90	1.01	6.832
Oxygen	48.58	16.00	3.036
Nitrogen	0.43	14.01	0.031
Sulfur	0.13	32.06	0.004

**Step (6) Determining the approximate chemical formula with and without sulfur**

**(a) Computing normalized mole ratios**

Element	Mol ratios	
	Sulfur = 1	Nitrogen = 1
Carbon	718.2 $\left(\frac{2.873}{0.004}\right)$	92.7 $\left(\frac{2.873}{0.031}\right)$
Hydrogen	1708.0 $\left(\frac{6.832}{0.004}\right)$	220.4 $\left(\frac{6.832}{0.031}\right)$
Oxygen	759.0	97.9
Nitrogen	7.8	1.0
Sulfur	1.0	0

(b) Chemical formula with sulfur :  $C_{718.2}H_{1708}O_{759}N_{7.8}S$

(c) Chemical formula without sulfur :  $C_{92.7}H_{220.4}O_{97.9}N$

Step (7) Estimating energy content of the waste

$$\text{Energy content } kJ / kg = 337(36.3) + 1428 \left( 7.3 - \frac{51.1}{8} \right) + 95(0.1)$$

[Using equation **5.4** and values from **Step 4**]

$$= 12233 + 1303 + 9.5 = 13546$$

**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

**Waste Collection System:**

Solid Waste collection system (by external stakeholders) involves collection of waste from its various sources or from communal storage facilities and transportation of this waste into collection vehicles and unloading of waste from collection vehicles at communal collection points, processing places, transfer stations and final disposal sites.

This system is the largest cost functional element in most municipal solid waste management systems whereas its efficient management can result in significant cost savings.

**Classification of Collection System:**

The following divisions of collection systems may help the solid waste manager to optimize the design and operation of collection services more efficiently, particularly if a wide range of collection vehicles is required.

They are:

1. Primary collection
2. Secondary collection

**1. *Primary Collection System:***

The first stage of collection system which involves the transportation of collected waste from or near the source of generation by external stakeholders to the final disposal sites but more often it involves transportation to communal collection bins or points, processing or transfer station.

Although this service is not common in poorer parts of the developing world, but increasing no. of micro enterprises and (or) community based organizations forming in wealthier communities (both in industrialized and developing countries) perform this task.

**2. *Secondary collection System:***

It involves the collection of waste from communal bins, storage points or transfer station and transportation to the final disposal site.

Solid waste collection systems are classified on the basis of the availability of collection services, the mode of operation and type of waste materials collected.

The basic collection scheme on the basis of availability of services is categorized into four groups. They are:

Communal system

Block system

Kerbside/ Alley collection

Door- to -door collection

**Communal system:**

This system is common (for all categories of waste) in low-income countries where cost savings is more important than service provision, as this system reduces considerably the no. of collection points. In this system waste generators are responsible for bringing their waste to one or no. of (if a separate collection system exists for different fractions of solid waste) communal collection points or bins.

The principal disadvantages of this system is that containers or collection points are located in a public place which in many situations , leads to indiscriminate disposal of waste outside the container.

Hence, the economy of this system mostly depends on public-co-operation. It is therefore essential to pay more attention to improving the design, operation & maintenance practices of a communal system to increase public acceptance and to optimize the productivity of this system.

Communal systems in many industrialized countries are common for a selected fraction of waste materials such as waste generators are expected to bring their bulky items (furniture or household electrical appliances) & garden waste to central collection sites, material banks & drop-off centers. The use of portable storage containers maximizes the productivity of labour and vehicle of such collection system.

**Block Collection:**

Waste generators are responsible for bringing their waste to collection vehicles (vehicles follow a predetermined route at prescribed intervals) at the time of collection. The collection vehicles generally stop at all street intersections or selected collection points & a bell is rung on their arrival so people can bring their waste to the collection vehicles.

This system has low to medium labour and vehicle productivity, but it minimizes the spread of waste on streets.

A regular and well organized collection services is essential so that generators know exactly when to bring out their waste.

**Kerbside/Alley Collection Method:**

Waste generators place the waste containers or bags (sacks) on the kerb or in the alley on a specific day (or specific days) for collection by external actors. They retrieve their containers from the kerb or alley after the waste has been collected.

This method is most common in industrialized countries and in the wealthier communities of some developing countries.

A regular and well organized collection service is essential so that generators know exactly when to leave out their waste. In case of irregular collection, generators may place their storage container permanently at the kerb. The sparse collection system (once weekly) may be a cost effective option even in developing economies.

**Door- to-door collection:**

In this method, generators place waste containers at their back gate or intermediate vicinity of their property on a specific day (or days) for collection. The collection crews enters each property , takes out the containers or bags & if appropriate sets the containers back after emptying waste into collection vehicles.

This is more common in industrialized countries, but an increasing no. of micro enterprises and/ or community based organizations are forming in wealthier communities in many developing countries.

This system involves increased labour costs compared to the Kerbside/alley connection method as it involves entering all premises.

In dustbin exchange system, each member of collection crews starts the day with a clean standard dustbin, which is taken to and deposited at the first property. The full containers is carried out & emptied into the collection vehicle, & this empty bin is then taken into the next property.

This system has yet to be receiving public attention, but as with the use of bags for waste it maximizes the productivity of crew, as retrieval of containers is not required.

**Table 6.1:** Comparison of various methods of solid waste collection

Description	Communal	Block	Kerbside	Door-to-door
Co-operation of generators in carrying waste	Yes	Yes	Yes	No
Co-operation of generators in emptying waste	Yes	Optional	No	No
Need for scheduled services	No	Optional	Yes	No
Susceptibility to scavenging	Very high	None	High	None
Average crew size	1-2 (portable) 2-4 (stationary)	1-3	1-3	3-7
Complaints regarding trespassing	No	No	No	Yes
Level of services	Poor	Fair	Good	Very good
Collection cost	Low	Medium	High	Very high

Source: Habitat (undated)

**Table 6.2:** Typical values for haul constant coefficients, m and n

Type of haul	Speed limit km/h	m h/trip	n h/km
Communal	88	0.016	0.011
Block	72	0.022	0.014
Kerbside	56	0.034	0.018
Door-to-door	40	0.050	0.025

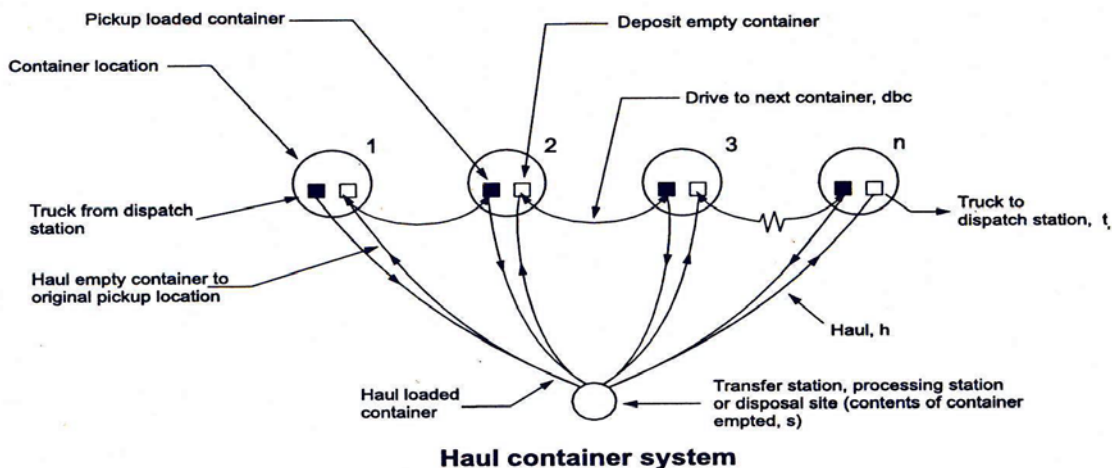
Adapted from: Peavy et al., 1985

**Table 6.3:** Typical data for computing equipment and labour requirements for hauled and stationary container collection

Collection			Pick up loaded container and deposit empty container, h/trip	Empty contents of loaded container, h/container	At-site time $q$ , h/trip
Vehicle	Loading method	Compaction ratio, z			
Hauled container (Tilt-frame)	Mechanical	2.0–4.0	0.50		0.129
Stationary container (Compactor)	Mechanical	2.0–4.0		0.050	0.15

**Collection methods on the basis of mode of operation may be broadly categorized into two systems**

1. **Hauled containers** - In this system an empty container (known as a drop-off box) is hauled to the storage site to replace the container that is full of waste, which is then hauled to the processing point, transfer station or disposal site.
2. **Stationary containers** - In this system, containers used for the storage of waste remain at the point of collection. The collection vehicles generally stop alongside the storage containers and collection crews loads the waste from the storage containers into the collection vehicles and then transport the waste to the processing, transfer or disposal site.



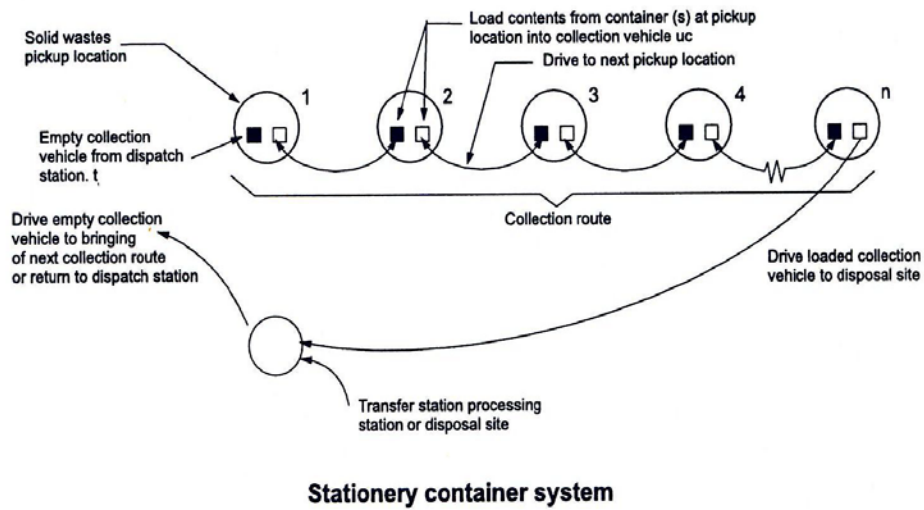


Figure 14.2 Schematic diagrams of hauled and stationary container systems  
(after Peavy et al. 1986)

**Definition of term**

The activities involved in collection of solid wastes can be resolved into four unit operations: pick up, haul, at-site and off route.

**Table 6.4:** Definition of term for the activities involved in the collection of solid wastes

Term	Definition
<u>Pickup (<i>P</i>)</u>	
Hauled-container system, $P_{hcs}$	The time spent picking up the loaded container, the time required to redeposit the container after its contents have been emptied, and the time spent driving to the next container.
Stationary-container system, $P_{scs}$	The time spent loading the collection vehicle, beginning with the stopping of the vehicle prior to loading the contents of the first container and ending when the contents of the last container to be emptied have been loaded.
<u>Haul (<i>h</i>)</u>	
Hauled-container system, $h_{hcs}$	The time required to reach the disposal site, starting after a container whose contents are to be emptied has been loaded on the truck, plus the time after leaving the disposal site until the truck arrives at the location where the empty container is to be redeposited. Time spent at the disposal site is not included.
Stationary-container system, $h_{scs}$	The time required to reach the disposal site, starting after the last container on the route has been emptied or the collection vehicle is filled, plus the time after leaving the disposal site until the truck arrives at the location of the first container to be emptied on the next collection route. Time spent at the disposal site is not included.
<u>At-site (<i>s</i>)</u>	The time spent at the disposal site, including the time spent waiting to unload as well as the time spent unloading.
<u>Off-route (<i>W</i>)</u>	All time spent on activities that are nonproductive from the point of view of the overall collection operation. Necessary off-route time includes (1) time spent checking in and out in the morning and at the end of the day, (2) time lost due to unavoidable congestion, and (3) time spent on equipment repairs and maintenance. Unnecessary off-route time includes time spent for lunch in excess of the stated lunch period and time spent on taking unauthorized coffee breaks, talking to friends, etc.

**Hauled container system:**

$T_{hcs}$  = Time required per trip, which also corresponds to the time required per container, is equal to the sum of pick-up, at-site and haul times and given by the following equation:

$$T_{hcs} = PT_{hcs} + q + m + nx$$

where,

$PT_{hcs}$  = pick-up time per trip for hauled – container system, h/trip

q = at-site time per trip, h/trip

m= empirical haul constant, h/ trip

n = empirical haul constant, h/ km

x = round- trip haul distance, km/trip

$PT_{hcs}$  = the time spent picking up the loaded container, the time required to redeposit the container after its contents have been emptied and the time spent driving to the next container.

$$PT_{hcs} = pc + uc + dbc$$

where, pc = pick-up time per trip, h/trip

uc = time required to unload empty container, h/trip

dbc = average time spent driving between container locations, h/ trip( determined locally)

Haul time ( $h_{hcs}$ ): the time required to reach the disposal site, starting after a container whose contents are to be emptied has been loaded on the truck plus the time after leaving the disposal site until the truck arrive the location where the empty container is to be re-deposited . Time spent at the disposal site is not included.

$$h_{hcs} = m + nx$$

Where, m= empirical haul constant, h/ trip

n = empirical haul constant, h/ km

x = round- trip haul distance, km/trip

$M_d$  = The number of trips that can be made per vehicle per day with a hauled – container system, including a factor to account for off-route activities, is determined using equation,

$$M_d = \frac{(1 - W)L - (t_1 + t_2)}{T_{hcs}}$$

Where,  $M_d$  = no. of trips per day, trip /d

L= length of the working day, h/d

$W$  = off-route factor, expressed as a fraction

$t_1$  = time from garage to the first container location, h

$t_2$  = time from garage to the last container location to garage, h

Assuming that the number of containers to be emptied per week is known, the time required per week can be estimated by,

$$D_w = N_w [PT_{hcs} + q + m + nx] / \{(1 - W) * L\}$$

If weekly number of trips is unknown, it can be estimated as follows:

$$N_w = V_w / Cf$$

$N_w$  = number of trips per week, trip/ wk

$V_w$  = weekly waste generation rate, Yd<sup>3</sup> / wk

$C$  = average container size carried per trip, Yd<sup>3</sup> / trip

$f$  = weighed average container utilization factor

### **Stationary Container**

$$T_{scs} = PT_{scs} + q + m + nx$$

Where,

$T_{scs}$  = Time required per trip, for stationary container system,

$PT_{scs}$  = pick-up time per trip for stationary container system, h/trip

$q$  = at-site time per trip, h/trip

$m$  = empirical haul constant, h/ trip

$n$  = empirical haul constant, h/ km

$x$  = round- trip haul distance, km/trip

$PT_{scs}$  = the time spent in loading the collection vehicle, beginning with the stopping of the vehicle prior to loading the contents of the first container and ending when the last container to be emptied have been loaded.

$$PT_{scs} = C_t uc + (S-1) (dbc)$$

Where,

$C_t$  = Number of container emptied per trip, h/trip

$uc$  = average time required to unload container, h/container

$S$  = Number of container pick up locations per trip,

$dbc$  = average time spent driving between container locations, h/ location( determined locally)

Haul time ( $h_{scs}$ ) = the time required to reach the disposal site, starting after last container on the route has been emptied or the collection vehicle is filled plus the time after leaving the disposal site until the truck arrives at the location of the first container to be emptied on the next collection route . Time spent at the disposal site is not included.

$$h_{scs} = m + nx$$

Where,  $m$  = empirical haul constant, h/ trip

$n$  = empirical haul constant, h/ km

$x$  = round- trip haul distance, km/trip

The number of containers that can be emptied per collection trip is related directly to the volume of the collection vehicle and the compaction ratio that can be achieved. This number is given by:

$$C_t = V_v z / V_c f$$

Where,

$V_v$  = volume of collection vehicle,  $m^3$ /trip

$V_c$  = container volume ,  $m^3$  / container

$z$  = compaction factor

$f$  = weighted container utilization factor

The number of trips required per day, trips/d

$$M_{dc} = V_d / V_v Z$$

Where,

$M_{dc}$  = number of collection trips required per day, trips/d .

$V_v$  = volume of collection vehicle, m<sup>3</sup>/trip

$V_d$  = daily waste generation rate, m<sup>3</sup>/d

z= compaction factor

L = length of the working day

$$L = \frac{(t_1 + t_2) + M_{dc} (PT_{SCS} + q + m + nx)}{1 - W}$$

**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

**Point of Collection:**

Access to the solid waste storage point for waste collection requires special attention in planning and approval of bld. Plans and design, particularly in towns and cities.

The choice of collection of storage and collection points mostly depends on:

Access to the property (housing).

Physical characteristics of the property.

Availability of waste management resources.

The common collection services available to particular types of properties, particularly in industrialized countries.

**Detached dwellings:**

Block collection, kerbside/alley or door-to-door collection services are all practical for detached dwellings (a small cottage to a luxurious villa).

The detached dwellings are surrounded by a garden or a walled courtyard is suitable for door-to-door collection. The waste generators can place their bins outside the house and use of proper storage containers (protected from rain, diseases carriers, view) minimizes the demand for frequent collection while in tropical climate, frequent collection may be required to minimize the odour nuisance.

**Terraced dwellings:**

Block collection, kerbside/alley or door-to-door collections are common in terraced dwellings (no. of single or two-storey dwellings in a continuous block). If there is an access to the back yard or a small walled courtyard in the front of house, then door-to-door collection is suitable. From small portable bins and roll- out containers are used in here.

**Low and medium -rise dwellings:**

Block collection, kerbside/alley or door-to-door collection are also practiced at low and medium-rise dwellings .Apartment blocks which have balconies at the rear, can be reached by external staircase, if bins are kept, door-to-door collection is possible otherwise waste crews can go to the door of each apartment to collect waste bins or bags; alternatively communal bins or containers may be placed at a convenient location for waste collection.

**High – rise dwellings:**

The following waste handling and storage methods are commonly practiced:

Waste generators are responsible for bringing their waste to no. of selected small bins or communal containers placed in a suitable location within their premises.

Bld. maintenance personnel or porters are responsible for bringing their waste to communal containers.

Communal containers receive waste through waste chutes (to reduce volume in conjunction with waste chute large waste compactor are used in industrialized countries).

**Frequency of waste collection:**

The frequency of waste collection by external stakeholders greatly influences the waste collection costs and depends on a no. of factors such as:

Quantity of waste

Rate of generation

Characteristics of waste

Climate

Density & type of housing

Availability of space within the premises

Size & type of storage facilities (small, large, individual or communal)

Attitude of generators

Available resources

The countries have tropical and sub-tropical climates need frequent collection of waste as the decomposition of organic /putrescible fractions of solid waste occurred rapidly than in the countries of temperate climate. More frequent collection may be necessary in the case of block / kerbside collection to improve convenience of waste handling for generators and collection crews.

**Street Cleansing:**

Street waste generally arises from public behavior, littering in the street. In many developing countries; however, this waste also arises from failure / inadequacy of waste collection services which leads to generators to dispose of their waste in the streets.

The cost of removing waste which has been scattered in the street is much higher than that of collecting the same waste from their source of origin.

The street cleansing is a very important part of solid waste management, because absence of this service can block drainage systems, can be hazard to traffic, and ultimately can pose a serious threat to public health and the environment.

The street cleansing can be both manually and mechanically by using a wide variety of tools and equipment. Although mechanical equipment is widely used in industrialized countries, many developing countries still rely on the manual labour working with small tools (brooms, shovels & handcarts).

The ways to minimize environmental damage and to maximize the cost-effectiveness of the street cleansing services:

1. Expansion of collection services
2. Minimization of street waste by education campaign (also law enforcement)
3. Optimization of systems (both labour and equipment)
4. Selection of appropriate tools and equipment

### **Transfer Station**

Definition:

- ❖ A **transfer station** is a building or processing site for the temporary deposition of waste. Transfer stations are often used as places where local waste collection vehicles will deposit their waste cargo prior to loading into larger vehicles. These larger vehicles will transport the waste to the end point of disposal in an incinerator, landfill, or hazardous waste facility, or for recycling.
- ❖ In the future, transfer stations could be equipped with material recovery facilities and with localized mechanical biological treatment systems to remove recyclable items from the waste stream.
- ❖ A materials recovery facility or materials reclamation facility or materials recycling facility (MRF - pronounced "murf") is a specialized plant that receives, separates and prepares recyclable materials for marketing to end-user manufacturers. Generally, there are two different types: clean and dirty MRFs.
- Benefits of transfer station:
- ❖ Costs--The main reason for waste transfer is to optimize the productivity of vehicles and collection crews as they remain closer to routes, while larger vehicles make the longer trip to processing and disposal sites and ultimately reduces overall costs. It can also be integrated with other functional elements of integrated waste management options (recycling , resources recovery & waste –to- energy facility) to improve overall waste mgt. performance.

- ❖ Minimize collection vehicle routing complexities-- Makes the planning process more flexible and a combination of human & animal powered small motorized and more sophisticated vehicles with hydraulic or pneumatic system can be used in different areas depending on the accessibility to those areas and collection method.
- ❖ Provide an opportunity to increase waste density-- In areas where compaction vehicles are not available , transfer station may be used to compact the waste so that greater quantities can be carried( most economical) at once to the final disposal sites.
- ❖ Minimize illegal waste dumping--Particularly in developing countries where the human-and – animal powered and small motorized vehicles are used for the collection of waste are often unsuitable for traveling long distances.
- ❖ Can serve as a controlled place for sorting and processing the waste- Particularly in many low-income countries where a thriving informal economy exists in recycling of waste, these stations can minimize health hazard and may limit the amount of waste picking that is done in the streets, which will reduce the amount of waste that is scattered around communal bins and waste accumulation points.
- ❖ Minimize traffic congestion—It reduces the no. of vehicles for long distance haulage and may reduce fuel consumption thus reduce environmental pollution.
- ❖ Reduce maintenance costs of collection vehicles—These vehicles stay on well paved roads and are not traveling on rough roads, particularly in landfill sites.
- ❖ Improve waste dumping efficiency at final disposal site– A reduced no. of vehicles at the disposal sites.

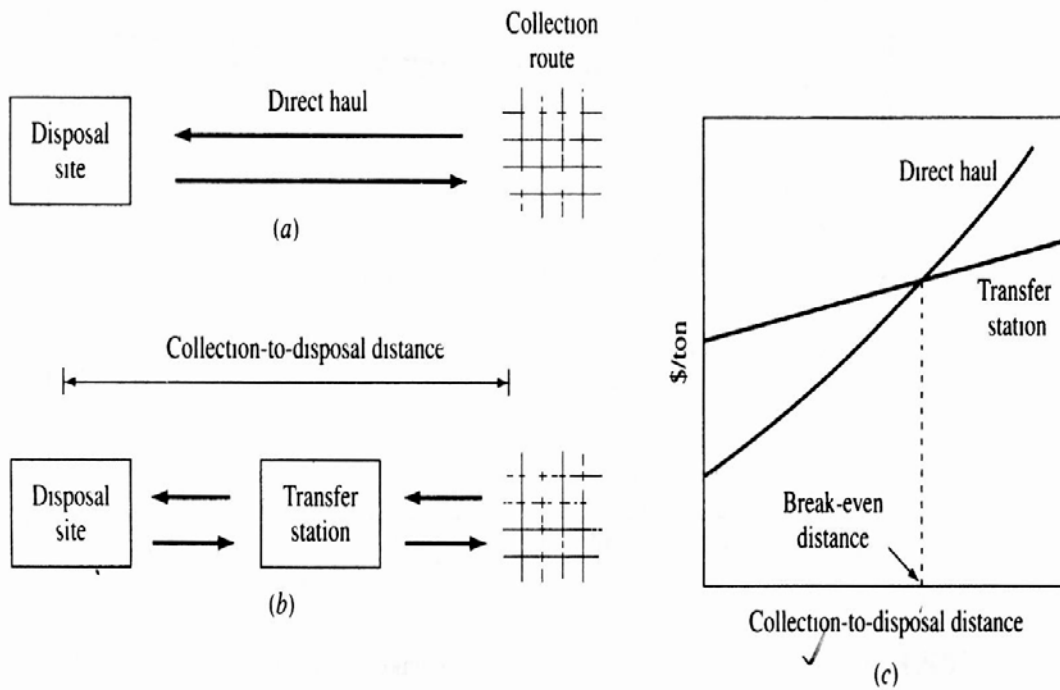
The main problems of transfer station:

- ❖ Increased traffic volume, noise and air pollution in the surrounding areas .
- ❖ Unless they are properly maintained there is a potential for environmental damage (leachate, odour, disease carriers, aesthetic and similar problem) in surrounding areas.

In the planning and design of transfer station a no. of factors should be considered:

- Location- governed by the proximity of the collection route, access to the major haulage routes, isolation from the community.
- Quantity of waste to be transferred/ handled
- Types & no. of primary and secondary vehicles served.
- Types of transfer operations( recycling, resource recovery, garage for vehicles etc.).

- Equipment requirements( depends on activities at a particular transfer station).
- Waste characteristics.
- Climate.
- Sanitation provision.
- Costs.



**FIGURE 9.17** The cost curve for a direct-haul system (a) starts lower but rises more steeply than the cost curve when a transfer station is included (b). At some distance, where the curves cross, the transfer station option becomes more cost effective (c).

CE 431  
Solid Waste Management  
(Credit 2.0, Class Period 2 hours/week)

**Problem on Hauled-Container Collection System**

Solid waste from an industrial park is to be collected in large containers, some of which will be used in conjunction with stationary compactors. Based on traffic studies on similar parks, it is estimated that the average time to drive from the garage to the first container ( $t_1$ ) and from the last container to the garage ( $t_2$ ) each day will be **15** and **30** minutes respectively. If the average time required to drive between containers is **6 minutes** and the one-way distance to the disposal site is **30 km** (speed limit: **88km/h**), determine the number of containers that can be emptied per day, based on a **7-hr working day**.

**Solution:**

(a) Determine the pick-up time per trip,  $PT_{hcs}$

$$PT_{hcs} = pc + uc + dbc$$

$$= 0.5 + (6/60) = \underline{0.6 \text{ h/trip}}$$

**pc** = pick-up time per trip, h/trip

**uc** = unloading/depositing time for empty container, h/trip

**dbc** = avg time spent driving between container locations, h/trip

Collection					
Vehicle	Loading method	Compaction ratio, z	Pick up loaded container and deposit empty container, h/trip	Empty contents of loaded container, h/container	At-site time q, h/trip
Hauled container (Tilt-frame)	Mechanical	2.0–4.0	0.50	pc + uc	q
Stationary container (Compactor)	Mechanical	2.0–4.0		0.050	0.15

(b) Determine the time required per trip,  $T_{hcs}$

$$T_{hcs} = PT_{hcs} + q + m + nx$$

$$= 0.6 + 0.129 + 0.016 + 0.011 \times 30 \times 2$$

$$= \underline{1.40 \text{ h/trip}}$$

$q$  = at-site time per trip, h/trip  
 $m$  = empirical haul constant, h/trip  
 $n$  = empirical haul constant, h/km  
 $x$  = round trip haul distance, km/trip

Type of haul	Speed limit km/h	m h/trip	n h/km
Communal	88	0.016	0.011
Block	72	0.022	0.014
Kerbside	56	0.034	0.018
Door-to-door	40	0.050	0.025

Adapted from: Peavy et al., 1985

(c) Determine the number of trips per day,  $M_d$

$$M_d = \frac{(1 - W)L - (t_1 + t_2)}{T_{hcs}}$$

$$= [(1 - 0.17) \times 7 - (0.25 + 0.5)] / 1.40$$

$$= 3.11 \text{ trips/d}$$

$$M_d \text{ (actual)} = 3 \text{ trips/d}$$

$W$  = off-route factor = 0.17 (assumed)  
 $L$  = length of working day, h/d = 7 h  
 $t_1$  = time from garage to first container location, h = 15/60 = 0.25 h  
 $t_2$  = time from last container location to garage, h = 30/60 = 0.5 h

(c) Determine the actual length of the working day

$$3 = [(1 - 0.17) \times L - (0.25 + 0.5)] / 1.40$$

$$\underline{L = 6.75 \text{ h (essentially 7 hrs)}}$$

**Problem on Stationary-Container Collection System**

Solid wastes from commercial area are to be collected using a stationary-container collection system having 5 cubic meter containers. Determine the appropriate truck capacity for the following conditions:

- Container utilization factor = 0.70
- Average number of containers at each location = 2
- Collection vehicle compaction ratio = 2.5
- Container unloading time = 0.15h/container (uc)
- Average drive time between container location = 0.15h
- One way haul distance = 25km
- Speed limit = 88 km/h
- Time from garage to first container location = 0.35h
- Time from last container location to garage = 0.25h
- Number of trips to disposal site per day = 2 ( $M_{dc}$ )
- Length of working day = 8h

**Solution:**

**(a)** Determine the time available for each trip,  $T_{scs}$

$$L = [(t_1 + t_2) + M_{dc} (T_{scs})] / (1 - W)$$

$$T_{scs} = \{[8 \times (1 - 0.15)] - (0.35 + 0.25)\} / 2$$

Therefore,  $T_{scs} = 3.1$ h

$L = 8$ h  
 $W = 0.15$  (assumed)  
 $t_1 = 0.35$  h  
 $t_2 = 0.25$  h  
 $M_{dc} = 2$

**(b)** Determine the pick-up time per trip,  $PT_{scs}$

$$T_{scs} = PT_{scs} + q + m + nx$$

$$PT_{scs} = 3.1 - [0.15 + 0.016 + 0.011 \times 25 \times 2]$$

$$= \underline{\underline{2.38 \text{ h/trip}}}$$

$q = 0.15$   
 $m = 0.016$   
 $m = 0.011$   
 $x = 25$  km

(c) Determine the number of containers emptied per trip,  $C_t$

$$PT_{scs} = C_t uc + (S-1) dbc$$

$$2.38 = C_t \times 0.15 + (0.5C_t - 1) \times 0.15$$

$$C_t = 11.24 = \underline{\mathbf{11 \text{ containers/trip}}}$$

$$PT_{scs} = 2.38 \text{ h/trip}$$

$uc$  = Container unloading time = 0.15  
hr/container (for scs)

$$dbc = 0.15 \text{ h}$$

$C_t$  = number of containers emptied per trip,  
container/trip

$S$  = number of container pick-up locations  
per trip, locations/trip

$$= C_t / 2 \text{ (as 2 containers/location)}$$

[ 1 location = 2 containers

Therefore,  $S$  locations =  $2S$  containers

So,  $C_t = 2S$ , i.e.  $S = C_t / 2$ ]

(c) Determine the required capacity of the collection vehicle,  $V_v$

$$C_t = (V_v \times z) / (V_c \times f)$$

$$V_v = \underline{\mathbf{15.4 \text{ m}^3}}$$

$16 \text{ m}^3$  or nearest standard size can be used.

$$C_t = 11 \text{ containers/trip}$$

$z$  = compaction ratio = 2.5

$V_c$  = container volume,  $\text{m}^3/\text{container} = 5 \text{ m}^3$

$f$  = weighted container utilization factor = 0.7

---

**Problem on Economic Comparison of Transport Alternatives**

Determine the break-even time for a stationary-container system and a separate transfer and transport system for transporting wastes collected from a metropolitan area to a landfill disposal site. Assume the following cost and system data are applicable.

1. Transportation costs:

(a) Stationary-container system using an 18 m<sup>3</sup> compactor = \$20/h

(b) Tractor-trailer transport unit with a capacity of 120 m<sup>3</sup> = \$25/h

2. Other costs:

(a) Transfer station operating cost, including amortization = \$0.40/m<sup>3</sup>

(b) Extra cost for unloading facilities for Tractor-trailer transport unit = \$0.05/m<sup>3</sup>

3. Other data:

(a) Density of wastes in compactor = 325 kg/m<sup>3</sup>

(b) Density of wastes in transport units = 150 kg/m<sup>3</sup>

**Solution**

1. Convert cost data to units of \$/ton. min

(a) **Stationary-container system:**

Operating cost = (\$20/h)/(60 min/h) = \$0.33/min

Tons/load = (18 m<sup>3</sup> × 325 kg/m<sup>3</sup>) / (1000 kg/ton) = 5.85 ton

Therefore, operating cost = (\$0.33/min) / 5.85 ton = **\$0.0564/ ton. min**

(b) **Transfer-transport system:**

Operating cost = (\$25/h)/(60 min/h) = \$0.42/min

Tons/load = (120 m<sup>3</sup> × 150 kg/m<sup>3</sup>) / (1000 kg/ton) = 18 ton

Therefore, operating cost = (\$0.42/min) / 18 ton = **\$0.0233/ ton. min**

(c) **Transfer station cost:**

Operating cost = (\$0.40/ m<sup>3</sup>) / (0.15/ton) = \$2.67/ ton

(d) **Unloading cost:**

Operating cost = (\$0.05/ m<sup>3</sup>) / (0.15/ton) = \$0.33/ ton

2. Prepare a plot of cost versus haul time in minutes and determine break-even time.

(a) Fixed cost for transfer and transport system:

Cost/ ton = \$2.67 + \$ 0.33 = \$3.00

(b) Variable cost at 100 min:

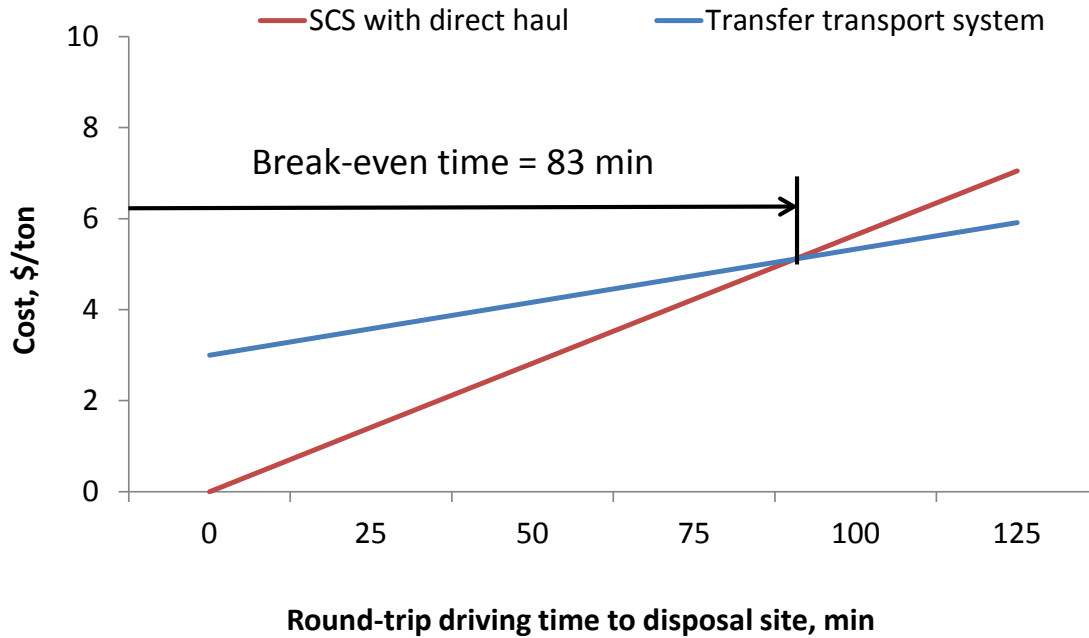
(i) Stationary container system

Cost/ton = (\$0.0564/ ton. min) × 100 min = \$5.64 /ton

(ii) Transport system

Cost/ton = (\$0.0233/ ton. min) × 100 min = \$2.33 /ton

(c) The above data are plotted in the following figure, where the break-even point is found as **83 min.**



**Comparison of two systems:**

- (i) Before the break-even time, SCS seems to be more economic
- (ii) At break-even time, two systems are indifferent.
- (iii) After the break-even time, transfer transport system seems to be more economic

**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

**Solid Waste Collection Vehicle:**

**Selection of Collection Vehicle:**

The careful selection of appropriate vehicles is crucial for a well functioning solid waste management. The general considerations for selecting a suitable vehicle are:

1. Territory- hilly, plain land, density of housing
2. Type of properties- detached dwellings , high – rise dwellings, commercial bld. etc
3. Transport regulation- permitted maximum load
4. Travel distance- distance to communal / transfer station or final disposal
5. Integration- possibility of integration with existing practices
6. Performance- convenience( loading height), material loading/ unloading efficiency , operating dimensions, and turning radius, safety mechanism
7. Access road- width of road, type of surface, corner radius, maneuvering space
8. Storage facilities- enclosure, bins, roll-out bins, bags, etc
9. Quantity of waste- rate of generation and frequency of collection
10. Waste characteristics- constituents, abrasive, dense, low-density
11. Traffic levels- vehicles should be harmonious with existing traffic
12. Standardization- minimize overall maintenance costs
13. Payload capacity- the amount of waste that can be carried depends on the weight of vehicles( i.e, vehicles with lower body weight can carry more waste)
14. Size of cab- often it is overlooked although it does not cost much
15. Technical know-how- availability of skilled labour for operation and maintenance
16. Cost- capital, operation, and maintenance cost

### **Types of Collection Vehicle:**

A range of waste collection vehicle types, from the basic human- and – animal powered vehicle(handcarts etc) which is more common in developing countries, to the most sophisticated motorized vehicles (world. more common in industrialized countries) , are useful in different parts of the world.

Some of these vehicles have been specially designed for this purpose, while others were initially intended for use in different activities.

Waste collection and transportation equipment (mostly used in industrialized countries), depending on the types of collection bodies adapted and available with a compaction mechanism, can be divided into 4 general categories:

- Compaction vehicle
- Semi-compaction vehicle
- Non-compaction vehicle
- Container handling systems

### **Compaction vehicle:**

- Widely used in industrialized countries to compact waste before long-range transportation, and in many cases this is done during collection.
- The heavy weight of the body a compacting mechanism ( in the range of 3-5 tons) reduces the payload capacity of the vehicle and thus increases operation and maintenance costs.

### **Non-compaction vehicles:**

- Solid waste in developing countries is typically of higher density , so pay full load of waste collection vehicles can be obtained without any compaction mechanism.
- In many industrialized countries , these vehicles are also used to carry specific waste( large bulky items, furniture etc).
- However , non-compaction collection vehicles generally require a larger body than compaction vehicles to attain their full payload.

Examples:

- Open trucks/ high – sided open –top- vehicles
- Tractor and open trailers, Side loading roll-top vehicles, Front loading high-sided enclosed vehicles etc.

**Semi-compaction vehicles:**

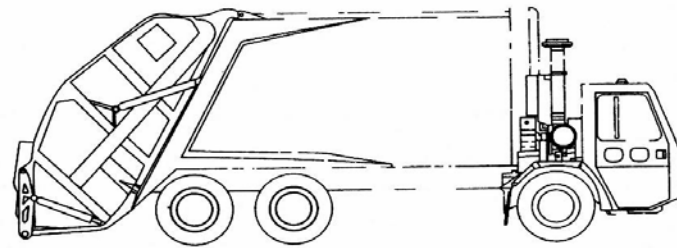
Side – loading , moving barrier semi-compaction vehicles, Fore-and-aft semi-compaction vehicles, Side-loading –hopper semi-compaction vehicles.

**Container handling systems:**

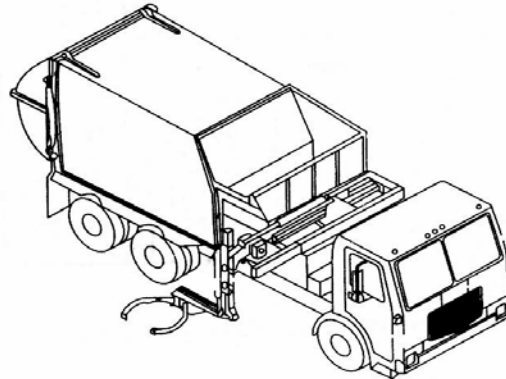
- Container handling systems are used in attempt to reduce the loading time, and hence maximize the productivity of the vehicles.
- The containers can be placed just about anywhere that space allows ; for example , at a transfer station or throughout residential areas as communal bins.
- They are filled with waste while not attached to the vehicles and subsequently either emptied into a vehicle on site, or collected and taken ( in case of hauled-container systems) to the final disposal site for emptying.

Example:

- Truck-mounted front-loading container-handling vehicles
- Truck-mounted rear-loading container-handling vehicles
- Tractor and trailer container systems
- Container hoist vehicles
- Roll-on roll-off (hook lift) trucks
- Others transports are :
- Rail transport, river transport, pneumatic and hydraulic transport



Rear-loading packer truck



Automated side-loader packer

**FIGURE 9.13** Examples of a rear-loading packer truck and a side-loading truck with an automated arm to pick up trash containers.

#### Maintenance of collection vehicles:

Purchase of waste collection vehicles does not solve the waste management problem unless they are properly maintained. **The overall productivity of a vehicle depends on the total amount of time the vehicle remains operational during its productive life.** Generally vehicle maintenance is being carried out in the following two types:

1. Preventive maintenance
2. Breakdown maintenance

#### Preventive maintenance:

Preventive maintenance in the service of vehicle that occurs when they seems to be working efficiently in order to identify problems before they occur. Preventive maintenance should be carried out at regular intervals that are generally based on distance of a vehicle travelled or hours of operation. Minor preventive maintenance activities should be carried out daily or weekly.

### Breakdown maintenance:

Breakdown or crisis maintenance is the repair of the vehicle once problem have already occurred. In the developing countries, this is the only sort of maintenance that occurs. It is easy to plan and works to simply as a response to problems as they occur. However, it may lead to long down times (the length of time that the vehicle is out of operation).

### **Collection vehicle routing**

The selection of proper collection routes is important to maximize the productivity of collection vehicles to reduce waste collection costs. The principal approaches to design the collection routes may be broadly classified as:

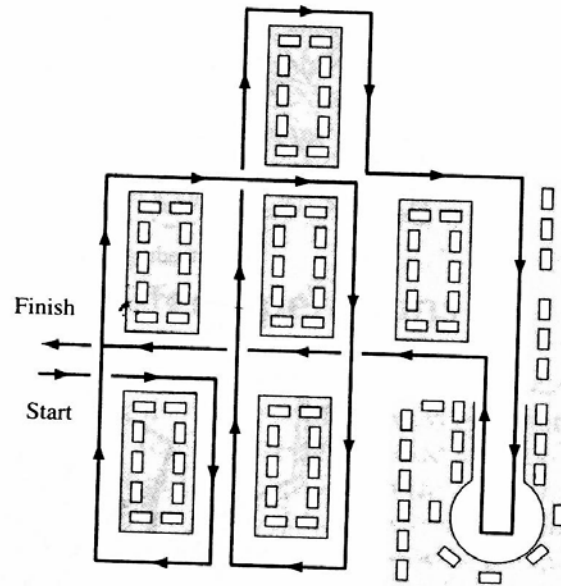
- Heuristic
- Deterministic

#### Heuristic

This is an old system of assigning routes which mainly based on experience and intuition and therefore depends on the experience of the users

In large urban centres, often micro-routing is done with equitable distribution of equipment and labour taking the consideration of the following factors:

- identification of existing policies as regard collection and its frequency
- lowest street retracing
- Initiation of collection routes as close to garage as possible considering heavily travelled routes.
- Rounds should be of a similar length (for similar vehicles) related mainly to the quantity of waste that can be carried in the vehicle at one time ( and hence generation rates and waste composition) but also related to distance and working hours of the collectors.
- Routes having traffic should be served before or after the rush hours.
- Large quantity waste sources should at the beginning of the day.
- In case of a one- way street, collection routes should began near upper end of the street and working down it through the looping process.



**FIGURE 9.14** A heuristic route emphasizing right turns and a minimum amount of deadheading.

- Using the above principal the steps involved in the heuristic method:
- Preparing the maps showing sources and quantities of solid waste
- Identification of introductory routes to develop balance routes by trial and error.
- Deterministic
- The deterministic approach attempts to detect the optimum solution through developing mathematical models with the input of local data.

**Economic costs - It includes:**

- The economic costs of solid waste collection includes:
- Planning and design
- Procurement , operation and maintenance of waste collection equipment
- Skilled and unskilled labour and drivers involved directly in collection services

- A percentage of administrative costs
- Resource recovery( if there is a resource recovery system not a source but in the collection stream)

### **Economics of collection-**

To decide on the truck size that would provide the cheapest waste transport, it is need to know the annual cost of owning and operating trucks including the cost of the crew that makes the pick-ups.

Transfer station-

The cost of transfer station itself depends on many factors, including its size, local construction costs and the price of land. In addition, transfer stations can employ a variety of technological features that also contribute to costs.

#### ❖ Calculation of economic costs

- Annual cost-In most cases, operating and maintenance costs are generally available as annual costs, but often, capital costs are not available as annual costs. Thus the capital costs can be converted into annual costs by multiplying the total capital cost by the appropriate capital recovery factors (CRF):

$$CRF = [i(1+i)^N] / [(1+i)^N - 1]$$

where,

i= interest per annum

N= loan maturity period

#### ❖ Present value

- In solid waste management , the present value( either cost of waste management or weight of solid waste) are generally estimated by using a set of financial tables or the following equation( Habitat)

$$PV = [c^t] / [(1+r)^{t-1}]$$

where,

c= cost incurred (or total tonnage of waste collected) in year t

r= opportunity cost of capital\*

\* **Capital Opportunity Costs** – This is the benefit/ profit that can be achieved by investing the money in a profitable venture (for example, investing money in a share market, bank and similar institutions). In developing countries, the profit margin often lies in the range of 8 – 15 percent, but the country often invest money to manage solid waste collection with the interest rate of 0 – 4 percent.

### **Environmental costs:**

The major environmental impacts associated with collection systems involve:

- Consumption of energy and generation of atmospheric emissions
- Production of storage facilities( e.g., bags, bins)
- Maintenance of storage containers
- Treatment (e.g, separation , home composting) of waste materials at sources
- Environmental benefits

### **Economics of Solid Waste Collection**

To decide on the truck size that would provide the cheapest waste transport, we need to know the annual cost of owning and operating trucks, including the cost of the crew that makes the pickups.

Finding the annualized cost of each truck involves using an engineering economy calculation in which capital cost, amortized over the lifetime of the vehicle, is added to the estimated annual maintenance and fuel costs.

The relationship between the purchase price of capital equipment, such as trucks and the amortized yearly cost is given by –

$$A = P \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right]$$

where, A = annual cost (\$/yr)  
P = purchase price, (\$)  
i = interest rate, discount rate (yr<sup>-1</sup>)  
n = amortization period (yr)

The quantity in brackets in the above equation is known as the “capital recovery factor”, CRF (i, n). One way to interpret the equation is to think of **A** being annual payments that would pay off a loan of **P** dollars in **n** years, if the loan interest is **i** (in decimal).

For example, a mid-size collection vehicle costing \$180000, if amortized over a 5-yr period using a 10 percent discount rate, would have an annualized cost of

$$A = \$180000 \left[ \frac{0.10(1 + 0.10)^5}{(1 + 0.10)^5 - 1} \right]$$
$$= \$180000 \times 0.2638/\text{yr} = \$47484/\text{yr}$$

These vehicles are usually heavy and their start-and-stop driving pattern leads to very low fuel efficiency – less than 2 miles per gallon is typical. An average truck driven 50 miles/day, 260 d/yr, at 2 mile/gallon and \$3 per gallon would cost almost \$20000 per yr in fuel alone.

If maintenance, insurance and other costs are added, this typical packer truck can easily cost on the order of \$80000 per year, excluding the labor cost of the crew.

The annualized cost of a vehicle will depend on its size and usage. One approach to analyzing its economics is to use a simple linear model as follows:

$$\text{Annualized cost (\$/yr)} = \alpha + \beta V$$

where,  $\alpha$  and  $\beta$  are empirically determined estimates based on a survey of available vehicles

V = truck volume

**Problem: An Economic Analysis of Refuse Collection**

Suppose the annualized cost of purchasing, fueling and maintaining a compactor truck is given by the following expression:

$$\text{Annualized cost (\$/yr)} = 25000 + 4000V$$

Where, V is the truck volume in cubic yards. Suppose these trucks require two person crews, with labor charged at \$24 per hr each (including benefits).

Perform an economic analysis of the collection system, in which a 14.4 yd<sup>3</sup> truck collects refuse from 340 households each day. Each household generates 60 lbs of refuse per week. The trucks and crew work 5 days per week and curb-side pickup is provided once a week for each house. What is the cost per ton of refuse collected and what is the cost per household?

**Solution**

Assuming 8-hr working days, for 5 days/week and 52 weeks/yr, the annualized cost of labor per truck would be

$$\begin{aligned} \text{Labor cost} &= 2 \text{ persons} \times \$24/\text{hr} \times 8 \text{ hr/d} \times 5 \text{ d/wk} \times 52 \text{ wk/yr} \\ &= \mathbf{\$99840/\text{yr}} \end{aligned}$$

<b>Crew size = 2 persons / truck</b> <b>Labor charge = \$24 per hr each</b>
--

$$\begin{aligned} \text{Annualized truck cost (\$/yr)} &= 25000 + 4000 \times 14.4 \\ &= \mathbf{\$82600/\text{yr}} \end{aligned}$$

<b>Annualized cost = 25000 + 4000V</b> <b>Truck volume, V = 14.4 yd<sup>3</sup></b>
--

$$\text{Total annual cost of truck and crew} = \$82600 + \$99840 = \mathbf{\$182440/\text{yr}}$$

Over a 5-day week, 1700 households (5 × 340 = 1700) are served by each truck.

<b>Refuse collected from 340 households per day</b> <b>Refuse generation rate = 60 lbs/week</b>
--

The total amount of refuse collected by 1 truck in 1 yr is

$$\text{Annual refuse} = (1700 \text{ households} \times 60 \text{ lb/week} \times 52 \text{ wk/yr}) / 2000 \text{ lb/ton} = 2652 \text{ ton/yr}$$

Therefore, the **annual cost per ton** =  $(\$182440/\text{yr}) / (2652 \text{ ton}/\text{yr}) = \mathbf{\$68.80/\text{ton}}$

**Annual cost per household** =  $(\$182440/\text{yr}) / 1700 \text{ households} = \mathbf{\$107.32/\text{yr}}$

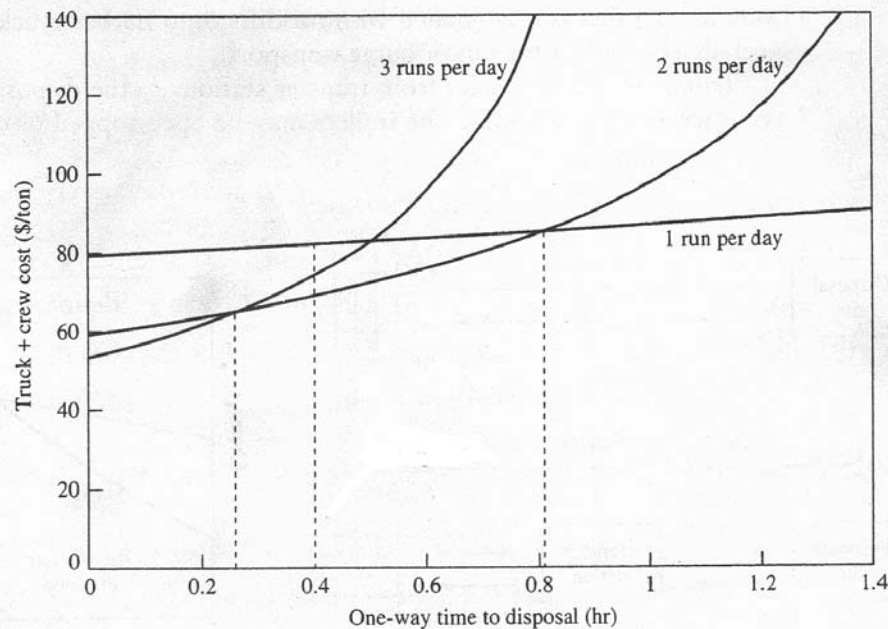
However, the total amount billed to each customer will be considerably higher after incorporating transfer station fees, administrative costs, overhead, profits and so on.

**Note:**

TABLE 9.17

<b>Comparison of Costs for Trucks Making One, Two, or Three Trips Per Day to a Disposal Site</b>						
Number of Trips Per Day	Houses Served Per Truck	Minimum Truck Size (yd <sup>3</sup> )	Annualized Costs		Cost Per Ton (\$/ton)	Cost Per Household (\$/yr)
			Truck (\$/yr)	Labor (\$/yr)		
1	2,061	34.9	164,556	99,840	\$82.25	\$128.31
2	1,702	14.4	82,643	99,840	\$68.80	\$107.32
3	1,344	7.6	55,338	99,840	\$74.02	\$115.47

Under the assumptions made in the analysis mentioned above, mid-sized trucks are optimum. Larger trucks make fewer runs to the disposal site, but their capital cost is too high. On the other hand, use of smaller trucks holds their capital cost down, but the extra time spent driving back and forth reduces the number of customers served, which more than offsets that advantage.



**FIGURE 9.16** The optimum number of trips to make per day to the disposal site is sensitive to the time needed to make the drive. For short distances, smaller trucks making more trips are optimum. For long distances, large trucks that can collect all day long before disposal become more cost effective. This figure is based on assumptions in Examples 9.6 and 9.7.

### Transfer Stations

As convenient, local landfills close it is often the case that the replacement site is located many miles away from the community that is being served. As that distance from the collection area increases, it takes more and more time to haul the refuse to disposal site, which leaves less and less time for each truck to actually collect the wastes.

At some point, it is better to construct a temporary repository for wastes dropped off by local garbage trucks. Larger, long-haul trucks are then used to transport wastes from the transfer station to the disposal site.

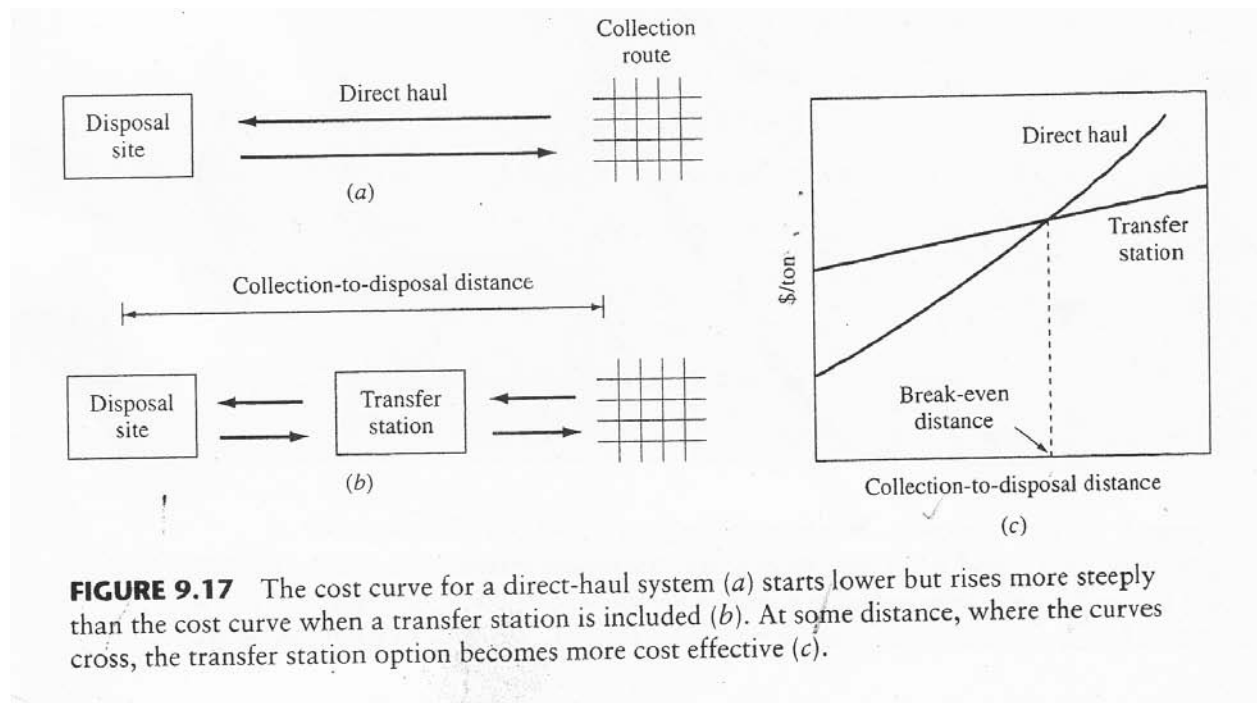
The cost of a transfer station itself depends on many factors, including its size, local construction costs and the price of land. In addition, transfer stations can employ a variety of technological features that also contribute to costs. For example –

(a) Simple transfer stations may consist of just a lightweight building shell with a thick concrete slab called a tipping floor. Collection vehicles drop their refuse onto the tipping floor while a front loader scoops it up and loads the transfer vehicles.

(b) More complex facilities may include hoopers for direct deposit of refuse from collection vehicles into transfer vehicles. They may also have compaction equipment to compress the waste before loading.

Trucks that haul wastes from transfer stations to disposal site are usually large tractor-trailer vehicles. The trailers may be open-topped or closed, but closed trailers are preferred since they are less likely to spread debris along the highway and the wastes can be more easily compacted in the trailer.

Open trailers carry on the order of 40 to 120 yd<sup>3</sup> of refuse with densities of 200 to 300 lb/yd<sup>3</sup>. Since the density of wastes in closed trailers may be higher (500 to 800 lb/yd<sup>3</sup>), closed trailers are usually smaller (40 to 80 yd<sup>3</sup>) in order to keep the total vehicle weight below highway load limits.



**FIGURE 9.17** The cost curve for a direct-haul system (a) starts lower but rises more steeply than the cost curve when a transfer station is included (b). At some distance, where the curves cross, the transfer station option becomes more cost effective (c).

**Problem: Costs of a Transfer Station and Its Vehicles**

A transfer station handling 300 tons/day, 5 days per week, costs \$5 million to build and \$150000 per year to operate. An individual tractor-trailer costs \$140000 and carries 15 tons/trip. Operation and maintenance costs (including fuel) of the truck are \$50000/yr; the driver makes \$40000 per year (including benefits). The capital costs of the building and transfer trucks are to be amortized over a 10-yr period using a 12% discount factor.

Suppose, it takes 30 minutes to make a one-way trip from the transfer station to the disposal site and 7 round trips per day are made. Find the transfer station and hauling cost in dollars per ton.

**Solution**

$$CRF = \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right] = \frac{0.12(1+0.12)^{10}}{(1+0.12)^{10} - 1}$$

= 0.1770/yr

**CRF** = Capital Recovery factor  
**P** = purchase price = \$5000000  
**i** = discount factor = 12% = 0.12  
**n** = amortization period = 10yr  
**Operating cost** = \$150000/yr

The annualized cost of the transfer station is therefore

$$\$5000000 \times 0.177/\text{yr} + \$150000/\text{yr} = \$1035000/\text{yr}$$

Per ton of waste, that works out to be

**Station capacity** = 300 tons/day  
**Working period** = 5 days/week

$$\text{Transfer station cost} = \frac{\$1035000/\text{yr}}{300\text{ton}/\text{day} \times 5\text{days}/\text{week} \times 52\text{weeks}/\text{yr}}$$

**= \$13.27/ton**

**Single truck cost** = \$140000  
**O&M costs of truck** = \$50000/yr  
**Driver cost** = \$40000/yr  
**Truck capacity** = 15 tons/trip

The annualized cost of a single truck and its driver is

$$\$140000 \times 0.177/\text{yr} + \$50000/\text{yr} + \$40000/\text{yr} = \$114780/\text{yr}$$

Per ton of waste hauled, the truck and driver cost

$$\text{Truck and driver cost} = \frac{\$114780/\text{yr}}{15\text{ton}/\text{trip} \times 7\text{trips}/\text{day} \times 260\text{day}/\text{yr}}$$

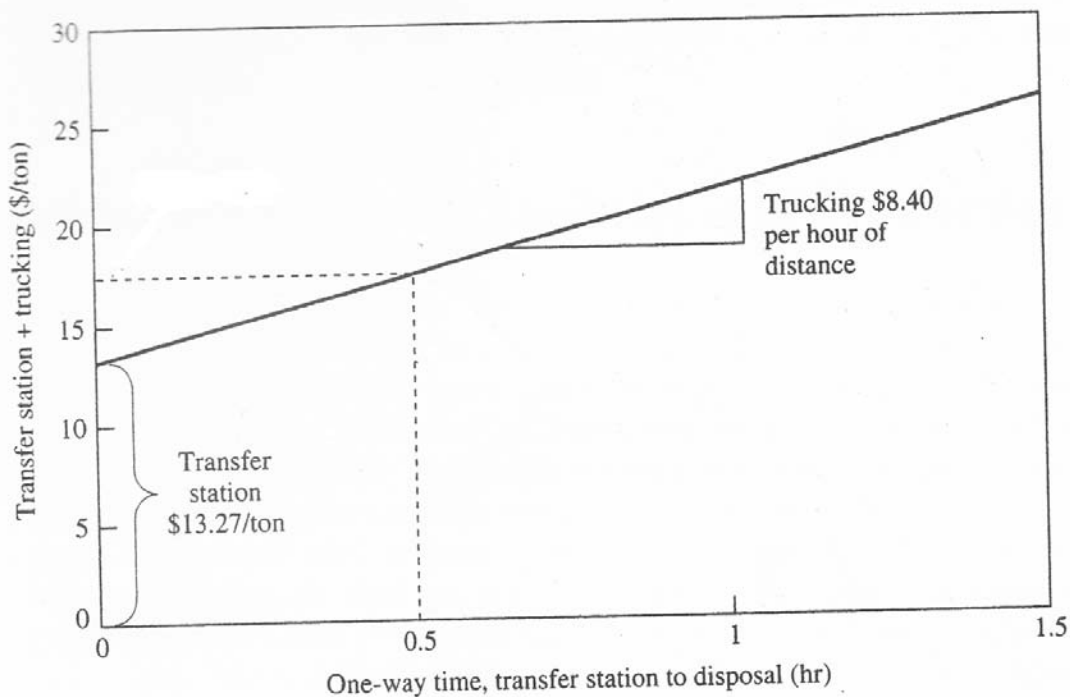
$$= \$4.20/\text{ton}$$

**Truck capacity** = 15 tons/trip  
**No of round trip** = 7 trip/day  
 (52 week/yr × 5day/week  
 = 260 day/yr)

Total cost of transfer station, trucks and driver = \$13.27 + \$4.20 = **\$17.47/ton**

Here, \$4.20/ton trucking cost was worked out for a particular trip time from transfer station to the disposal site of 30 min (0.5 hr) each way. That is, it is \$4.20/ton per 0.5 hr of distance between transfer station and disposal site, or \$8.40/ton per hour of distance. The transfer station itself has a fixed cost of \$13.27/ton.

A variable trucking cost over variable trip time, along with the fixed cost of the transfer station itself, results in the following graph.



**CE 431**  
**Solid Waste Management**  
**(Credit 2.0, Class Period 2 hours/week)**

### **Collection vehicle Routing Layout**

The layout of collection routes is a **four step process**.

(i) Prepare location maps. On a relatively large-scale map of the area to be serviced, the following data should be plotted for each solid-waste pick-up point: location, number of containers, collection frequency and if a stationary-container system with self-loading compactors is used, the estimated quantity of wastes to be collected at each pick-up location.

(ii) Prepare data summaries. Estimate the quantity of wastes to be collected from pickup locations serviced each day that the collection operation is to be conducted. Where a stationary container system is used, the number of locations that will be serviced during each pickup cycle must also be determined.

(iii) Lay out preliminary collection routs starting from the dispatch station or where the collection vehicles are parked. A rout should be laid out that connects all the pickup locations to be serviced during each collection day. The rout should be laid out so that the last location is nearest the disposal site.

(iv) Develop balanced routes. After the preliminary collection routes have been laid out, the haul distance for each route should be determined. Next, determine the labor requirements per day and check against the available work times per day. In some cases, it may be necessary to readjust the collection routes to balance the work load and the distance traveled.

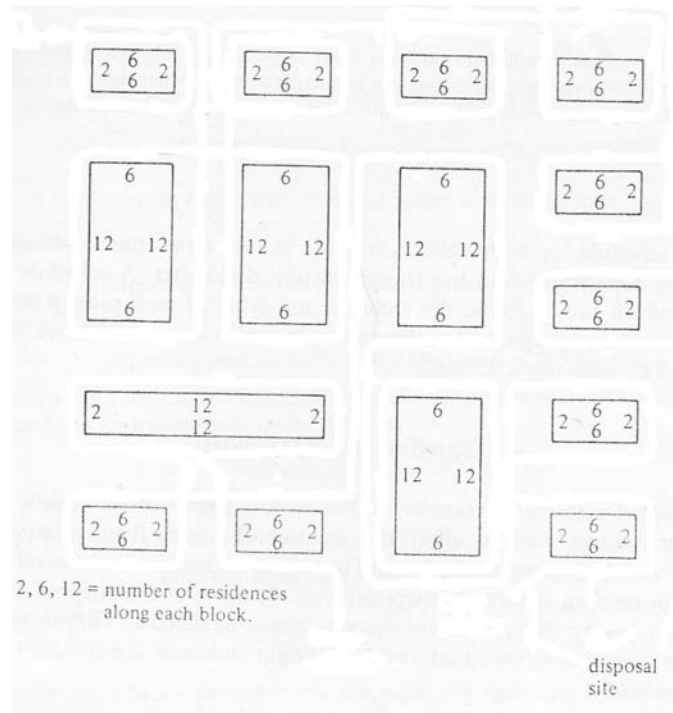
After the balanced routes have been established, they should be drawn on the master map.

### **Collection vehicle Routing Schedule**

A master schedule for each collection route should be prepared for use by the engineering department and the transportation dispatcher. A schedule for each route, on which can be found – the location and order of each pickup point to be serviced, should be prepared for the driver. In addition, a route book should be maintained by each truck driver.

**Problem on Laying Collection Routes**

Lay out collection routes for the residential area shown in the accompanying figure. Assume the following data are applicable:



**1. General**

- (a) Occupants per resident = 3.5
- (b) Solid waste generation rate = 1.6 kg/person.d
- (c) Collection frequency = 7 day/week
- (d) Type of collection service = curb
- (e) Collection vehicle capacity = 20 m<sup>3</sup>
- (f) Collection crew size = one person
- (g) Compacted density of solid wastes in collection vehicle = 325 kg/m<sup>3</sup>

**2. Route constraints**

- (a) No U-turns in streets

(b) Collection from each side of street with stand-up right-hand-drive collection vehicle

**Solution**

1. Determine **the number of residences** from which wastes are to be collected

$$\text{Residences} = 10 \times 16 + 4 \times 36 + 1 \times 28 = 332$$

2. Determine the **compacted volume of solid waste** to be collected per week

$$\begin{aligned}\text{Vol/wk} &= (332 \text{ residences} \times 3.5 \text{ persons/residence} \times 1.6 \text{ kg/person} \cdot \text{d} \times 7 \text{d.wk}) / 325 \text{ kg/m}^3 \\ &= 40.0 \text{ m}^3/\text{wk}\end{aligned}$$

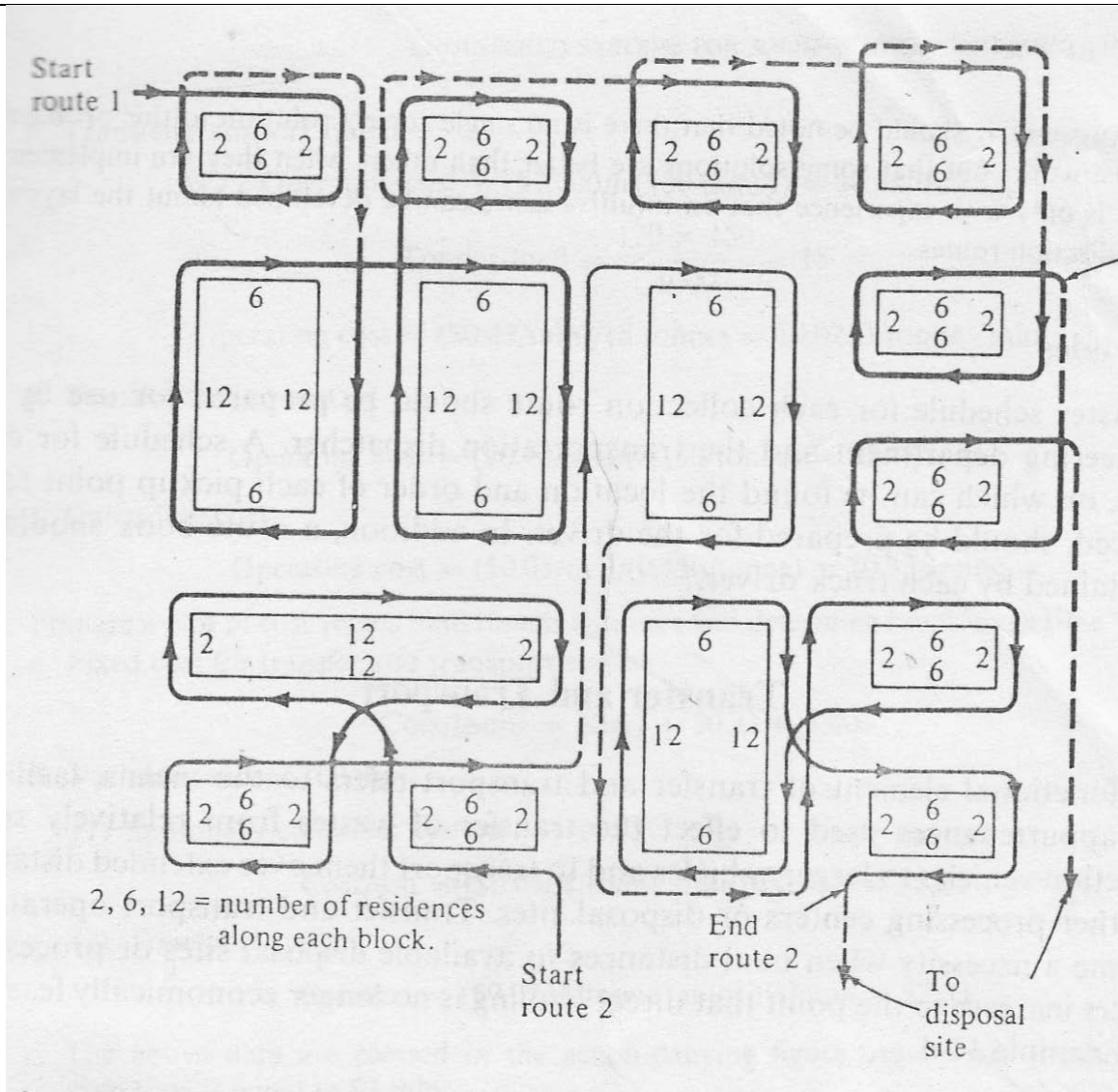
3. Determine the **number of trips/wk**

$$\text{Trip/wk} = (40 \text{ m}^3/\text{wk}) / (20 \text{ m}^3/\text{trip}) = 2$$

4. Determine the **average number of residences**, from which wastes are to be collected **each day**

$$\text{Residences/ trip} = 332 / 2 = 166$$

5. Lay out collection routs by trial and error, using the route constraints cited above as a guide. The two routes are shown in the figure.



**Note:** It should be noted that there is no single correct solution to this problem. It just works out that some solutions are better than others when they are implemented. It is only with experience that an intuitive sense can be developed about the layout of collection routes.