CHAPTER 6

SOLID WASTE GENERATION AND COLLECTION RATES

Knowledge of the quantities of solid wastes generated, separated for recycling, and collected for further processing or disposal is of fundamental importance to all aspects of solid waste management. As a means to understand the material presented in subsequent chapters, the following topics are considered in this chapter:

1. Importance of waste quantities
2. Measures and methods used to quantify solid waste quantities
3. Waste generation rates
4. Factors that affect waste generation and collection rates
5. Types and quantities of materials recovered from MSW
6. Quantities of household hazardous wastes
7. Waste characterization and diversion studies

6-1 IMPORTANCE OF WASTE QUANTITIES

The quantities of solid waste generated and collected are of critical importance in determining compliance with federal and state waste diversion programs; in selecting specific equipment; and in designing of waste collection routes, materials recovery facilities (MRFs), and disposal facilities.

Compliance with Federal and State Diversion Programs

Information on the total quantity of MSW as well as the quantity of waste that is now recycled or otherwise does not become part of the waste stream will be required to establish and assess the performance of mandated recycling programs. For example, if a 25 percent level of recycling is mandated, the following question must be answered: Is the 25 percent based on the actual quantity generated, or is it based on the amount currently collected? If a high percentage of the waste now generated is already recycled, then a 25 percent reduction in the amount collected may be difficult to achieve. The impacts of recycling on the quantity of waste collected are considered further in Section 6-3.

Design of Solid Waste Management Facilities

As the diversion and recycling of waste materials increase, the quantities of waste generated, separated for recycling, collected, and ultimately requiring disposal in landfills become determinants in planning and designing solid waste management facilities. For example, the design of special vehicles for the curbside collection of source-separated wastes depends on the quantities of the individual waste components to be collected. The sizing of MRFs depends on the amount of waste to be collected as well as the variations in the quantities delivered hourly, daily, weekly, and monthly. Similarly, the sizing of landfills depends on the amount of residual waste that must be disposed of after all the recyclable materials have been removed.

6-2 MEASURES AND METHODS USED TO ASSESS SOLID WASTE QUANTITIES

The purpose of this section is to introduce the reader to the measures and methods used to quantify solid waste quantities, the materials balance approach for estimating solid waste quantities, and the statistical techniques used to analyze waste generation rates.

Measures Used to Quantify Solid Waste Quantities

The principal reason for measuring the quantities of solid waste generated, separated for recycling, and collected for further processing or disposal is to obtain data that can be used to develop and implement effective solid waste management programs. Therefore, in any solid waste management study, extreme care must be exercised in deciding what actually needs to be known and in allocating funds for data collection. The measures and units used to quantify solid waste quantities are discussed below.

Volume and Weight Measurements. Both volume and weight are used for the measurement of solid waste quantities. Unfortunately, the use of volume as a measure of quantity can be misleading. For example, a cubic yard of loose wastes is a different quantity from a cubic yard of wastes that has been compacted in a collection vehicle, and each of these is different from a cubic yard of wastes that has been compacted further in a landfill. Accordingly, if volume measurements are to be used, the measured volumes must be related to either the degree of compaction of the wastes or the specific weight of the waste under the conditions of storage.

To avoid confusion, solid waste quantities should be expressed in terms of weight. Weight is the only accurate basis for records because tonnages can be measured directly, regardless of the degree of compaction. Weight records are also necessary in the transport of solid wastes because the quantity that can be hauled usually is restricted by highway weight limits rather than by volume. On the other hand, volume and weight are equally important with respect to the capacity of landfills.

Expressions for Unit Waste Generation Rates. In addition to knowing the sources and composition of the solid wastes that must be managed, it is equally important to be able to develop meaningful ways to express the quantities generated. Suggested units of expression for different generation sources are considered in Table 6-1. Note, however, that unit generation data for commercial and

TABLE 6-1
Suggested units of expression for solid waste quantities

Type of waste	Discussion
Residential	Because of the relative stability of residential wastes in a given location, the most common unit of expression used for their generation rates is lb/capita · d. However, should the waste composition vary significantly from typical municipal wastes (Table 3-4), the use of lb/capita · d may be misleading, especially when quantities are being compared.
Commercial	In the past, commercial waste generation rates have also been expressed in lb/capita · d. Although this practice has been continued as an expedient, it adds little useful information about the nature of solid waste generation at commercial sources. A more meaningful approach would be to relate the quantities generated to the number of customers, the dollar value of sales, or some similar unit. Use of such factors would allow comparisons to be made throughout the country.
Industrial	Ideally, wastes generated from industrial activities should be expressed on the basis of some repeatable measure of production, such as pounds per automobile for an automobile assembly plant or pounds per case for a packing plant. When and if such data are developed, it will be possible to make meaningful comparisons between similar industrial activities throughout the country.
Agricultural	Where adequate records have been kept, solid wastes from agricultural activities are now most often expressed in terms of some repeatable measure of production, such as lb of manure/1400-lb cow · d and lb of waste/ton of raw product. At present, data are available on the amounts of solid waste generated from a number of agricultural activities associated with field and row crops.

industrial activities are somewhat limited. Consequently, it has been expedient in many cases to use the same units for these activities as those used for residential wastes, as opposed to the more rational units cited in Table 6-1. The most comprehensive waste records now available are those kept at MRFs, transfer stations, and landfills.

Methods Used to Estimate Waste Quantities

Waste quantities are usually estimated on the basis of data gathered by conducting a waste characterization study, using previous waste generation data, or some combination of the two approaches. Methods commonly used to assess solid waste quantities are a (1) load-count analysis, (2) weight-volume analysis, and (3) materials-balance analysis. In this discussion, it will be helpful to remember that most measurements of waste quantities do not accurately represent what they are reported or assumed to represent. For example, in predicting residential waste generation rates, the measured rate seldom reflects the true rate because there

(a)

(b)

FIGURE 6-1
Solid waste hauled by individuals (*a*) to a convenience transfer station and (*b*) to a recycling center. In the load-count method of analysis used to determine waste quantities, the type, estimated volume, and weight of waste brought in with each vehicle is recorded. If scales are not available, average specific weight values are used to estimate the weight.

are confounding factors (e.g., onsite storage and the use of alternative disposal locations) that make the true rate difficult to assess. Most solid waste generation rates reported in the literature prior to about 1990 are actually based on measurement of the amount of waste collected, not the actual amount generated.

Load-Count Analysis. In this method, the number of individual loads and the corresponding waste characteristics (types of waste, estimated volume) are noted over a specified time period (see Fig. 6-1). If scales are available, weight data are also recorded. Unit generation rates are determined by using the field data and, where necessary, published data. The application of this method is illustrated in Example 6-1.

Example 6-1 Estimation of unit solid waste generation rates for a residential area. From the following data estimate the unit waste generation rate per week for a residential area consisting of 1200 homes. The observation location is a local transfer station that receives all of the wastes collected for disposal. The observation period was one week.

1. Number of compactor truck loads = 9
2. Average size of compactor truck = 20 yd^3
3. Number of flatbed loads = 7
4. Average flatbed volume = 2 yd^3
5. Number of loads from individual residents' private cars and trucks = 20
6. Estimated volume per domestic vehicle = 8 ft^3

Solution

1. Set up the computation table to estimate the total weight. Use the specific weight data given in Table 4-1 to convert the measured waste volumes to weight.

Item	Number of loads	Average volume, yd^3	Specific weight,[a] lb/yd^3	Total weight, lb
Compactor truck	9	20	500	90,000
Flatbed truck	7	2	225	3,150
Individual private vehicle	20	0.30	150	900
Total, lb/wk				94,050

[a] Based on limited on-site weight and volume measurements.

2. Determine the unit waste collection rate based on the assumption that each household is comprised of 3.5 people.

$$\text{Unit rate} = \frac{94{,}050 \text{ lb/wk}}{(1200 \times 3.5)(7 \text{ d/wk})}$$

$$= 3.2 \text{ lb/capita} \cdot \text{d} = 1.45 \text{ kg/capita} \cdot \text{d}$$

Comment. The difficulty in using such data is knowing whether they are truly representative of what needs to be measured. For example. how many loads were hauled elsewhere? How much waste material was separated for recycling? How much material was stored on the homeowner's premises? How much of the food waste was ground up and discharged to the sewer? All such questions tend to confound the observed data in a statistical sense.

Weight-Volume Analysis. Although the use of detailed weight-volume data obtained by weighing and measuring each load (see Fig. 6-2) will certainly provide better information on the specific weight of the various forms of solid wastes at a given location, the question remains: What information is needed in terms of study objectives?

Materials Mass Balance Analysis

The only way to determine the generation and movement of solid wastes with any degree of reliability is to perform a detailed materials balance analysis for each generation source, such as an individual home or a commercial or industrial activity. In some cases, the materials balance method of analysis will be required to obtain the data needed to verify compliance with state-mandated recycling programs.

Preparation of Materials Mass Balances. The approach to be followed in the preparation of a materials mass balance analysis is as follows. First, draw a system boundary around the unit to be studied (see Fig. 6-3). The proper selection of the system boundary is important because, in many situations, it will be possible to simplify the mass balance computations. Second, identify all the activities that cross or occur within the boundary and affect the generation of wastes. Third, identify the rate of waste generation associated with each of these activities. Fourth, using appropriate mathematical relationships, determine the

FIGURE 6-2
Weighing of collection vehicle at entrance to transfer station using platform scales. In the weight/volume method of analysis used to determine waste quantities, the volume of each truck is estimated.

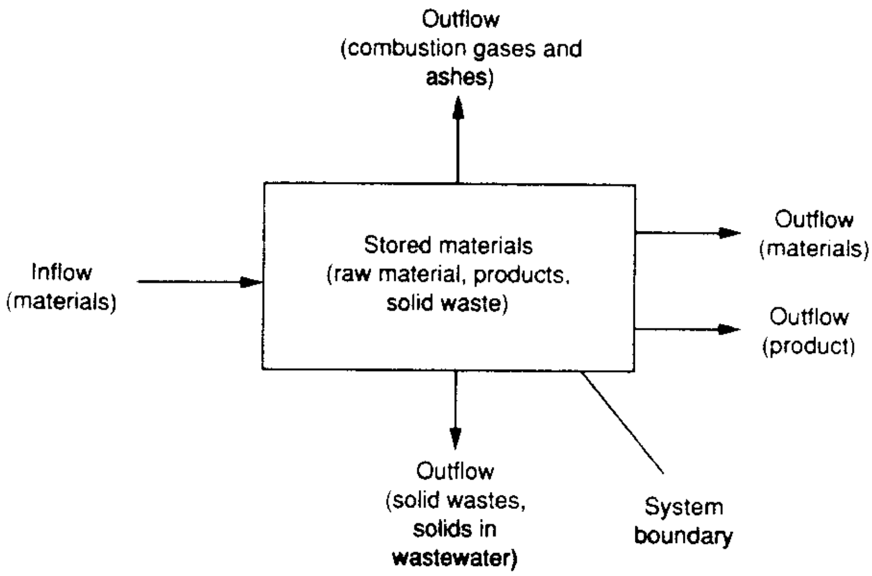


FIGURE 6-3
Definition sketch for materials balance analysis used to determine solid waste generation rates.

quantity of wastes generated, collected, and stored. The materials mass balance can be formulated as follows:

1. General word statement:

Rate of accumulation of material within the system boundary	=	rate of flow of material into the system boundary	−	rate of flow of material out of the system boundary	+	rate of generation of waste material within the system boundary	(6-1)

2. Simplified word statement:

$$\text{Accumulation} = \text{inflow} - \text{outflow} + \text{generation} \tag{6-2}$$

3. Symbolic representation (refer to Fig. 6-3):

$$\frac{dM}{dt} = \Sigma M_{in} - \Sigma M_{out} + r_w \tag{6-3}$$

where dM/dt = rate of change of the weight of material stored (accumulated) within the study unit, lb/d
ΣM_{in} = sum of all of the material flowing into study unit, lb/d
ΣM_{out} = sum of all of the material flowing out of study unit, lb/d
r_w = rate of waste generation, lb/d
t = time, d

In some biological transformation processes (e.g., composting) the weight of organic matter will be reduced and, therefore, the term r_w will be negative. In writing the mass balance equation the rate should always be written as a positive term. The correct sign for the term will be added when the appropriate rate expression is substituted for r_w. Before substituting numerical values in any mass balance expression, a unit check should always be made to ensure that units of the individual quantities are consistent. The analytical procedures used for the solution of mass balance equations usually are governed by the mathematical form of the final expression [6].

Application of Materials Mass Balance. In practice, the most difficult aspect of applying a mass balance analysis for the determination of waste quantities is defining adequately all of the inputs and outputs crossing the system boundary. A simplified materials-balance analysis is illustrated in Example 6-2.

Example 6-2 Materials-balance analysis. A cannery receives on a given day 12 tons of raw produce, 5 tons of cans, 0.5 tons of cartons, and 0.3 tons of miscellaneous materials. Of the 12 tons of raw produce, 10 tons become processed product, 1.2 tons end up as produce waste, which is fed to cattle, and the remainder is discharged with the wastewater from the plant. Four tons of the cans are stored internally for future use, and the remainder is used to package the product. About 3 percent of the cans used are damaged. Stored separately, the damaged cans are recycled. The cartons are used for packaging the canned product, except for 5 percent that are damaged and subsequently separated for recycling. Of the miscellaneous materials, 25 percent is stored internally for future use; 50 percent becomes waste paper, of which 35 percent is separated for recycling with the remainder being discharged as mixed waste; and 25 percent becomes a mixture of solid waste materials. Assume the materials separated for recycling and disposal are collected daily. Prepare a materials balance for the cannery on this day and a materials flow diagram accounting for all of the materials. Also determine the amount of waste per ton of product.

Solution

1. On the given day, the cannery receives

    12 tons of raw produce
    5 tons of cans
    0.5 tons of cartons
    0.3 tons of miscellaneous materials

2. As a result of internal activity,
    (*a*) 10 tons of product is produced, 1.2 tons of produce waste is generated, and the remainder of the produce is discharged with the wastewater
    (*b*) 4 tons of cans are stored and the remainder is used, of which 3 percent are damaged
    (*c*) 0.5 tons of cartons are used of which 3 percent are damaged
    (*d*) 25 percent of the miscellaneous materials is stored; 50 percent becomes paper waste, of which 35 percent is separated and recycled, with the remainder disposed of as mixed solid waste; the remaining 25 percent of the miscellaneous materials are disposed of as mixed waste.
3. Determine the required quantities
    (*a*) Wastes generated from raw produce
        i. Solid waste fed to cattle = 1.2 ton (1089 kg)
        ii. Waste produce discharged with wastewater = (12 − 10 − 1.2) ton = 0.8 ton (726 g)

(*b*) Cans
  i. Damaged and recycled = (0.03)(5 − 4) ton = 0.03 ton (27 kg)
  ii. Used for production of product = (1 − 0.03) ton = 0.97 ton (880 kg)

(*c*) Cartons
  i. Damaged and recycled = (0.03)(0.5 ton) = 0.015 ton (14 kg)
  ii. Cartons used in product = (0.5 − 0.015) ton = 0.485 ton (440 kg)

(*d*) Miscellaneous material
  i. Amount stored = (0.25)(0.3 ton) = 0.075 ton (68 kg)
  ii. Paper separated and recycled = (0.50)(0.35)(0.3 ton) = 0.053 ton (48 kg)
  iii. Mixed waste = (0.3 − 0.075) − 0.053) ton = 0.172 ton (156 kg)

(*e*) Total weight of product = (10 + 0.97 + 0.485) ton = 11.455 ton (10,392 kg)

(*f*) Total material stored = (4 + 0.075) ton = 4.075 ton (3696 kg)

4. Prepare a materials balance and flow diagram for the cannery for the day in question

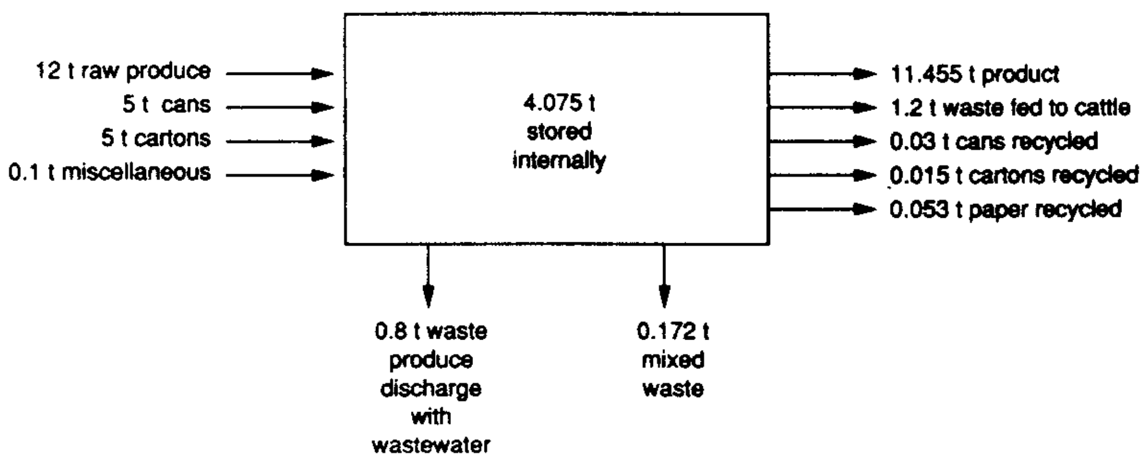
(*a*) The appropriate materials balance equation is

$$\text{Amount of material stored} = \text{inflow} - \text{outflow} - \text{waste generation}$$

(*b*) The materials balance quantities are as follows:
  i. Material stored = (4.0 + 0.075) ton = 4.075 ton
  ii. Material input = (12.0 + 5.0 + 0.5 + 0.3) ton = 17.8 ton
  iii. Material output = (10.0 + 0.97 + 0.485 + 1.2 + 0.03 + 0.015 + 0.053) ton = 12.753 ton
  iv. Waste generation = (0.8 + 0.172) ton = 0.972 ton
  v. The final materials balance is

$$4.075 = 17.8 - 12.753 - 0.972 \text{ (mass balance checks)}$$

(*c*) Materials balance flow diagram is given below



5. Determine the amount of waste per ton of product:

(*a*) Recyclable material = (1.2 + 0.03 + 0.015 + 0.053) ton/11.455 ton = 0.11 ton/ton

(*b*) Mixed waste = (0.8 + 0.172) ton/11.455 ton = 0.085 ton/ton

Comment. This simple example illustrates the computational approach involved in the preparation of a materials-balance analysis used to quantify solid waste generation rates. If the internal processing activities are more complex, the amount of work involved in arriving at a materials balance is significant. Because materials balance computations involve a considerable amount of bookkeeping, they are best done using a spreadsheet.

Statistical Analysis of Measured Waste Quantities

In developing solid waste management systems, it is often necessary to determine the statistical characteristics of the observed solid waste generation rates. For example, for many large industrial activities it would be impractical to provide container capacity to handle the largest conceivable quantity of solid wastes to be generated in a given day. The container capacity to be provided must be based on a statistical analysis of the generation rates and the characteristics of the collection system.

The first step in assessing the statistical characteristics of a series of observations is to determine whether the observations are distributed normally or are skewed (log normal). The nature of the distribution can be determined most readily by plotting the data on arithmetic and logarithmic probability graph paper (see Appendix D). Once the nature of the distribution is known, statistical measures that are used to describe the distribution include: the mean, median, mode, standard deviation, coefficient of variation, coefficient of skewness, and coefficient of kurtosis. The definitions of these measures are given in Appendix D. The determination of statistical measures for waste production data is illustrated in Example 6-3.

Example 6-3 Statistical analysis of solid waste collection data. Determine the statistical characteristics of the weekly waste production data obtained from an industrial account for a calendar quarter of operation.

Week no.	Waste, yd^3/wk	Week no.	Waste, yd^3/wk
1	29	8	37
2	30	9	38
3	35	10	35
4	34	11	33
5	38	12	32
6	41	13	31
7	40		

Solution

1. Determine graphically whether the waste production data are distributed normally or are skewed (log normal) using probability paper.

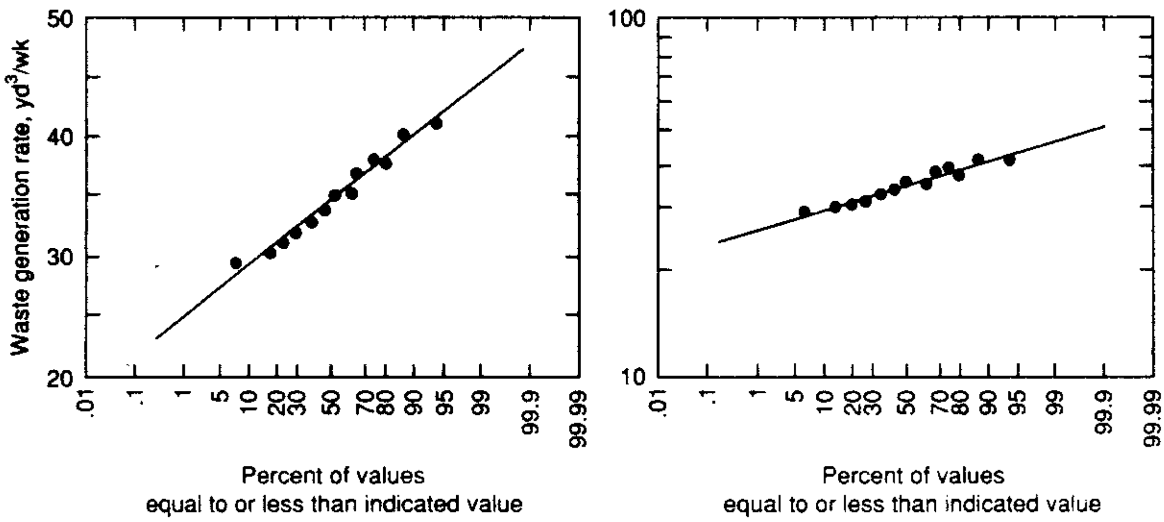
(*a*) Set up a data analysis table with three columns as described below.

i. In column 1, enter the rank serial number starting with number 1
ii. In column 2, arrange the waste production data in ascending order
iii. In column 3, enter the probability plotting position (see Appendix D)

Rank serial no., *m*	Waste, yd^3/wk	Plotting position,* %
1	29	7.1
2	30	14.3
3	31	21.4
4	32	28.6
5	33	35.7
6	34	42.9
7	35	50.0
8	35	57.1
9	37	64.3
10	38	71.4
11	38	78.6
12	40	85.7
13	41	92.9

*Plotting position = $[m/(n+1)]100$, $n = 13$

(*b*) Plot the weekly quantity of waste, expressed in yd^3/wk, versus the plotting position (determined above) on both arithmetic and logarithmic probability graph paper. The resulting plots are presented below. Because the data fall on a straight line in both plots, the waste production data can be described adequately by either type of distribution. The fact that the data can be described adequately with both distributions is often the case with waste production data.



2. Determine the statistical characteristics of the waste collection data.

(*a*) Set up a data analysis table to obtain the quantities needed to determine the statistical characteristics (refer to Appendix D for equations and definitions).

Waste, yd^3/wk	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$	$(x_i - \bar{x})^4$
29	−5.8	33.6	1131.6
30	−4.8	23.0	530.8
31	−3.8	14.4	208.5
32	−2.8	7.8	61.5
33	−1.8	3.2	10.2
34	−0.8	0.6	0.4
35	0.2	0.0	0.0
35	0.2	0.0	0.0
37	2.2	4.8	23.4
38	3.2	10.2	104.9
38	3.2	10.2	104.9
40	5.2	27.0	731.2
41	6.2	38.4	1477.6
453		173.2	4385.0
$\bar{x} = 453/13 = 34.8$			

(*b*) Determine the statistical characteristics

i. Mean

$$\bar{x} = \frac{\Sigma x}{n}$$

$$\bar{x} = \frac{453}{13} = 34.8 \text{ yd}^3/\text{wk}$$

ii. Median (the middle value)

Median = 35 yd^3/wk (see data table above)

iii. Mode

Mode = 3 Med − $2\bar{x}$ = 3(35) − 2(34.8) = 35.4

iv. Standard deviation

$$s = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n}}$$

$$s = \sqrt{\frac{173.2}{13}} = 3.65$$

v. Coefficient of variation

$$\text{CV} = \frac{100s}{\bar{x}}$$

$$\text{CV} = \frac{100(3.65)}{34.8} = 10.5$$

vi. Coefficient of skewness

$$\alpha_3 = \frac{2(\bar{x} - \text{Mod})}{s}$$

$$\alpha_3 = \frac{2(34.8 - 35.4)}{3.65} = -0.33$$

vii. Coefficient of kurtosis

$$\alpha_4 = \frac{\Sigma(x_i - \bar{x})^4/n}{s^4}$$

$$\alpha_4 = \frac{4385.0/13}{(3.65)^4} = 1.9$$

Comment. The term $(n + 1)$ is used to obtain the plotting positions in Step 1, as opposed to just n, to account for the fact that there may be an observation that is either larger or smaller than the largest or smallest in the data set. Reviewing the statistical characteristics it can be seen that the distribution is skewed ($\alpha_3 = -0.33$ versus 0 for a normal distribution) and is considerably flatter than a normal distribution would be ($\alpha_4 = 1.9$ versus 3.0 for a normal distribution).

6-3 SOLID WASTE GENERATION AND COLLECTION RATES

Data and information on the quantities of solid waste generated and collected are discussed in this section. Factors that affect the quantities generated are considered in Section 6-4.

Total Waste Generation in the United States

Based on an analysis of a number of data sources [1–4, 5, 8, 10] and on personal computations, the authors' estimate of the amount of municipal, industrial, and agricultural solid waste generated per capita in the United States for the year 1990 is reported in Table 6-2. A little over a ton of MSW is generated per capita per year in the United States. In using data on waste generation reported in the literature before about 1990, great care must be exercised because in most cases the data reported do not reflect the amount of waste generated, but are actually the amount of waste collected. As such, the quantities reported often do not

TABLE 6-2
Estimated total per capita solid waste quantities generated in the United States and selected states for the year 1990[a]

	Waste generation rate, lb/capita · yr					
	United States		California		Florida	
Waste	Range	Typical	Range	Typical	Range	Typical
MSW[b]	1450–3000	2225	1850–3500	2500	1350–2400	2200
Industrial waste	500–1750	750	750–1500	1000	250–750	500
Agricultural waste	250–3000	—[c]	1500–4000	3000	500–1500	1000
Total	2500–7750		3700–9000	6500	2050–4650	3500

[a] Developed in part from Refs. 1–4, 5, 8, 10.

[b] A detailed analysis of the waste categories that compose MSW are presented in Table 6-3.

[c] Must be estimated separately for each location.

Note: lb/capita · yr × 0.4536 = kg/capita · yr reflect the amount of waste material that was: (1) recycled (directly and indirectly), (2) ground up in kitchen food waste grinders, (3) burned in fireplaces, (4) composted, and (5) stored temporarily.

Unit Solid Waste Generation Rates

Often it is necessary to estimate the quantities of solid waste that will be generated, by waste category, within a community. Estimates of MSW quantities are usually based on the amount of waste generated per person per day. For industrial and agricultural wastes, the amounts of waste generated are, as noted in Table 6-1, based on some unit of production. The general values for industrial and agricultural waste reported in Table 6-2 must be verified locally because of the significant variations that exist in these categories.

Municipal Solid Wastes. The distribution of wastes that constitute the MSW of a community are reported in Table 6-3. If actual data are not available, the unit

TABLE 6-3
Estimated quantities for the waste categories comprising MSW generated per capita in the United States for the year 1990[a]

	Distribution of MSW, percent of total		Solid waste generation rate			
			lb/capita · yr		lb/capita · d	
Waste category[b]	Range	Typical	Range	Typical	Range	Typical
Residential and commercial, excluding special and hazardous wastes	50–75	62.0	1125–1700	1395.0	3.1–4.7	3.82
Special (bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires)	3–12	5.0	65–180	112.5	0.2–0.5	0.31
Hazardous	0.01–1.0	0.1	0.15–30	2.3	0.0004–0.082	0.0063
Institutional	3–5	3.4	65–110	76.5	0.2–0.3	0.21
Construction and demolition	8–20	14.0	180–450	315.0	0.5–1.2	0.86
Municipal services						
Street and alley cleanings	2–6	3.8	45–135	85.5	0.1–0.4	0.23
Tree and landscaping	2–5	3.0	45–110	67.5	0.1–0.3	0.19
Parks and recreational areas	1.5–3	2.0	30–65	45.0	0.08–0.2	0.12
Catch basin	0.5–1.2	0.7	10–30	15.7	0.03–0.08	0.04
Treatment plant sludges	3–8	6.0	68–180	135.0	0.2–0.5	0.37
Total		100.0		2250.0		6.16

[a] Data derived from Tables 3-3 and 6-2.

[b] See Table 6-2 for industrial and agricultural waste quantities.

Note: lb/capita · yr × 0.4536 = kg/capita · yr.

waste generation rates for MSW given in Table 6-3 can be used for estimating purposes.

Residential and commercial. As reported in Table 6-3, residential and commercial wastes, excluding special and hazardous wastes, comprise about 50 to 75 percent of the total MSW of a community. The individual components that comprise the residential and commercial portion of MSW were presented and discussed in Chapter 3 (see Table 3-7). The residential and commercial MSW generation data presented in Table 6-3 should be adjusted to reflect local conditions. For example, if kitchen food waste grinders are used extensively, the total quantity of MSW should be reduced by an appropriate amount. Information and data to use for estimating the distribution of special wastes are given in Table 6-4.

Institutional. As noted in Chapter 3, institutional sources of solid waste include schools, prisons, and hospitals. Excluding manufacturing wastes from prisons and medical wastes from hospitals, the distribution of waste components in the solid wastes generated at these facilities is quite similar to commingled residential and commercial MSW.

Construction and demolition. The quantities of construction and demolition waste are difficult to estimate and variable in composition, but typically

TABLE 6-4
Information and data that can be used to estimate the generation of residential and commercial special wastes[a]

Special waste	Information for estimating quantities
Bulky items, consumer electronics, and white goods	Best approach is to determine the number of homes, estimate the number of items per home, and use an average useful life for each item. Items recycled through charitable organizations must also be accounted for.
Household batteries	2.5 billion household batteries are purchased annually in the United States. A value of 10 household batteries/capita · yr can be used for estimating purposes.
Automotive (lead-acid) batteries	70 to 80 million automotive batteries are consumed and replaced annually in the United States. A value of 0.4 automotive batteries/capita · yr can be used for estimating purposes.
Used oil	200 million gallons of waste oil are generated annually by do-it-yourself oil changers. A value of 0.80 gal waste oil/capita · yr can be used for estimating purposes.
Automotive tires (passenger vehicles and light trucks)	190 million tires are discarded annually in the United States. A value of 0.80 tire/capita · yr can be used for estimating purposes. An alternative approach to estimating the number of waste tires generated per year is to estimate the number of cars and to use an average value for miles traveled per year (12,000 mi) and an average tire life (e.g., 35,000 mi/tire).

[a] Information abstracted from Chapter 15 of this text.

the distribution is about 40 to 50 percent rubbish (concrete, asphalt, bricks, blocks, and dirt), 20 to 30 percent wood and related products (pallets, stumps, branches, forming and framing lumber, treated lumber, and shingles), and 20 to 30 percent miscellaneous wastes (painted or contaminated lumber, metals, tar-based products, plaster, glass, white goods, asbestos and other insulation materials, and plumbing, heating and electrical parts).

Selected Industrial and Agricultural Wastes. Unit waste generation rates for selected industrial and agricultural activities are reported in Table 6-5. The rates given in this Table are related to some unit of production. By relating the unit rates of waste generation to some unit of production, comparisons can be made between facilities producing the same product in different parts of the country.

Solid Waste Collection Rates

Wastes that are collected include commingled wastes (in communities without recycling programs) and commingled wastes and source-separated wastes (in communities with recycling programs). The difference between the amount of residential and commercial MSW generated and the amount of waste collected for processing and/or disposal will typically vary from 4 to 15 percent. The differences can be accounted for by the amount of material (1) composted, (2) burned in fireplaces, (3) discharged to sewers, (4) given to charitable agencies, (5) sold at garage sales, (6) delivered to drop-off and recycling centers, and (7) recycled directly. In general, the percentage difference between the amount generated

TABLE 6-5
Unit solid waste generation rates for selected industrial and agricultural sources

Source	Unit	Range
Industrial		
Canned and frozen foods	ton/ton of raw product	0.04–0.06
Printing and publishing	ton/ton of raw paper	0.08–0.10
Automotive	ton/vehicle produced	0.7–0.9
Petroleum refining	ton/employee · d	0.04–0.05
Rubber	ton/ton of raw rubber	0.01–0.3
Agricultural		
Manures		
Chickens (fryers)	ton/1000 birds · yr	45–50
Hens (layers)	tons/1000 birds · yr	45–50
Cattle	lb/head · d	85–120
Fruit and nut crops	tons/acre · yr	1.3–2.5
Field and raw crops	tons/acre · yr	1.5–4.5

Note: tons × 907.2 = kg
lb × 0.4536 = kg

and collected will be smaller (4 to 6 percent) for apartments than for individual residences with adequate space for backyard composting (8 to 15 percent).

Variation in Generation and Collection Rates

The quantities of solid waste generated and collected vary daily, weekly, monthly, and seasonally. Information on the variations to be expected in the peak and minimum waste generation rates for solid wastes generated from individual residences, small commercial establishments, and small and large communities is presented in Table 6-6. This information can be used as a guide in the selection of equipment and in the sizing of solid waste management units. As shown in Table 6-6, the largest variation in waste generation rates occurs with individual residences and small commercial establishments. Residential waste generation rates usually peak during Christmas holiday season and during spring housecleaning days. In many communities, unlimited collection service is provided on designated clean-up days. In general, as the size of the waste source increases (e.g., from individual residences to a community) the variation in the peak day, week, and month decreases. Typical monthly weight data from a transfer station are shown in Fig. 6-4. Because of the random waste generation pattern illustrated in Fig.6-4, total weight data collected on a given month can be significantly in error. For example, if the weight for the month of February were used for estimating waste quantities, the actual average quantity would have been underestimated by 40 percent.

TABLE 6-6
Peak and minimum waste generation factors for solid wastes generated from individual residences, small commercial establishments, and small and large communities[a]

	Individual residence		Small commercial establishment		Small community		Large community	
Factor[b]	Range	Typical	Range	Typical	Range	Typical	Range	Typical
			Peak waste generation factors					
Peak day	2.0–4.0	3.0	1.75–3.5	2.5	1.5–2.5	2.0	1.5–2.25	1.9
Peak weeks	1.5–3.5	2.5	1.5–2.5	2.25	1.25–2.0	1.75	1.25–2.0	1.5
Peak month	1.25–2.5	2.0	1.25–2.0	1.75	1.25–1.75	1.5	1.15–1.75	1.25
			Minimum waste generation factors					
Minimum day	0.15–0.5	0.20	0.25–0.5	0.4	0.35–0.6	0.5	0.5–0.7	0.6
Minimum week	0.25–0.6	0.5	0.4–0.6	0.5	0.5–0.7	0.6	0.6–0.8	0.7
Minimum month	0.5–0.7	0.6	0.5–0.7	0.65	0.6–0.8	0.7	0.7–0.9	0.8

[a] The reported factors are exclusive of extreme waste generation events (i.e., values greater than the 99- or less than the 1-percentile value).

[b] Ratio of peak or minimum values to average value.

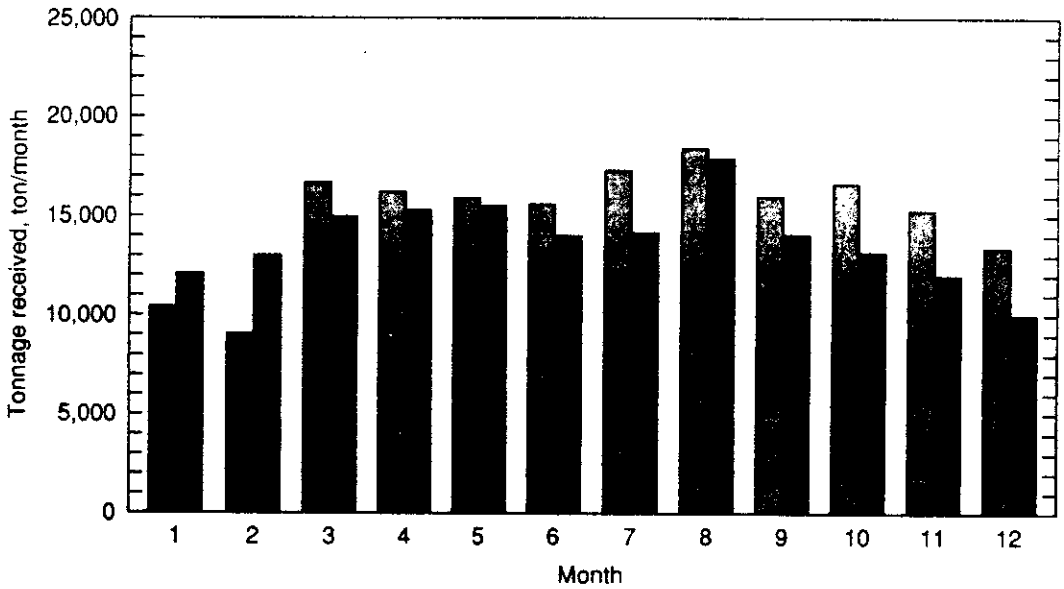


FIGURE 6-4
Variation in the monthly quantity of solid waste received at a transfer station over a two-year period.

6-4 FACTORS THAT AFFECT WASTE GENERATION RATES

The affect of (1) source reduction and recycling activities, (2) public attitudes and legislation, and (3) geographic and physical factors on the generation of solid waste are considered in the following discussion.

Effect of Source Reduction and Recycling Activities on Waste Generation

The effects of source reduction and the extent of recycling activities on waste generation are considered in the following discussion.

Source Reduction. Waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, minimum volume of material, and/or a longer useful life. Waste reduction may also occur at the household, commercial or industrial facility through selective buying patterns and the reuse of products and materials. Because source reduction is not a major element in waste reduction at the present time, it is difficult to estimate the actual impact that source reduction programs have had (or will have) on the total quantity of waste generated. Nevertheless, source reduction will likely become an important factor in reducing the quantity of waste generated in the future. For example, if the postage rate for bulk mail were increased significantly, the quantity of bulk mail would be reduced sharply. Some of the other ways in which source reduction can be achieved follow:

- Decrease unnecessary or excessive packaging (see Fig. 6-5)
- Develop and use products with greater durability and repairability (e.g., more durable appliances and tires)
- Substitute reusable products for disposable, single-use products (e.g., reusable plates and cutlery, refillable beverage containers, cloth diapers and towels)
- Use fewer resources (e.g., two-sided copying)
- Increase the recycled materials content of products
- Develop rate structures that encourage generators to produce less waste [8]

Extent of Recycling. The existence of recycling programs within a community definitely affects the quantities of wastes collected for further processing or disposal. Whether such operations affect the quantities of waste generated is another question. Until more information is available, no definite statement can be made on this issue.

Effect of Public Attitudes and Legislation on Waste Generation

Along with source reduction and recycling programs, public attitudes and legislation also significantly affect the quantities generated.

Public Attitudes. Ultimately, significant reductions in the quantities of solid wastes generated occur when and if people are willing to change—of their own volition—their habits and lifestyles to conserve natural resources and to reduce the economic burdens associated with the management of solid wastes. A program of continuing education is essential in bringing about a change in public attitudes.

States with Beverage Container Deposit Laws. A number of states now have beverage container deposit laws. The first was enacted in Oregon in 1972. In the

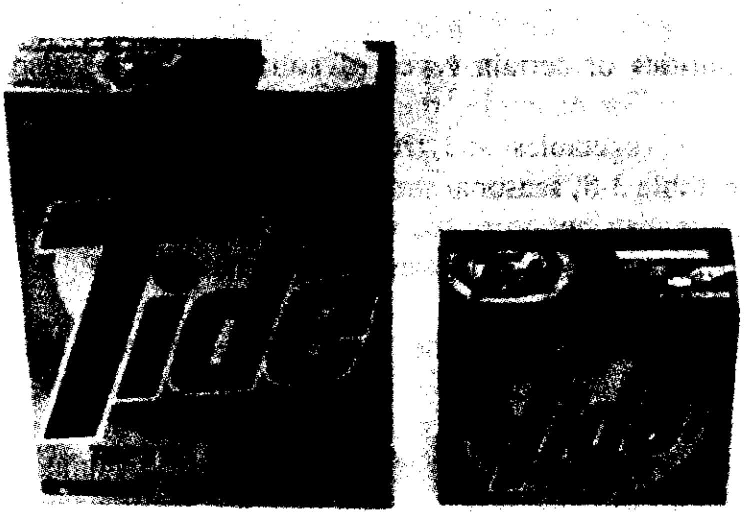


FIGURE 6-5
Reducing the size of the packaging required by reformulating product strength. Original strength on left and concentrated product strength on right.

states with container deposit laws, the return rates for bottles and cans vary from 93 to 96 percent and 90 to 96 percent, respectively [10]. It is anticipated that more states will enact container deposit laws covering a wide variety of container types not now included.

Legislation. Perhaps the most important factor affecting the generation of certain types of wastes is the existence of local, state, and federal regulations concerning the use of specific materials. Legislation dealing with packaging and beverage container materials is an example. Encouraging the purchase and use of recycled materials by allowing a price differential (typically 5 to 10 percent) for recycled materials is another method.

Effect of Geographic and Physical Factors on Waste Generation

Geographic and physical factors that affect the quantities of waste generated and collected include location, season of the year, the use of kitchen waste food grinders, waste collection frequency, and the characteristics of the service area. Because broad generalizations are of little or no value, the impact of these factors must be evaluated separately in each situation.

Geographic Location. The influence of geographic location the different climates that can influence both the amount of certain types of solid wastes generated and the time period over which the wastes are generated. For example, substantial variations in the amount of yard and garden wastes generated in various parts of the country are related to climates. That is, in the warmer southern areas, where the growing season is considerably longer than in the northern areas, yard wastes are collected not only in considerably greater amounts but also over a longer time. Because of the variations in the quantities of certain types of solid wastes generated under different climates, special studies should be conducted when such information will have a significant impact on the system. Often, the necessary information can be obtained from a load-count analysis.

Season of the Year. The quantities of certain types of solid wastes are also affected by the season of the year. For example, the quantities of food wastes related to the growing season for vegetables and fruits. Because of the wide variations reported previously in Table 3-8, seasonal sampling also will be required to assess changes in the percentage distribution of the waste materials comprising the MSW, especially in areas of the country with extensive vegetation.

Use of Kitchen Food Waste Grinders. While the use of kitchen food waste grinders definitely reduces the quantity of kitchen wastes collected, whether they affect quantities of wastes generated is not clear. Because the use of home grinders varies widely throughout the country, the effects of their use must be evaluated separately in each situation if such information is warranted. Unit waste allowances made in the field of wastewater treatment for estimating the additional suspended solids per capita contributed from homes with food grinders varies from 0.03 to 0.08 lb/capita · d [8]. Typically, the values used in the wastewater field only reflect the increase in solids removed at wastewater treatment facilities and do not reflect the material that has solubilized in the process of being transported. More realistic values for estimating the effect of food waste grinders are 0.08 to 0.12 lb/capita · d. Alternatively, for homes with food waste grinders one can assume that 25 to 33 percent of the total amount of food waste generated is ground up. The impact of kitchen food waste grinders on the weight and volume of waste collected is illustrated in Example 6-4.

Example 6-4 Impact of food waste grinders on weight and volume of solid wastes collected. The kitchen food waste grinder in a detached single-family dwelling has gone "on the fritz." Estimate the increase in both the volume and the weight of solid wastes to be collected over a one-week period. Also estimate what percentage of the food waste is ground up. Assume that the family has four members and that the collection frequency is once per week. Assume the amount of food waste that is normally ground up equals 0.10 lb/capita · d.

Solution

1. Estimate the total weekly solid waste production rate using the data from Table 6-3.

   Solid waste production, lb/wk

   $$= 4 \text{ persons} \times 7 \text{ d/wk} \times 3.82 \text{ lb/capita} \cdot \text{d} = 107.0 \text{ lb/wk}$$

2. Set up a computation table to determine the volume occupied by the total amount of solid waste generated in one week. Use the weight distribution data given in Table 3-7, column 3 (solid waste as collected plus ground up food waste) and the specific weight values given in Table 4-1.

Component	Solid wastes, %	Solid wastes, lb	Specific weight, lb/ft³	Volume, ft³
Organic				
Food wastes	9.4	10.1	18.1	0.56
Paper	33.8	36.3	5.6	6.48
Cardboard	6.0	6.4	3.1	2.06
Plastics	7.0	7.5	4.1	1.83
Textiles	2.0	2.1	4.1	0.51
Rubber	0.5	0.5	8.1	0.06
Leather	0.5	0.5	10.0	0.05
Yard wastes	18.4	19.7	6.7	2.94
Wood	2.0	2.1	14.8	0.14
Inorganic				
Glass	7.9	8.5	12.2	0.70
Tin cans	6.0	6.4	5.6	1.14
Aluminum	0.5	0.5	10.0	0.05
Other metal	3.0	3.2	20.0	0.16
Dirt, ashes, etc.	3.0	3.2	30.0	0.11
Total	100.0	107.0		16.79

3. Estimate the total amount of food waste that is discharged weekly to the sewer.

   Food waste discharged to sewer, lb/wk

   $$= 4 \text{ persons } \times 7 \text{ d/wk } \times 0.10 \text{ lb/capita} \cdot \text{d} = 2.8 \text{ lb/wk}$$

4. Compute the percentage of food waste that is ground up.

   $$\text{Percentage of food waste that is ground up} = (2.8 \text{ lb}/10.1 \text{ lb}) \times 100 = 27.7\%$$

5. Compute the weight and volume of solid waste without the food waste.

   $$\text{Weight} = 107.0 \text{ lb/wk} - 2.8 \text{ lb/wk} = 104.2 \text{ lb/wk}$$

   $$\text{Volume} = 16.8 \text{ ft}^3 - (2.8 \text{ lb}/18.1 \text{ lb/ft}^3) = 16.6 \text{ ft}^3$$

6. Compute the percent increase in weight and volume when the food waste that is now ground up is added to the solid waste.

   $$\text{Increase in weight,\%} = (2.8 \text{ lb}/104.2 \text{ lb}) \times 100 = 2.7$$

   $$\text{Increase in volume, \%} = [(16.8 - 16.6)/16.6] \times 100 = 1.2$$

Comment. Note that the removal of food waste from the residential waste stream results in a minor reduction in weight and has a minimal effect on volume. In fact, it could be argued that the food waste would take up even less space because it would tend to fill the void space that already exists in the solid waste placed in storage containers.

Frequency of Collection. In general, where unlimited collection service is provided, more wastes are collected. This observation should not be used to infer that more wastes are generated. For example, if a homeowner is limited to one or two containers per week, he or she may, because of limited container capacity, store newspapers or other materials; with unlimited service, the homeowner would tend to throw them away. In this situation the quantity of wastes generated may actually be the same, but the quantity collected is considerably different. Thus, the fundamental question of the effect of collection frequency on waste generation remains unanswered.

Characteristics of Service Area. Pecularities of the service area can influence the quantity of solid wastes generated. For example, the quantities of yard wastes generated on a per capita basis are considerably greater in many of the wealthier neighborhoods than in other parts of town. Other factors that will affect the amount of yard waste include the size of the lot, the degree of landscaping, and the frequency of yard maintenance.

6-5 QUANTITIES OF MATERIALS RECOVERED FROM MSW

The estimated percentages of total amount of waste material that is now (1992) recovered from MSW by waste category are reported in Table 6-7. For residential and commercial recycling in the United States estimates vary from about 12 to 16 percent. Information on the other sectors is so site-specific that few general-

TABLE 6-7
Materials and estimated amounts currently recovered for recycling in the United States (1992)[a]

Material	Percentage of total amount of waste material generated that is now recovered for recycling	Remarks
Aluminum	60–70	Primarily beverage containers
Paper	30–40	
Cardboard	40–50	
Plastics	4–5	Overall; 150 × 10^6 lb of plastic soft drink bottles were recycled in 1987 (about 20%)
Glass	6–10	
Ferrous metal	15–25	
Nonferrous metals	10–15	
Yard waste (compost)	5–10	Compost; biomass fuel
Refuse-derived fuel	<1	Produced from organic fraction of MSW
Construction and demolition wastes	15–25	
Wood	5–10	
Waste oil	20–30	
Tires	40–50	
Lead–acid batteries	75–85	
Household batteries	<1	
Overall total for United States based on weight[b]	12–16	

[a] Adapted in part from Refs. 1–4, 8–10.

[b] Reported values vary depending on the basis used for the computation.

izations are possible. At the present time, the degree of recycling depends on the type of recycling program that is in effect and on local regulations. Methods for determining existing recycling rates are considered further below.

6-6 QUANTITIES OF HOUSEHOLD HAZARDOUS WASTES

Special household wastes—including hazardous waste, used oil, old tires, and white goods—and construction and demolition wastes, are not usually collected with other municipal solid waste. As noted in Chapter 5, small amounts of hazardous waste compounds are, at present, normal constituents of solid wastes from residential (see Fig. 5-1), commercial, and light industry sources. Data on the quantities of hazardous waste are quite variable, depending on the method used to classify the hazardous waste materials. The results of a recently completed study of the hazardous waste constituents present in municipal waste are summarized in Table 6-8 [1]. The quantities reported in Table 6-8 were determined on the basis of their toxicity using the criteria given In Table 6-9. Only those compounds with

TABLE 6-8
Estimated annual tonnage of designated household hazardous waste in California solid waste[a]

Generic hazardous material	Concentration, ppm	Annual weight,[b] tons
Non-chlorinated organics	87	2,697
Chlorinated organics	0.2	6
Other organics	9	279
Pesticides	0.1	3
Latex (water base) paint	394	12,214
Oil-based paints	76	2,356
Waste oil	61	1,891
Automobile battery	1,661	51,491
Household battery	668	20,708
Total		91,645

[a]From Ref. 1.

[b]Based on a generation rate of 31 million tons per year.

a toxicity rating greater than four were considered in developing the data reported in Table 6-8. Using the data given in Table 6-8, the percentage of hazardous waste in the MSW generated in California is about 0.3 percent. If automotive batteries are excluded from the data reported in Table 6-7, the percentage of hazardous waste in the MSW is about 0.13 percent, essentially the same as the average value given in Table 6-3. If automotive and household batteries are excluded, the corresponding percentage is about 0.06 percent. Depending on the definition used for hazardous wastes, it is clear that a wide range of percentages can be reported.

Because different definitions are used in assessing the quantities of hazardous waste in municipal waste it is difficult to draw any firm conclusions concerning the actual quantities involved. It is interesting to note that if the tons of household

TABLE 6-9
Criteria used to classify hazardous wastes found in MSW with respect to toxicity[a,b]

Toxicity rating	Probable oral lethal dose
6—Super toxic	< 5 mg/kg
5—Extremely toxic	5–50 mg/kg
4—Very toxic	50–500 mg/kg
3—Moderately toxic	0.5–5 g/kg
2—Slightly toxic	5–15 g/kg
1—Probably nontoxic	> 15 g/kg

[a]From Ref. 1.

[b]Materials with a toxicity rating of 4 and above were used to develop the quantity data reported in Table 6-8.

batteries reported in Table 6-8 are projected for the United States using the data given in Table 6-2, the total amount would be about 160,000 tons per year. Given that a typical household battery weighs 50 grams, the corresponding number of batteries is 2,910,000,000. By comparison, it is estimated that more than 2,700,000,000 battery units were purchased in the United States in 1990 (see Chapter 15). If half the household batteries were alkaline, and it is assumed that each battery contains about 1200 mg of mercury, then, based on the data reported in Table 6-8, 1923 tons of mercury would enter the environment each year in California alone. This mercury is enough to kill 8,730,000,000 people based on a lethal dose of 200 mg per person. Clearly, the proper disposal of household batteries is an important issue that must be addressed.

6-7 WASTE CHARACTERIZATION AND DIVERSION STUDIES

As communities across the United States strive to comply with federal- and state-mandated diversion goals (25 percent by 1995 and 50 percent by the year 2000 in California), information must be available on the types and quantities of waste generated; on the types and quantities of waste currently separated for recycling, or otherwise diverted from landfill disposal; and on the types and quantities of waste collected for further processing or disposal. This information must be developed to define the current situation and to demonstrate that the mandated recycling goals will be met in the future.

Waste Characterization

The goal of a waste characterization study is to identify the sources, characteristics, and quantities of the waste generated. Waste characterization studies are difficult to perform because of the large number of sources and the limited number of waste samples that can be analyzed. The typical steps involved in a waste characterization study are as follows.

1. Gather Existing Information
   The use of existing information can save money, time, and serve as a cross reference. Existing information sources include
   - Previous solid waste management and planning studies and documents
   - Waste collection company records (public and private)
   - Processing facility records (e.g., composting facilities, incineration facilities, etc.)
   - Landfill and transfer station records
   - Previous waste disposal studies
   - Information from comparable communities
   - Department of Public Works
   - Utilities
   - Retail trade reports
   - Community employment records (Chamber of Commerce)

2. Identify Waste Generation Sources and Waste Characteristics
   - Sources
     - Residential
     - Commercial
     - Institutional
     - Construction and demolition
     - Municipal services
     - Water and wastewater treatment plants
     - Industrial
     - Agricultural
   - Develop waste categories (see Table 6-10, see also Table 3-10). The need for a detailed analysis of the individual waste components within each waste

TABLE 6-10
Typical waste categories that have been used for MSW characterization studies

Waste category	Types of waste
Residential and commercial	
Food waste	Wastes from the handling, preparation, cooking, and eating of foods
Paper	Old newspaper, high-grade (e.g., office, computer, etc.) paper, magazines, mixed paper, and other nonusable paper (e.g., wax impregnated, carbon paper, thermal FAX paper)
Cardboard	Old corrugated cardboard/kraft (recyclable, contaminated)
Plastics	PETE (soft drink bottles), HDPE (milk and water containers and detergent bottles), mixed (comingled) plastics, other plastics (PVC, LDPE, PP, and PS), film plastic
Textiles	Clothing, rags, etc.
Rubber	All types of rubber products excluding motor vehicle tires
Leather	Shoes, coats, jackets, upholstery
Yard wastes	Grass clippings, leaves, bush and tree trimmings, other plant materials
Wood	Waste building materials, wooden pallets
Miscellaneous	Disposable diapers
Glass	Container glass (clear, amber, green), flat glass (e.g., window glass), other noncontainer glass materials
Aluminum	Beverage containers, secondary aluminum (window frames, storm doors, siding, and gutters)
Ferrous metals	Tin cans, appliances and cars, other iron and steel
Special wastes	
Bulky items	Furniture, lamps, bookcases, file cabinets, etc.
Consumer electronics	Radios, stereos, television sets, etc.
White goods	Large appliances (stoves, refrigerators, washers, dryers)

(*continued*)

category presented in Table 6-10 will depend on the uses to be made of the information that is to be gathered.

3. Develop Sampling Methodology
   - Sample identification and characteristics including
     Source(s)
     Size of sample (e.g., pounds of waste separated)
     Number of samples needed for statistical significance
   - Duration of sampling period
   - Time of year
4. Conduct Field Studies
5. Conduct Market Surveys for Special Wastes
6. Assess Factors Affecting Waste Generation Rates

TABLE 6-10 (*continued*)

Waste category	Types of waste
Residential and commercial (*cont.*)	
Special wastes (*cont.*)	
Yard wastes collected separately	Grass clippings, leaves, bush and tree trimmings, tree stumps
Batteries	Household (alkaline, carbon-zinc, mercury, silver, zinc, and nickel-cadmium). Motor vehicle (lead-acid batteries)
Oil	Used oil from automobiles and trucks
Tires	Worn-out tires from automobiles and trucks
Hazardous	See generic product listings in Chapter 5
Institutional	Same types of waste as cited above under the categories of residential and commercial
Construction and demolition	Dirt; stones; concrete; bricks; plaster; lumber; shingles; and plumbing, heating, and electrical parts. Wastes from razed buildings, broken-out streets, sidewalks, bridges, and other structures
Municipal services	
Street and alley cleanings	Dirt, rubbish, dead animals, abandoned automobiles
Tree and landscaping	Grass clippings, bush and tree trimmings, tree stumps, old metal and plàstic pipe
Parks and recreational areas	Food wastes, newspaper, cardboard, mixed paper, soft drink bottles, milk and water containers, mixed plastics, clothing, rags, etc.
Catch basin	General debris, sand, used oil mixed with debris, etc.
Treatment plant residuals	Water and wastewater treatment plant sludges, ash from combustion facilities
Industrial	Varies with each region of the country
Agricultural	Varies with each region of the country

Assessment of Current Waste Diversions

The goal of a waste diversion study is to identify the types and quantities of waste materials that are now separated for recycling or otherwise diverted from disposal in landfills (see Table 3-10). The typical steps involved in a waste diversion study are as follows.

1. Gather Existing Information. Existing information sources include
   - Previous solid waste management studies
   - Previous waste diversion studies
   - Curbside recycling programs (public and private)
   - Materials recovery facilities (MRFs)
   - Buy-back centers
   - Drop-off centers
   - Tire and oil recycling centers
   - Private haulers (special wastes)
   - Charitable and service organizations
2. Develop Methodology for Estimating the Quantities of Waste Now Diverted
   - Residential
   - Commercial
   - Institutional
   - Construction and demolition
   - Municipal services
   - Water and wastewater treatment plants
   - Industrial
   - Agricultural
3. Identify Other Existing Activities
4. Conduct Field Studies
5. Assess Factors Affecting Waste Diversion Rates

Analysis of Total Waste Generated and Diverted

To assess the quantity of waste that is currently diverted, it will be necessary to first develop data on the total quantity of waste generated. The total waste generated will be made up of the amount of waste now placed in a landfill and the amount of waste now diverted. In determining the amount of waste diverted, a number of ambiguities will arise in the interpretation of what exactly is a waste material. Some states have ruled that the federal- and state-mandated diversion percentages (i.e., 25 and 50 percent) must be based on waste materials that are now discharged to landfills. Thus, if a material is considered a waste by a discharger, but is now totally recycled it could not be considered in determining the percentage diversion.

6-8 DISCUSSION TOPICS AND PROBLEMS

6-1. Consider a household that generates a certain amount of wastes per day. Of this amount, bottles and cans represent 20 percent (by weight) and are recycled by the family. Twenty percent of the paper wastes (32 percent total) is burned in the fireplace. The remaining papers along with the rest of the wastes are put into containers for collection. On a given day, 20 lb of consumer goods (food, newspapers, magazines, etc.) are brought into the house. The family consumes 7 lb of food that day, and 5 lb of food is stored. The magazines received represent 5 percent of the paper wastes of the day, and they are not thrown away. Draw a materials flow diagram of this problem and calculate the amount of solid wastes disposed of during this day.

6-2. Each week Segovia's grocery receives several shipments of fresh produce from a produce wholesaler. Even in midwinter, shipments of fresh produce arrive from the Southern Hemisphere. (As a loss leader Segovia's will sell grapes from Chile during the Northern Hemisphere's winter at a price close to that of local grapes during the late summer. The low price of these grapes will induce shoppers to come to the store, and they will buy other items while shopping there. Naturally, many grapes are sold at these prices.)

The consumption of fresh produce generates very little waste compared with more highly processed foods, but there is still waste. A shipment of Chilean grapes arrives at Segovia's in wooden boxes that contain 20 lbs of grapes. The boxes arrive strapped to pallets, 72 boxes to a pallet. Each box weighs 2.5 lbs empty and each pallet weighs 20 lbs. The boxes and pallets are crushed, bundled and sent to the landfill. In addition, there are a certain number of pieces of fruit that are damaged, loose, or otherwise unsalable. These are also thrown away.

Segovia's purchases paper bags with the store logo printed on them. These are distributed one per customer. Produce is packaged in plastic bags that are purchased by weight. The produce is weighed at the cash register, and the weight is recorded on the cash register tape. The weight of the plastic bags containing the produce is included in this weight.

One midweek shipment to Segovia's from the wholesaler consists of the following:

7200 lbs of Chilean seedless grapes
5000 lbs of Honduran bananas
20 gross of paper bags (1 gross = 12 dozen)
50 lbs of plastic produce bags

Assume that these plastic bags are used only in the banana and grape section of the store and, in the interest of the environment, shoppers do not use plastic bags for their bananas. At week's end it is found that all of the plastic bags have been used. There were 522 customers who shopped; they purchased 7142 lbs of grapes and 4544 lbs of bananas. Five customers were so overwhelmed at the bargain price of grapes that they bought an entire box (taking the box). Bananas are packaged in boxes of 50 lbs net. The banana boxes are cardboard and weigh 2 lbs. Bananas arrive in loose boxes—not on pallets. Compute a materials balance for the midweek produce shipment. (Courtesy of Robert Anex.)

6-3. Consider a privately owned retail business that sells metal accessories. The business receives approximately 250 lbs of new merchandise every day. Since much of the merchandise sold must be matched to an old sample for verification, most customers bring their old merchandise into the store. A number of customers leave their old parts behind to be disposed of by the business. It is estimated that about 20 percent of the total amount of metal sold is brought in and left by customers.

Of the amount of total merchandise received, approximately 9 percent of the weight is in packaging material (paper and cardboard). Eighty-seven percent of the packaging material is cardboard, of which 60 percent is recycled after the merchandise is unpacked. About 7 percent of the paper and 15 percent of the cardboard is sold with merchandise over the counter. The remaining paper and cardboard is disposed of in the dumpster.

The remaining weight of merchandise is metal parts and chemicals. Chemicals make up 11 percent of the total and all but 10 percent are sold daily. The remaining 10 percent is used within the business for cleaning equipment and is disposed of as hazardous waste. Seventy-eight percent of the metal parts are sold per day with the remainder stored internally. Perform a mass balance and a flow diagram. (Courtesy of Paul Renter.)

6-4. A small family-owned and operated orchard sells apples and cider daily during the fall. On a particular day in October, the store processing facility receives 300 bushels of unsorted apples. Each bushel of apples is transported in a wooden crate. Crates weigh 4 lbs each, and a bushel of apples weighs 40 lbs.

Also delivered to the store are containers in which the apples and cider will be sold: for the apples, 500 one-bushel cardboard boxes with a total weight of 100 lbs, and for the cider, 200 one-gallon plastic jugs with a total weight of 20 lbs. As the containers are unloaded, it is found that 2 percent of the contents of each container are damaged and must be discarded.

During the day, all of the apples harvested are sorted into one of the following categories by weight:

1. Cider apples—20 percent (average)
2. Utility apples—20 percent (average)
3. USDA Grade A apples—remainder of the apples

. The sales for this day were:

1. 75 gallons of cider
2. All bushels of utility apples
3. 140 bushels of Grade A apples

A container is provided with each gallon of cider or bushel of apples. Discounts are given to customers with their own containers. On the average, 20 percent of the apple and cider customers have their own containers. At the end of the day, all remaining unsold cider is stored in a bulk tank. The unsold apples are stored in wooden crates, except for 10 bushels that are placed in cardboard bushel containers, displayed and ready for sale for the next day. All empty wooden crates are removed and transported back to the orchard except for damaged crates, which are stored and repaired at the facility. On average, 5 percent of the wooden crates need repair.

From the above information, draw a materials flow diagram and calculate the amount of solid waste disposed of during this day. Assume the density of apple cider is 8.5 lbs/gal. (Courtesy of Linda Allen.)

6-5. An auto salvage yard receives each day, on the average, two junked cars weighing 4000 lbs apiece. Each car includes

5 qts motor oil
12 qts transmission oil
1 qt steering oil
5 qt clutch oil
4 gal dilute antifreeze mixture

2 gal gasoline
1 oil filter
1 transmission oil filter
4 rubber tires

Once the car has been stripped of these, the remaining weight distribution is

20 percent nonrecyclable materials
80 percent recyclable steel, aluminum, etc.

Each day the yard sells 2 complete engines, which represent 20 percent of the car's weight once the fluids, tires, oil filters, and brake shoes have been removed. Also sold each day are

80 lbs of misc. metal parts
15 lbs of misc. nonmetal parts
2 rubber tires

Each day after sales, 50 percent of the remaining nonrecyclable material is shipped to the landfill and 25 percent of recyclable metals and 2 rubber tires are recycled. The rest are stored for future sales.

Prepare a materials mass balance analysis assuming that the oils have a density of 1 lb/qt, other toxic liquids have a density of 5 lb/gal, the tires weigh 25 lbs each, the asbestos brake shoes, oil filter, and transmission filter weigh 10 lbs combined. (Courtesy of William Sutcliffe.)

6-6. The residential and commercial solid wastes of a city of 25,000 people are collected on Tuesday and Saturday mornings. The volume of wastes collected has been recorded for one year, and the data are given below. Prepare a frequency histogram for each collection day. Find the mean, median, mode, standard deviation, and coefficient of variation for each distribution (see Appendix D). Discuss briefly the nature of the distribution and its significance.

Generation rate, yd^3/collection	Frequency	
	Tuesday	Saturday
800–899	0	0
900–999	0	0
1000–1099	4	1
1100–1199	9	3
1200–1299	14	4
1300–1399	11	9
1400–1499	7	11
1500–1599	4	10
1600–1699	2	7
1700–1799	0	4
1800–1899	1	2
1900–1999	0	1

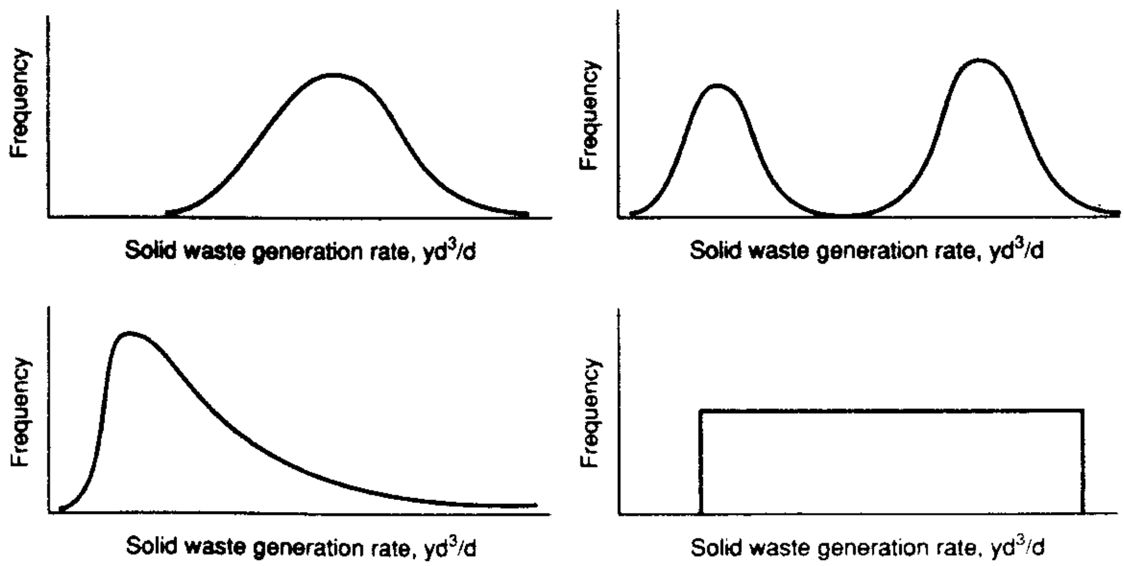
6-7. Given the following daily solid waste generation data for a period of 10 days for location A, determine the type of distribution, mean, standard deviation, and coefficient of variation.

	Generation rate, yd^3/d			
	Location			
Day	A	B	C	D
1	34	10	20	38
2	48	20	28	46
3	290	110	33	52
4	61	120	39	54
5	205	70	34	40
6	170	140	24	41
7	120	60	25	48
8	75	50	30	57
9	110	100	35	62
10	90	30	30	50
11		40		60
12		130		44

6-8. Solve Problem 6-7 using the waste generation data for location B, C, or D (location to be selected by instructor).

6-9. What conclusions can be drawn from frequency plots (histograms) of solid waste generation?

6-10. The shape of a solid waste generation frequency curve reflects the nature of the generating facility. From the following frequency curves, what can be deduced about the facility's activity and operation?



6-11. What makes up white goods at your university or work location? How are the white goods now collected and disposed of?

6-12. How are bulky items, consumer electronics, white goods, oil, tires, and batteries now handled in your community? What fraction of the individual components are now recycled?

6-13. Determine the nature of the waste distribution, the average (mean) value, and the peak-to-average value for the following monthly tonnage data recorded at a transfer station: 250, 218, 209, 276, 315, 300, 260, 293, 246, 289, 189, 334.

6-14. Obtain the monthly weight data from your local transfer station or disposal site for the past year. Plot the data on logarithmic graph paper and determine the nature of the waste distribution, the mean value, and the peak-to-average ratio.

6-15. One of the first steps in conducting a solid waste management study is the identification of factors contributing to the generation of solid wastes now and in the future. In outline form, list the factors that affect the generation of municipal, industrial, and agricultural solid wastes in your community, and list those that may affect generation in the future.

6-16. In your first position as a junior city engineer, you are assigned by your supervisor to report on the generation rates and composition of solid wastes for various sources of your community. How would you go about it? If these data were needed in 30 days and thus you had no time to assess seasonal effects, how would you estimate this factor?

6-17. Should construction and demolition wastes be counted in determining the waste diversion percentage for a community?

6-18. How should the waste categories given in Table 6-10 be modified if you were to conduct a waste characterization for your community, university, work activity, or other? (To be selected by the instructor.)

6-9 REFERENCES

1. Bomberger, D. C., R. Lewis, and A. Valdes: *Waste Characterization Study: Assessment of Recyclable and Hazardous Components*, report prepared for California Waste Management Board, SRI International, Menlo Park, CA, 1988.
2. California Solid Waste Management Board: *Solid Waste Generation Factors in California*, Technical Information Series, Bulletin 2, State of California, Sacramento, 1989.
3. Franklin, W. (ed.), and M. Franklin: "III. Solid Waste Stream Characteristics," in F. Kreith (ed.), *Integrated Solid Waste Management: Options for Legislative Action*, Genium Publishing Corporation, Schenectady, NY, 1990.
4. Freeman, H. M.: "Source Reduction As an Option for Municipal Waste Management," in F. Kreith (ed.), *Integrated Solid Waste Management: Options for Legislative Action*, Genium Publishing Corporation, Schenectady, NY, 1990.
5. Neissen, W. R.: "Properties of Waste Materials," in D. G. Wilson (ed.), *Handbook of Solid Waste Management*, Van Nostrand Reinhold, New York, 1977.
6. Tchobanoglous, G. and E. D. Schroeder: *Water Quality: Characteristics, Modeling, Modifications*, Addison-Wesley, Reading, MA, 1985.
7. Tchobanoglous, G. and F. L. Burton: *Wastewater Engineering: Treatment Disposal and Reuse* 3rd. ed., McGraw-Hill, New York, 1991.
8. U.S. Environmental Protection Agency: *Characterization of Municipal Waste in the United States: 1960–2000*, 1988 Update, Washington, DC, 1988. Available through National Technical Information Service (NTIS), Springfield, VA.
9. U.S. Environmental Protection Agency: *Decision-Makers' Guide To Solid Waste Management*, EPA/530-SW89-072, Washington, DC, November 1989.
10. U.S. Environmental Protection Agency: *Characterization of Municipal Solid Waste in the United States: 1990 Update*, EPA/530-SW-90-04, Washington, DC, June 1990.