CHAPTER 9
SOLUTIONS

9-1 Solid waste container sizes

Given: High school population = 881; 30 class rooms; 0.11 kg/cap.d plus 3.6 kg/room; density = 120 kg/m^3 ; Wednesday & Friday pickup; containers: 1.5; 2.3, 3.0, 4.6 m

Solution:

a. Daily solid waste generation

(30 rooms)(3.6 kg/room) = 108.0 kg/d

(881 students)(0.11 kg/student) = 96.91 kg/d

Total = 108.0 + 96.91 = 204.91 kg/d

b. Daily volume

$$V = \frac{204.91\,\text{kg/d}}{120\,\text{kg/m}^3} = 1.71\,\text{m}^3/\text{d}$$

c. Collection schedule

Wednesday pickup includes Friday, Monday and Tuesday

Friday pickup includes Wednesday and Thursday

Therefore,

Total Volume = (3 d)(1.71 m^3/d) = 5.12 m^3

d. Number and size of containers

Many combinations possible:

One of 1.5 m^3 and one of 4.6 m^3 = 6.10 m^3 okay

One of 2.3 m^3 and one of 3.0 m^3 = 5.30 m^3 okay

Two of 3.0 m^3 = 6.0 m^3 okay

9-2 Annual solid waste volume from stone works

Given: 6 employees; 1 kg/cap d; density = 480 kg/m^3
Solution:

a. Calculate annual mass produced

(6 employees)(1 kg/cap d)(365 d/y) = 2,190 kg/y

b. Calculate volume

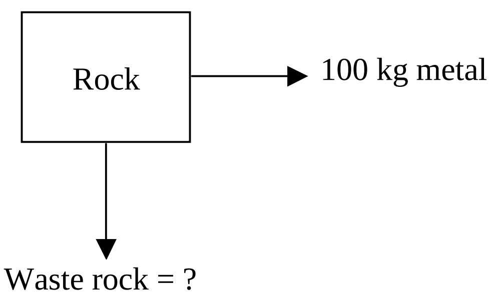
$$V = \frac{2190\,\text{kg}/\text{y}}{480\,\text{kg}/\text{m}^3} = 4.56\text{m}^3$$

9-3 Waste rock production

Given: 100 kg of metal, ore containing 50%, 25%, 10%, 5% and 2.5% metal

Solution:

a. Mass balance



b. At 50% metal = 0.50 metal

$$\frac{100\text{kg}\cdot\text{metal}}{0.50} = 200\,\text{kg of rock at 50\% ore yields 100 kg of metal}$$

$$\text{Waste rock} = \frac{200\text{kg}\cdot\text{rock} - 100\text{kg}\cdot\text{metal}}{100\text{kg}\cdot\text{metal}} = 1.0\,\text{kg waste rock/kg metal}$$

c. Similarly

25% $$\frac{\frac{100\text{kg}\cdot\text{metal}}{0.25}-100\text{kg}}{100\text{kg}} = 3\text{kg waste rock/kg metal}$$

10% 9 kg/kg metal

5% 19 kg/kg
2.5% 39 kg/kg

9-4 Average density of household waste

Given: Volume of container = 0.0757 m ; mass of empty container = 3.63 kg; 8 weighings

Solution:

a. Assume all cans full. Calculate density as shown in following example calculation:

$$\text{Density} = \frac{7.26\text{kg} - 3.63\text{kg}}{0.0757\text{m}^3} = 47.95\,\text{kg}/\text{m}^3$$

b. Tabulated values

Gross Mass (kg)	Net Mass (kg)	Density (kg/m^3)
7.26	3.63	47.95
7.72	4.09	54.03
10.89	7.26	95.90
7.26	3.63	47.95
8.17	4.54	59.97
6.35	2.72	35.93
8.17	4.54	59.97
8.62	4.99	65.92
		Total = 467.63

c. Mean density

$$X = \frac{467.63}{8} = 58.4\,\text{kg}/\text{m}^3$$

9-5 Density of compacted waste

Given: Problem 9-4, compact to 37% of original volume

Solution:

a. Note that the definition of density is

$$\text{Density} = \frac{\text{mass}}{\text{unit} \cdot \text{volume}}$$

b. From Problem 9-4 density = 58.4 kg/m^3
Then

$$\text{Compacted} \cdot \text{Density} = \frac{58.4\text{kg}}{\text{m}^3} \times \frac{1}{0.34} = 158\,\text{kg}/\text{m}^3$$

9-6 Density of Davis, CA MSW

Given: Table 9-3 with paper, cardboard, plastics, glass, and tin cans removed

Solution:

a. Tabular computation showing fractions removed

Component	Mass (kg)	Volume (m^3)
Total	45.4	0.429
Paper	-19.6	-0.240
Cardboard	-2.98	-0.0297
Plastics	-0.82	-0.013
Glass	-3.4	-0.018
Tin cans	-2.36	-0.0268
NEW TOTAL	**16.27**	**0.1015**

$$\text{New Density} = \frac{16.27\text{kg}}{0.1015\text{m}^3} = 160.29\,\text{kg}/\text{m}^3$$

9-7 Number and size of trucks

Given: Gobs of data and assumptions: see text.

Solution:

a. Calculate mean time per collection stop

(3 cans/wk = 1.5 can per collection for twice a week pickup)

t_p = 18.00 s + (12.60 s/can)(1.5 can) + 0

t_p = 36.90 s/stop or 0.615 min or 0.0103 h

b. Number of pickup locations per crew (Eqn. 9-3). The average haul speed(s) is determined from Figure 9-6: 48.0 km/h

$$N_p = \frac{\frac{8.0}{2} - \frac{2(24)}{48} - (2)\frac{20}{60} - \frac{7.5}{60} - \frac{0.5}{2}}{0.0103} = \frac{1.9583}{0.0103} = 190 \text{ pickups per load}$$

c. Volume per pickup

Waste generation rate = (1.17 kg/cap d)(4 people) = 4.68 kg/d

For twice a week pickup assume 4 days between pickups

(4.68 kg/d)(4 d) = 18.72 kg

$$V_p = \frac{18.72\text{kg}}{144.7\,\text{kg}/\text{m}^3} = 0.1294\text{m}^3$$

d. Compute compaction ratio

$$r = \frac{475\,\text{kg}/\text{m}^3}{144.7\,\text{kg}/\text{m}^3} = 3.2827$$

e. Volume of truck (note numerator of N_p is same as bracket of Eqn. 9-1)

$$V_T = \frac{0.1294}{(3.2827)(0.0103)}(1.9583) = 7.49\text{m}^3$$

Since the smallest volume truck is 9.0 m^3, Volume of truck = 9.0 m^3

f. Number of trucks

The number of trucks required is a function of the population that must be served. An assumption must be made about the number of work days, i.e. pickup days per week. I have assumed 5 days/wk.

$$\frac{44000\text{people}}{4\text{people}/\text{residence}} = 11000\text{stops}$$

11,000 stops x 2 pickups/wk = 22,000 stops/wk

$$\frac{22000\text{stops}/\text{week}}{5\text{days}/\text{week}} = 4400\text{stops}/\text{d}$$

$$\frac{4400\text{stops}/\text{d}}{(190\text{stops}/\text{load})(2\text{loads}/\text{d})} = 11.57 \text{ or 12 trucks}$$

9-8 Collection parameters for Forty Two

Given: Gobs of data, see problem.

Solution:

a. Volume per pickup

V = (2.53 cans/stop)(0.1136 m /can) = 0.2874 m3

Solve Eqn. 9-1 for t_p (mean time per collection stop)

$$t_p = \frac{V_p}{V_T(R)}\left[\frac{H}{N_d} - \frac{2(x)}{s} - 2t_d - t_u - \frac{B}{N_d}\right]$$

$$\frac{2(x)}{s} + 2t_d + t_u = 1.0\text{h}$$

B = (0.5h for breaks) + (0.40h for maintenance) = 0.90 h

$$t_p = \frac{0.2874}{(17.0)(3.97)}\left[\frac{8.0}{1} - 1.00 - \frac{0.90}{1}\right] = 0.00402(6.10)$$

t_p = 0.024522 h or 1.47132 min or 88.3 s/stop

b. Number of pickup locations per load

$$N_p = \frac{6.10}{0.024522} = 248.76 \text{ or 249 locations/load}$$

c. Number of trucks

Assume 4 people/collection stop

$$\text{No. of stops} = \frac{361564}{4} = 90391 \text{ stops}$$

$$\frac{90391\text{stops}}{(5\text{d}/\text{wk})(249\text{stops}/\text{load})(2\text{loads}/\text{d})} = 36.30 \text{ trucks}$$

with 15% out of service

36.30 x 1.15 = 41.75 or 42 trucks required

9-9 Evaluation of collection system for Bon Chance

Given: collection data

Solution:

a. Mean time per stop and mean time to next stop using Eqn. 9-2

V_p = (2.95 cans/stop)(0.0911 m^3/can) = 0.2687 m^3/stop

Given in problem statement

R = 3.28

$$\frac{2x}{s} + 2t_d + t_u = 1.50\text{h}$$

B = (0.5h for breaks) + (0.6h for maintenance) = 1.10 h

$$t_p = \frac{0.2687}{(18.0)(3.28)}\left[\frac{8}{2} - 1.50 - \frac{1.10}{2}\right] = 0.00887\text{h}$$

b. Number of pick up locations

$$N_p = \frac{1.95}{0.00887} = 219.78 \text{ or 220 per load}$$

c. Number of stops

$$\text{No. of stops} = \frac{161565\text{people}}{2.5\text{people/stop}} = 64626\text{stops}$$

d. Number of trucks

$$\text{No. of trucks} = \frac{64626\text{stops}}{(5\text{d/wk})(220\text{stops/load})(2\text{loads/d})} = 29.37\text{trucks}$$

e. Allowance for trucks out of service (15%)

No. of trucks = (29.37)(1.15) = 33.78 or 34 trucks

9-10 Truck size

Given: Example 9-1 with no rear of yard pickup and one trip to disposal site

Solution:

a. Mean time per collection

tp = 0.72 + 0.54 = 1.26 min or 0.0210 h

b. Volume of truck

$$V_T = \frac{0.11}{(3.77)(0.0210)}\left[\frac{8}{1} - \frac{2(6.4)}{27} - 2\frac{13}{60} - \frac{6}{60} - \frac{0.5}{1}\right]$$

V_T = (1.3894)(8 - 0.4741 - 0.4333 - 0.100 - 0.500)

V_T = (1.3894)(6.4926) = 9.021 or 9 m^3 / truck

c. Number of pickup locations

$$N_p = \frac{6.4926}{0.0210} = 309 \text{ pickups per load}$$

9-11 Rework collection data for Forty Two

Given: Problem 9-8 and t_{bp} = 28.20 s and a = 12.80 s/can; trips to disposal site = 1/day

Solution:

a. Calculate t_p

t_p = 28.20 + 12.80 (2.53) = 60.58 s

t_p = 1.009667 min or 0.016828 h

b. Number of pickup locations

$$N_p = \frac{\frac{8}{1} - 1.00 - \frac{0.90}{1}}{0.016828} = \frac{6.10}{0.016828}$$

Np = 362.39 or 362 locations/load

c. Number of trucks

$$\frac{90391}{(5\text{d}/\text{wk})(362\text{stops}/\text{d})} = 49.94 \text{ trucks}$$

With 15% out of service

49.94 x 1.15 = 57.43 or 57 trucks required

9-12 Annual cost per megagram and average weekly charge for Midden

Given: Gobs of data, see problem statement.

Solution:

a. Annual truck cost

Notes: V_T = 7.49 m^3 = volume carried not 9 m^3 volume of truck from Problem 9-7
N_T = (2 per d)(5 d/wk)(52 wk/y) = 520
x_T = Average annual distance/N_T

$$A_T = \frac{(1000)(106628)}{(7.49)(475)(520)(5)}\left[1 + \frac{0.1150(5+1)}{2}\right] + \frac{1000\left(\frac{16412}{520}\right)(5.50)}{(7.49)(475)}$$

A_T = (11.527)(1.345) + 48.79

A_T = 15.50 + 48.79 = \$64.29/Mg

b. Annual labor cost

$$A_L = \frac{(1000)(1)(14.00)(8.0)}{(7.49)(475)(2)}[1+1.0138]$$

A_L = (15.74)(2.0138) = \$31.70/Mg

c. Total cost

TC = A_T + A_L = \$95.99 or \$95/Mg

d. Weekly charge

Weekly volume SW = (1.17 kg/cap-d)(7d)(4 people/house) = 32.76 kg/wk

e. Cost plus profit (20%)

\$96/Mg x 1.20 = \$115.20/Mg

f. Cost per week per household

$$\frac{\$115.20\,/\,\text{Mg}}{1000\,\text{kg}/\text{Mg}} \times 32.76\,\text{kg}/\text{wk} = \$3.77\,/\,\text{wk}$$

9-13 Annual and weekly cost (2 person and 1 person crew)

Given: Gobs of data, see problem statement
NOTE: density of compacted waste not given! It should be 400 kg/m^3

Solution:

a. See the following spreadsheet calculations

Collection Data

Population =	361564	
No. of people per stop	4	
No. of containers =	2.53	
Collection days/wk =	5	
V_p =	0.1136	m^3
r =	3.97	
H =	8	h
N_d =	1	
$(2x/s-2t_d-t_u)$ =	1	h
B =	0.9	h
t_p		
Crew of 1 =	0.0118	h
Crew of 2 =	0.00883	h

Truck Capacity

			Standard size	
V_T =				
Crew of 1 =	14.8	m^3	15	m^3
Crew of 2 =	19.8	m^3	21	m^3

No. of stops

N_p		
Crew of 1 =	516.9	stops per load
Crew of 2 =	690.8	stops per load
Total =	90391	stops per week

Number of trucks

Crew of 1 =	35.0
Crew of 2 =	26.2

Cost Data

Capital cost (F)		
15 m^3 =	$122,000	side loader
21 m^3 =	$141,000	rear loader
D_T =	400	kg/m^3
N_T =	260	trips/y
Y =	5	years
Interest rates		
for Nosleep	0.0825	
Avg. annual distance	11797	km
X_t =	45.37308	km
OM		
15 m^3 =	$5.75	per km
21 m^3 =	$6.55	per km
A(T) for Nosleep		
15 m^3 =	$63.88	per Mg
21 m^3 =	$54.70	per Mg

Labor costs

for Nosleep					
				Total	
Crew of 1 =	1	$16.00		$16.00	per hour
Crew of 2 =	3	$15.25	$14.70	$29.95	per hour

Overhead (OH)	
for Nosleep	0.7504

A_L for Nosleep			
Crew of 1 =	$37.87	per Mg	15 m^3
Crew of 2 =	$53.04	per Mg	21 m^3

Total charges			
for Nosleep			
Crew of 1 =	$101.75	per Mg	12 m^3
Crew of 2 =	$107.74	per Mg	18 m^3

Average weekly charge		
SW gen. Per stop	28.95798	kg/wk
Crew of 1 =	$2.95	per wk
Crew of 2 =	$3.12	per wk

9-14 Bon Chance annual cost

Given: Gobs of data, see problem statement

Solution:

a. See following spreadsheet calculations

Collection Data

Population =	161565	
No. of people per stop	2.5	
No. of containers =	2.95	
Collection days/wk =	5	
V_p =	0.0911	m^3
r =	3.28	
H =	8	h
N_d =	1	
$(2x/s-2t_d-t_u)$ =	1.5	h
B =	1.1	h
t_p		
Crew of 1 =	0.01147	h
Crew of 2 =	0.0095	h
Crew of 3 =	0.0083	h

Truck Capacity

			Standard size	
V_T =				
Crew of 1 =	13.1	m^3	15	m^3
Crew of 2 =	15.8	m^3	18	m^3
Crew of 3 =	18.1	m^3	21	m^3

No. of stops

N_p		
Crew of 1 =	470.8	stops per load
Crew of 2 =	568.4	stops per load
Crew of 3 =	650.6	stops per load
Total =	64626	stops per week

Number of trucks

Crew of 1 =	27.5
Crew of 2 =	22.7
Crew of 3 =	19.9

Cost Data

Capital cost (F)		
$15\ m^3$ =	$122,000	
$18\ m^3$ =	$131,500	
$21\ m^3$ =	$141,000	
D_T =	400	kg/m(3)
N_T =	260	trips/y
Y =	5	years
Interest rates		
for Bon Chance	0.0625	
Avg. annual distance	15260	km
X_t =	58.69	km
OM		
$15\ m^3$ =	$5.75	per km
$18\ m^3$ =	$6.55	per km
$21\ m^3$ =	$7.60	per km
A_T for Bon Chance		
$15\ m^3$ =	$85.83	per Mg
$18\ m^3$ =	$81.27	per Mg
$21\ m^3$ =	$79.53	per Mg

Labor costs

for Bon Chance						
					Total	
Crew of 1 =	1	$19.90			$19.90	per hour
Crew of 2 =	2	$18.64	$12.58		$31.22	per hour
Crew of 3 =	3	$18.64	$12.58	$12.58	$43.80	per hour

Overhead (OH)	
for Bon Chance	0.7504

A_L for Bon Chance		
Crew of 1 =	$53.28	per Mg
Crew of 2 =	$69.23	per Mg
Crew of 3 =	$84.86	per Mg

Total charges			
for Bon Chance			V_T
Crew of 1 =	$139.11	per Mg	15 m^3
Crew of 2 =	$150.50	per Mg	18 m^3
Crew of 3 =	$164.39	per Mg	21 m^3

Average weekly charge		
SW gen. Per stop	32.77	kg/wk
Crew of 1 =	$4.56	per wk
Crew of 2 =	$4.93	per wk
Crew of 3 =	$5.39	per wk

9-15 Routing for Redbud, ID

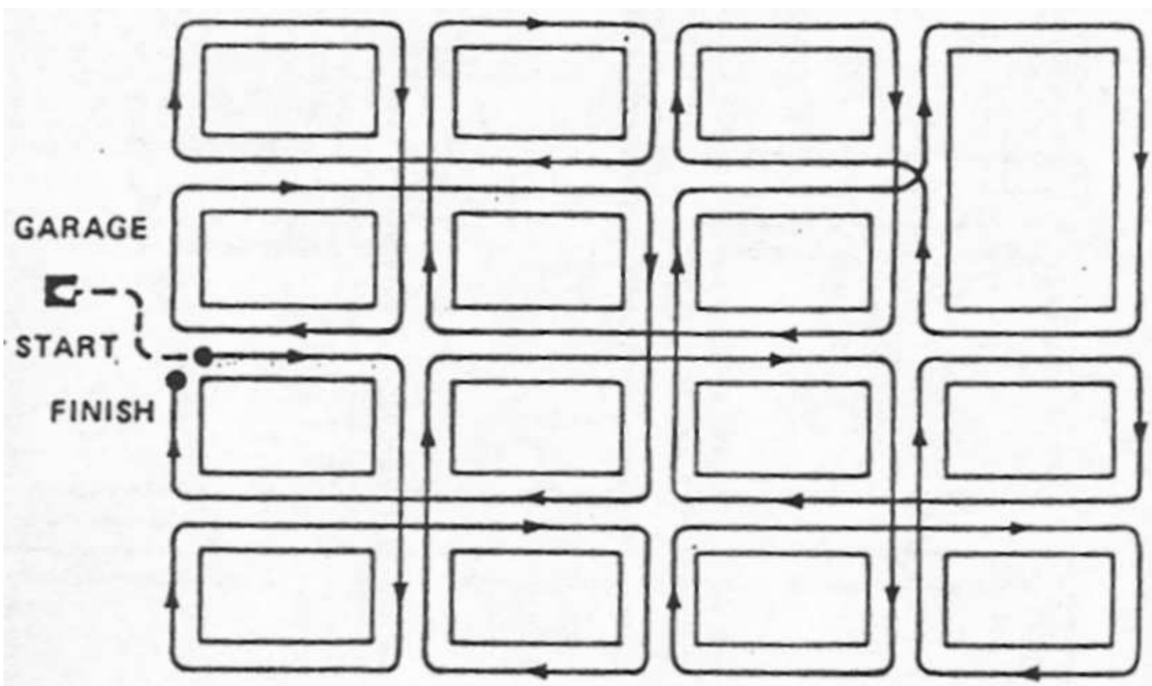


Figure S-9-15: Redbud routing

9-16 Routing for Mundy, MN

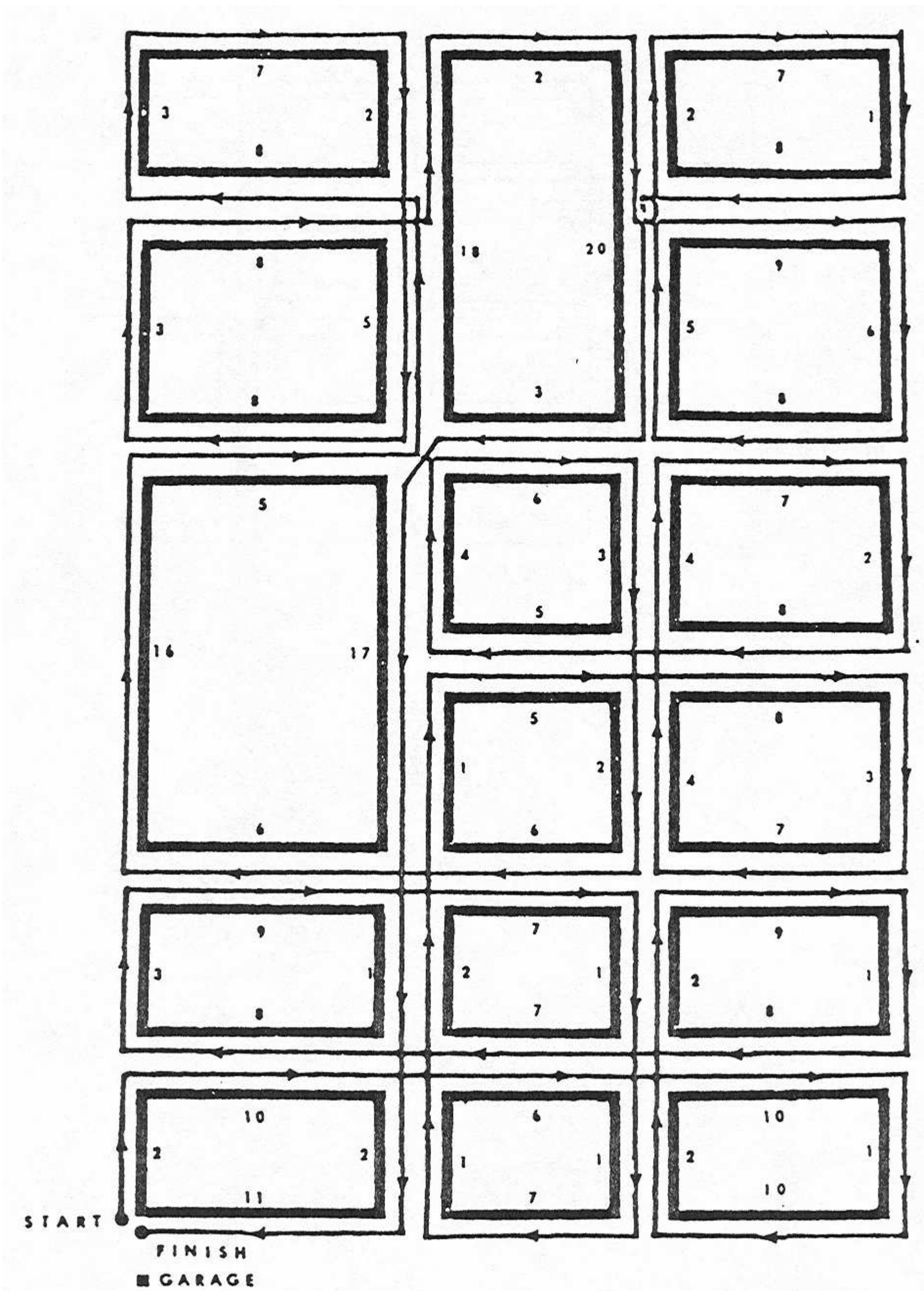


Figure S-9-16

9-17 Routing for Mundy, MN with one way streets

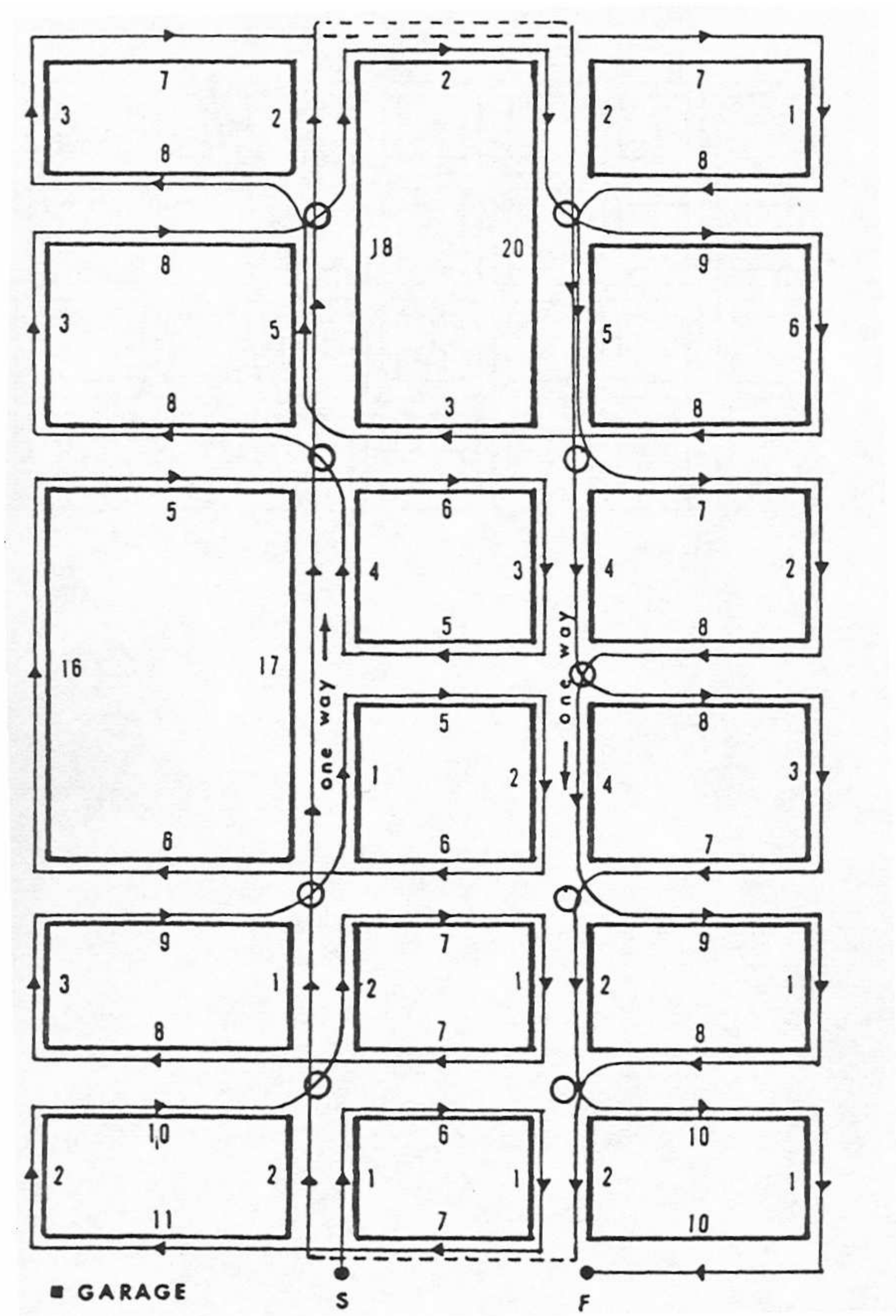


Figure S-9-17

9-18 Routing for Travail, AR

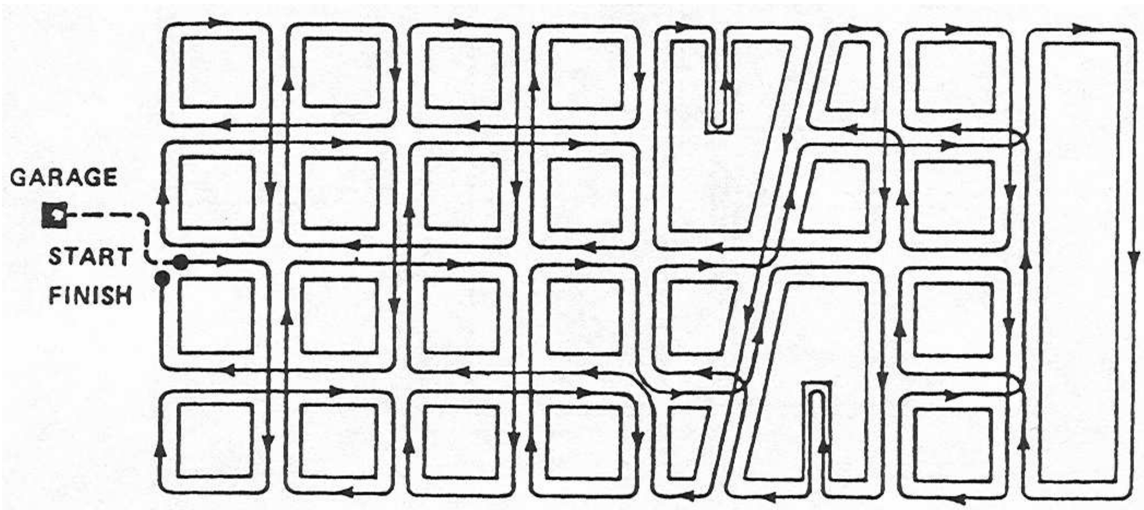


Figure S-9-18

9-19 Troublesome Creek routing

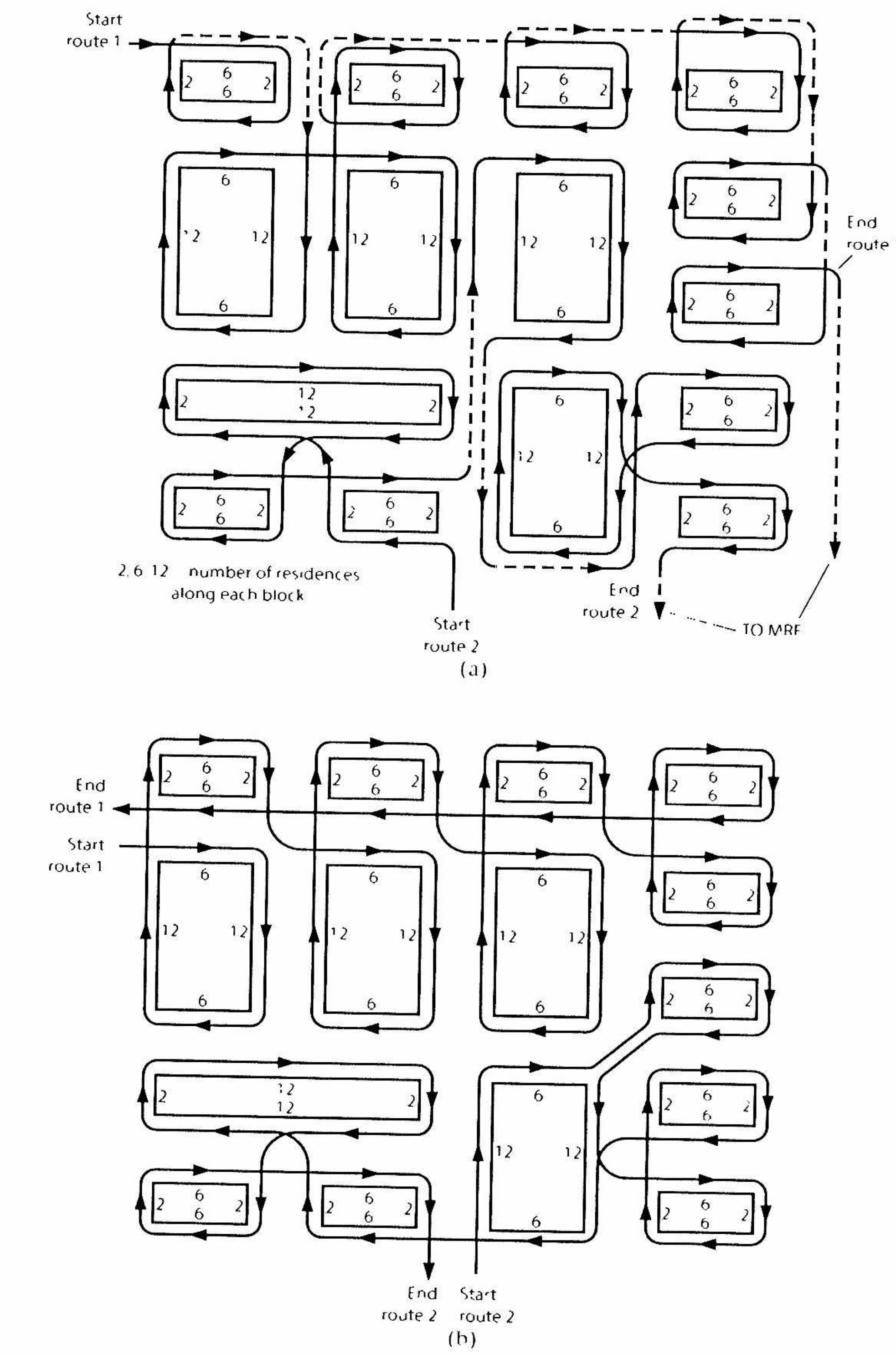


Figure S-9-19

9-20 Routing from Olson, N.C.

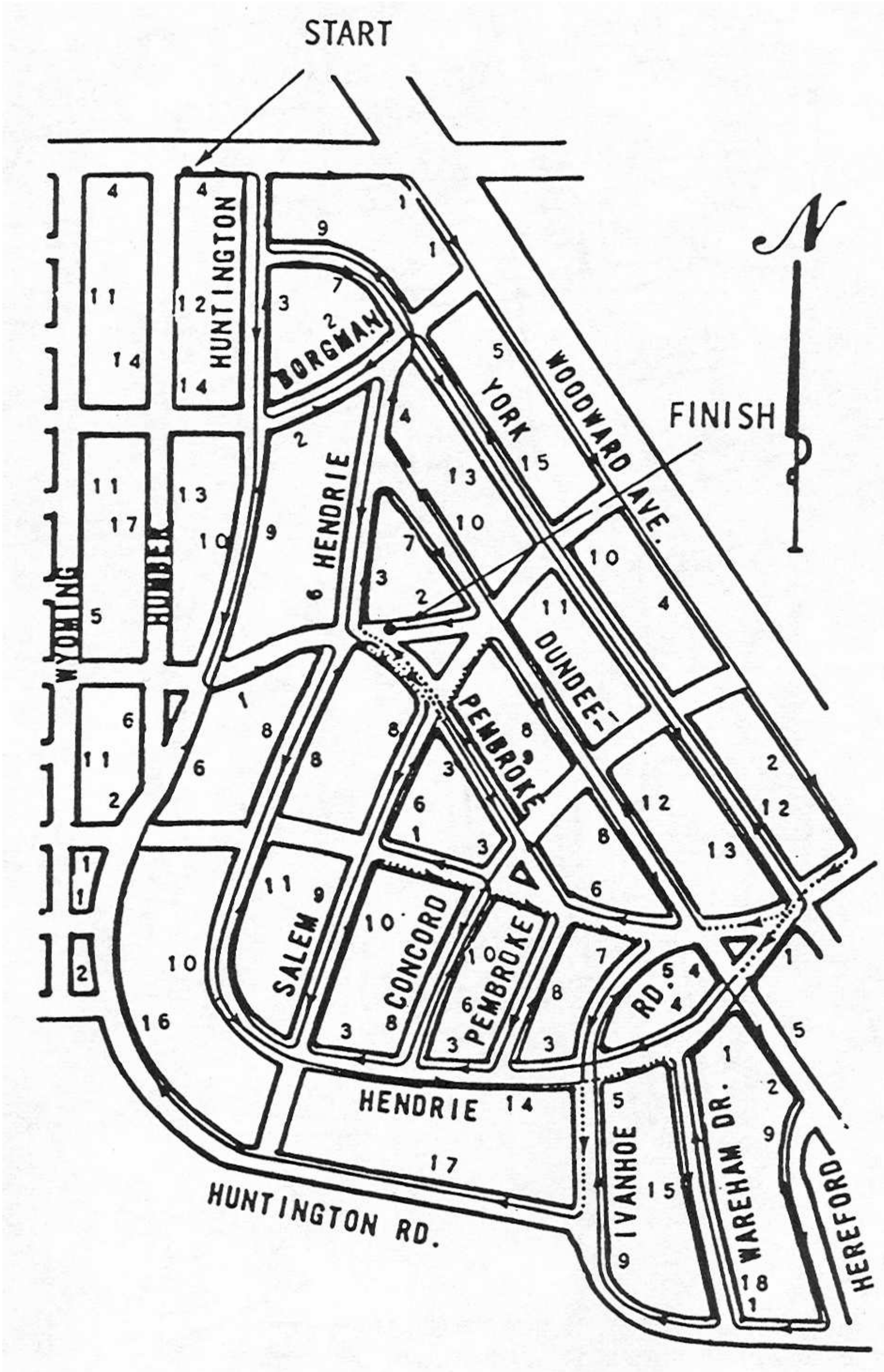


Figure S-9-20

9-21 Routing for Masters, MS

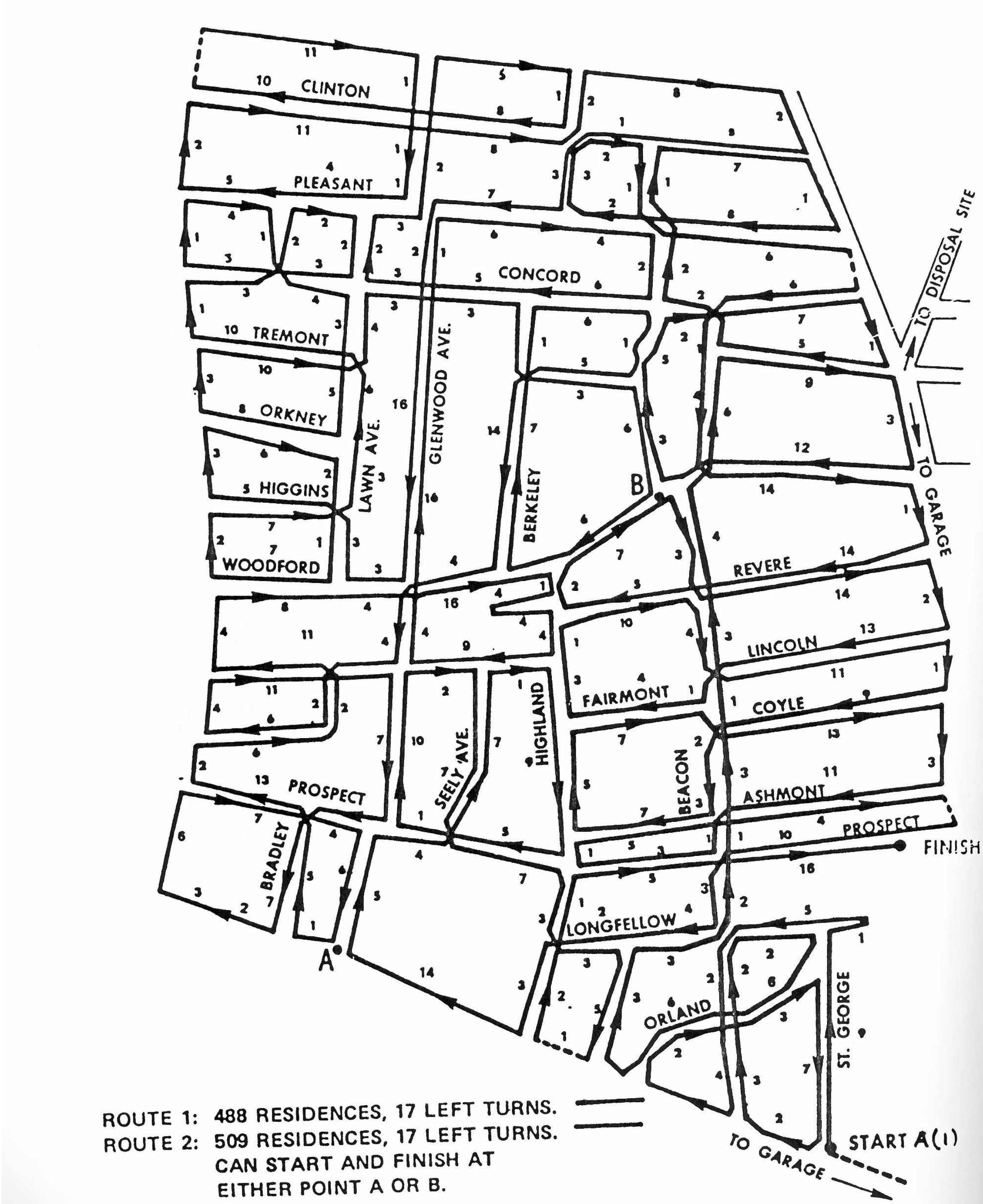


Figure S-9-21

9-22 Equation for hauling cost versus distance

NOTE: THIS IS NOT A TRIVIAL PROBLEM!

Given: Data from Problems 9-7 and 9-12, $V_T = 9.0\ m^3$

Solution:

a. Number of trips per year

N_T = (2 trips/d)(5 d/wk)(52 wk/y) = 520 trips/y

b. The cost equations (Eqns. 9-4 and 9-5) may be written as follows using the data from Problems 9-7 and 9-12

Truck cost

$$A_T = \frac{(1000)(117000)}{(9.0)(475)(520)(5)}(1.2625) + \frac{(1000)(x)(6.46)}{(9.0)(475)} = 13.29 + 1.511x$$

c. Labor cost where H_t is the round trip travel time

$$A_L = \frac{(1000)(1)(17.74)(H_t)}{(9.0)(475)(2)}[1 + 1.0138] = \frac{17740H_t}{8550}(2.0138)$$

$A_L = 4.18H_t$

d. The total cost equation

$$TC = 13.29 + 1.511x + 4.18H_t$$

9-23 Equations for hauling cost versus distance

Given: Data from Problems 9-8, 9-11, 9-13 and fixed $V_T = 18.0\ m^3$

Solution:

a. Number of trips per year

N_T = (1 trip/d)(5 d/wk)(52 wk/y) = 260 trips/y

b. Truck cost

$$A_T = \frac{(1000)(131500)}{(18.0)(400)(260)(5)}(1.2025) + \frac{(1000)(x)(6.55)}{(18.0)(400)}$$

A_T = 16.89 + 0.9097x

c. Labor cost

$$A_L = \frac{(1000)(16.0)(H_t)}{(18.0)(400)(1)}[1 + 0.7504] = 2.222H_t(1.7504) = 3.89H_t$$

d. Total cost

TC = 16.89 + 0.9097x + 3.89H_t

9-24 Equation for hauling distance

Given: Crew of 2, 18.0 m^3 truck

Solution:

a. A_T is same as for 9-23

A_T = 16.89 + 0.9097x

b. A_L for crew of 2 at $15.25 for driver + $14.70 for collector

$$A_L = \frac{(1000)(15.25 + 14.70)(H_t)}{(18.0)(400)(1)}[1 + 0.7504] = (4.16)(H_t)(1.7504) = 7.28H_t$$

c. Total cost

TC = 16.89 + 0.9097x + 7.28H_t

9-25 Should transfer station be used?

Given: 9.53 MG/wk, 64.0 km one-way crew of one. Transfer station = $19,000 @ 8.50% for 5y plus $15,000 O&M

Solution:

a. Cost of hauling using solution for Problem 9-22 with total haul distance > 80km (i.e. 2(64) = 128 km)

$$H_t = \frac{2(64\text{km})}{80\,\text{km/h}} = 1.6\text{h}$$

$TC = 53.15 + 0.75(128) + 4.18(1.6) = \$155.83$ to haul without transfer

b. Transfer station costs

Amortization of capital cost over 5y

A = \$25,000(A/P, 6%, 5y)

A = \$25,000(0.2374) = \$5,935

Total annual cost

TC = \$5,935 + \$20,000 = \$25,935

Annual solid waste generation rate

(9.53 Mg/wk)(52 wk/y) = 495.56 Mg/y

Cost per Mg for transfer station

$$\frac{\$25,935}{495.56\,\text{Mg/y}} = \$52.35/\text{Mg}$$

Transfer truck haul

TC = 47.98 + 0.55(128) + 2.59(1.6) = \$122.50/Mg

Total Transfer + Haul = \$52.35 + \$122.50 = \$174.85

Transfer station costs more than direct haul. Trooper should NOT build the transfer station.

9-26 Solid waste transfer station for Calamity, GA

Given: Gobs of data and crew of 3 cost curve from Problem 9-23

Solution:

a. For crew of 3 direct haul

TC = 13.22 + 0.6319(93.4) + 3.869(1.08) = \$76.42/Mg

b. Transfer station cost

Amortization

A = $1,200,000 (A/P, 6.0%, 8y)

From compound interest tables

A/P = 0.1610

A = $1,200,000(0.1610) = $193,200

Total costs

TC=$193,200+$55,000+$64,900+($6.55/km)(2)(46.7km)(5d/wk)(52wk/y)

TC = $313,100 + $795,301 = $1,108,401

Waste generation

$(0.425\ Mg/m^3)(48800\ m^3/y) = 20740\ Mg$

Cost/Mg

$$\frac{1108401}{20740} = \$53.44\,/\,Mg\ < \$76.42/Mg$$

Construct transfer station – it is cheaper.

9-27 Volume of landfill

Given: Table of mass fractions; assume cell height of 2.40 m and normal compaction; 20 y life

Solution:

a. Mass of solid waste/y

(44000 pop)(1.17 kg/cap-d)(365 d/y) = 18,790,200 kg/y or 18,790 Mg/y

b. Compute weighted compaction ratio (using Table 9-8)

Component	Mass Fraction	Normal	Weighted Compaction Ratio
Food Waste	0.0926	2.8	0.26
Paper	0.4954	5	2.48
Plastic, rubber, wood	0.0438	4.45*	0.19
Textiles	0.0379	2.5	0.09
Metals	0.0741	4.25*	0.31
Glass	0.1668	1.7	0.28
Misc.	0.0894	1.2	0.11
			3.72

* Average of components; i.e. (5.6 + 3.3)/2 = 4.45

c. Compute density of compacted fill

D_c = (144.7 kg/m^3) (3.73) = 539.12 kg/m^3

d. Volume per day

$$\frac{(44000\text{people})(1.17\,\text{kg}/\text{cap}\cdot\text{d})}{539.12\,\text{kg}/\text{m}^3} = 95.49\,\text{m}^3/\text{d}$$

e. Area per day

Assume spread in 0.3 m layer

$$\frac{95.49\,\text{m}^3/\text{d}}{0.3\text{m}} = 318.30\,\text{m}^2/\text{d}$$

f. Time to complete cell

Using 0.15 m/d cover then 0.3 m sw + 0.15 m soil = 0.45 m and it will take

$$\frac{2.4\text{m} - 0.15\text{m}}{0.45\text{m}} = 5\,\text{d to complete cell}$$

g. Soil volume Not ignoring soil separating cells

For daily cover

(3 cells/stack)(5 lifts/cell)(318.30 m^2/d)(0.15 m) = 716.18 m^3

plus 0.15 m for intermediate cover

(3 cells/stack)(318.30)(0.15) = 143.24 m^3

plus final cover

(318.30)(0.15) = 47.75 m^3

plus soil separating stack (square @ (318.3)1/2 = 17.84 m)

(0.03 m)(2.4 m high)(17.84 m long)(3 cells) = 38.54 m^3

for two sides

2(38.54 m3) = 77.08 m^3

for total soil volume

Vsoil = 716.18 + 143.24 + 47.75 + 77.08

Vsoil = 984.25 m^3

h. Volume of solid waste

Vsw = (95.49 m^3/d)(15 d/stack) = 1417.35 m^3/stack

i. Value for E

$$E = \frac{984.25 + 1417.35}{1417.35} = 1.69$$

j. Volume of landfill

$$V_{LF} = \frac{(18790\,\mathrm{Mg/y})(1.69)}{0.53912\,\mathrm{Mg/m^3}}(20\mathrm{y}) = 1{,}178{,}034\mathrm{m}^3$$

or V_{LF} = 1,180,000 m^3

k. Area of landfill

$$A_{LF} = \frac{1180000\mathrm{m}^3}{(3)(2.4) + 0.3} = 157{,}333.33 \text{ or } 157{,}000\ \mathrm{m}^2$$

9-28 Landfill volume with 50% of paper removed

Given: Problems 9-7 and 9-27

Solution:

a. Mass fractions from solution to 9-27 minus 50% of paper. Assume 1.000 Mg to start

Component	New Mass	Mass Fraction*	Normal Compaction	Weighted Compaction Ratio
Food Waste	0.0926	0.1231	2.8	0.3447
Paper	0.2477	0.3293	5	1.646
Plastic, rubber, wood	0.0438	0.0582	4.45	0.19
Textiles	0.0379	0.05038	2.5	0.1259
Metals	0.0741	0.0985	4.25	0.4186
Glass	0.1668	0.2217	1.7	0.3769
Misc.	0.0844	0.1188	1.2	0.1426
Total	0.7473	0.99998		3.2447

* Mass/Total

b. Compute density of compacted fill

$D_c = (144.7 \text{ kg/m}^3)(3.245) = 469.5 \text{ kg/m}^3$

c. Mass per day corrected for recycling (New mass = 75.23%)
See Prob. 9-7 for data

(44000 people)(1.17 kg/cap-d)(0.7523) = 38728.40 kg/d

d. Volume per day

$$\frac{38728.4 \text{ kg/d}}{469.5 \text{ kg/m}^3} = 82.489 \text{ m}^3/\text{d}$$

e. Area per day

Assume spread in 0.3 m layer

$$\frac{82.489 \text{ m}^3/\text{d}}{0.3\text{m}} = 274.96 \text{ m}^2/\text{d}$$

f. Time to complete cell

Using 0.15 m/d cover then 0.3 m sw + 0.15 m soil = 0.45 m and it will take

$$\frac{2.40\text{m} - 0.15\text{m}}{0.45\,\text{m/d}} = 5 \text{ d to complete cell}$$

g. Soil volume <u>NOT</u> ignoring soil separating cells

for daily cover

(3 cells/stack)(5 lifts/cell)(274.96 m^2/d)(0.15 m) = 618.66 m^3

plus 0.15 m for intermediate cover

(3 cells/stack)(274.96)(0.15) = 123.73 m^3

plus final cover

(274.96)(0.15) = 41.25m^3

plus soil separating stack (square @ $(275.96)^{1/2}$ = 16.58 m)

(0.3 m)(2.4 m)(16.58 m)(3 cells) = 35.82 m^3

for two sides

(2)(35.82 m^3) = 71.63 m^3

for a total soil volume

Vsoil = 618.66 + 123.73 + 41.25 + 71.63 = 855.27 m^3

h. Volume of solid waste

Vsw = (82.489 m^3/d)(15 d/stack) = 1237.34 m^3/stack

i. Value for E

$$E = \frac{855.27 + 1237.34}{1237.34} = 1.69$$

j. Volume of landfill

$$V_{LF} = \frac{(38728.40\,\text{kg/d})(365\,\text{d/y})(1.69)}{(469.5\,\text{kg/m}^3)} \times 20\text{y} = 1{,}017{,}662 \text{ or } 1{,}020{,}000 \text{ m}^3$$

k. Area of landfill

$$A_{LF} = \frac{1020000\text{m}^3}{(3\text{cells})(2.4\text{m}) + 0.3\text{m}} = 136000\text{m}^2$$

NOTE: This is a savings of 157,000 – 21,000 m^2 or about 13% of the land area.

9-29 Landfill for Binford, VT

Given: 50 Mg/d, 5 d/wk, spread at 122 kg/m3 ; compacted from 0.5 m to 0.25 m; 3 lifts per day and daily cover = 0.3 m; ignore all other cover material

Solution:

a. Mass of solid waste per year

(50 Mg/d)(5 d/wk)(52 wk/y) = 13,000 Mg/y

b. Compacted density

In compacting from 0.50 m to 0.25 m the density as compacted will be

$$\left(122\,\text{kg/m}^3\right)\frac{0.50\text{m}}{0.25\text{m}} = 244\,\text{kg/m}^3$$

c. Estimate of E

$$E = \frac{(3\text{lifts})(0.25\text{m}) + 0.15\text{m}}{(3)(0.25)} = 1.20$$

d. Volume of landfill

$$V_{LF} = \frac{(13000\,\text{Mg/y})(1.20)}{0.244\,\text{Mg/m}^3} = 63{,}934.43 \text{ or } 64{,}000\text{ m}^3$$

e. Daily area

$$A_{LF} = \frac{50\,\text{Mg/d}}{\left(0.244\,\text{Mg/m}^3\right)(0.75\text{m})} = 273\text{m}^2$$

9-30 Theoretical production of CH_4

Given: 20.3 kg of rapidly decomposing MSW, density of methane = 0.7167 kg/m^3 at STP

Solution:

a. From the text –the chemical formula for rapidly decomposing MSW is

$C_{68}H_{111}O_{50}N$

b. From the reaction equation (9-8)

$$C_{68}H_{111}O_{50}N + \left(\frac{4(68) - 111 - 2(50) + 3(1)}{4}\right)H_2O \rightarrow \left(\frac{4(68) + 111 - 2(50) - 3(1)}{8}\right)CH_4 + ...$$

OR

$$C_{68}H_{111}O_9N + \left(\frac{64}{4}\right)H_2O \rightarrow \left(\frac{280}{8}\right)CH_4 + ...$$

$$C_{68}H_{111}O_9N + (16)H_2O \rightarrow (35)CH_4 + ...$$

c. Calculate GMW of reactant and product

$C_{68}H_{111}O_9N = 1741$

35 CH_4 = 560

d. Ratio of GMW times mass of waste

$$\frac{560}{1741}(20.3\text{kg}) = 6.53\text{kg}$$

e. Estimate volume of gas at STP

$$\frac{6.53\text{kg}}{0.7167\ \text{kg}/\text{m}^3} = 9.11\ \text{m}^3 \text{ of } CH_4$$

9-31 Theoretical production of CH_4 and CO_2

Given: 3.3 kg of slowly decomposing MSW, density of CH_4 = 0.7167 kg/m^3 and CO_2 = 1.9768 kg/m^3 at STP

Solution:

a. From the text – the chemical formula for slowly decomposing MSW is

$C_{20}H_{29}O_9N$

b. From the reaction equation (9-8)

$$C_{20}H_{29}O_9N + \left(\frac{4(20) - 29 - 2(9) + 3(1)}{4}\right)H_2O \rightarrow \left(\frac{4(20) + 29 - 2(9) - 3(1)}{8}\right)CH_4$$
$$+ \left(\frac{4(20) - 29 + 2(9) + 3(1)}{8}\right)CO_2 + NH_3$$

OR

$$C_{20}H_{29}O_9N + (9)H_2O \rightarrow (11)CH_4 + (9)CO_2 + NH_3$$

c. Calculate GMW's of reactant and products

$C_{20}H_{29}O_9N$ = 427

11 CH_4 = 176

9 CO_2 = 396

d. Ratio of GMW times mass of waste

CH_4 $\frac{176}{427}(3.3\text{kg}) = 1.36\text{kg}$

CO_2 $\frac{396}{427}(3.3\text{kg}) = 3.06\text{kg}$

e. Estimate volume of each gas at STP

CH_4 $\frac{1.36\text{kg}}{0.7167\,\text{kg}/\text{m}^3} = 1.90\text{m}^3$

CO_2 $\frac{3.06\text{kg}}{1.9768\,\text{kg}/\text{m}^3} = 1.55\text{m}^3$

Total = 1.90 + 1.55 = 3.45 m^3

9-32 Recycling

Given: New equation for t_p and Probs. 9-8 and 9-13

Solution:

a. New pickup time

$t_p = 22.6 + 3.80\ (1.53) + 5.50\ (3.00)$

$t_P = 44.91$ s or 0.75 min or 0.0125 h

b. New V_T

$$V_T = \frac{0.2874}{(3.97)(0.0125)}(2.55) = 14.80\text{m}^3$$

c. Recompute costs

$$A_T = \frac{1000(99000)}{(14.8)(400)(260)(5)}\left[1 + \frac{0.0825(5+1)}{2}\right] + \frac{1000\left(\frac{11797}{260}\right)4.55}{(14.8)(400)}$$

$A_T = (12.864)(1.25) + 34.87 = 50.95$

$$A_L = \frac{(1000)(3)(11.08)(8.0)}{(14.8)(400)(2)}[1 + 0.6764]$$

$A_L = (\$22.46)(1.6764) = \$37.65/\text{Mg}$

d. Total cost

TC = \$50.95 + \$37.65 = \$88.60/Mg

Without recycling the cost was \$72.86/Mg thus the savings would have to be
\$88.60 - \$72.86 = \$15.74/Mg or greater

9-33 Reduction in landfill volume with recycling program

Given: Example 8 5 and 50% paper and 80% glass and metal recycled

Solution:

a. Mass of solid waste generated

Component	Fraction removed	Mass fraction removed
Paper	(0.4317)(0.5) = 0.2159	(0.2159)(780) = 168.36
Tin cans	(0.0520)(0.8) = 0.0416	(0.0416)(780) = 32.45
Nonferrous	(0.0150)(0.8) = 0.0120	(0.0120(780) = 9.36
Ferrous	(0.0430)(0.8) = 0.0344	(0.0344)(780) = 26.83
Glass	(0.0749)(0.8) = 0.0599	(0.0749)(780) = 46.74

Total fraction removed = 0.3638

Total mass fraction removed = 283.76 Mg

Alternate calc.

780 Mg/y x (1   0.3638) = 496.22 Mg/y

b. New weighted compaction ratio

Component	New Mass	New Mass/ Fract.*	Normal Compaction Ratio	Weighted Compaction Ratio
Food waste	73.87	0.1487	2.8	0.4164
Paper	168.40	0.3390	5.0	1.6950
Coardboard	50.70	0.1021	4.0	0.4084
Plastics	14.12	0.0284	6.7	0.1903
Textiles	1.56	0.0031	5.6	0.0174
Leather	11.70	0.0236	3.3	0.0779
Garden	111.70	0.2249	4.0	0.8996
Wood	27.30	0.0550	3.4	0.1870
Glass	11.68	0.0235	1.7	0.0400
Tin cans	8.11	0.0163	5.6	0.0913
Nonferrous	2.34	0.0047	5.6	0.0263
Ferrous	6.70	0.0135	2.9	0.0392
Dirt, etc.	8.58	0.0173	1.2	0.0208
Total	496.76			4.1093

* New Mass/496.76

c. The density of the compacted fill

Dc = (106)(4.11) = 435.66 kg/m3 or 0.436 Mg/m3

d. New volume

$$V = \frac{496.22\,\text{Mg/y}}{0.43566\,\text{Mg/m}^3} \times \frac{1}{52} \times \frac{1}{5} = 4.38\,\text{m}^3/\text{d}$$

e. In 0.3 m layers

$$\frac{4.38\,\mathrm{m}^3/\mathrm{d}}{0.3} = 14.60\,\mathrm{m}^2/\mathrm{d}$$

f. Soil volumes

Soil separating stack

(0.3)(2.4)(14.6)1/2(3 cells)(2 sides) = 16.5

For daily cover

(3 cells/stack)(5 lifts/cell)(14.60 m2)(0.15 m) = 32.85 m3

Plus 0.15 m intermediate cover for week

(3 cells/stack)(14.60 m2)(0.15 m) = 6.57 m3

Plus final 0.3 m

(14.60 m2)(0.3 m) = 4.38

Total soil volume

Vsoil = 32.85 + 6.57 + 4.38 + 16.5 = 60.30

g. The solid waste volume

Vsw = (4.38 m3/d)(15 d/stack) = 65.70 m3/stack

h. The value for E

$$E = \frac{65.70 + 60.03}{65.70} = 1.9137$$

i. Volume of landfill

$$V_{LF} = \frac{(496.76)(1.9137)}{0.43566} \times 20\mathrm{y} = 43{,}641.78 \text{ or } 44{,}000\ \mathrm{m}^3$$

j. Area of landfill

$$A_{LF} = \frac{44000}{(3)(2.4)+0.3} = 5866.67 \text{ or } 5900 \text{ m}^2$$

9-34 Maximum drainage distance (EPA method)

Given: rainfall = 4.0 cm/mo, k = 2.0 x 10^{-2} cm/s, slope = 1.0%

Solution:

Use Equation 9-9 with EPA max length of 0.3 m

a. Convert rainfall rate to m/s

$$r = \left(\frac{4.0\text{cm}}{\text{month}}\right)\left(\frac{10^{-2}\text{m}}{\text{cm}}\right)\left(\frac{1\text{month}}{30\text{d}}\right)\left(\frac{1\text{d}}{86400\text{s}}\right) = 1.54\times10^{-8} \text{ m/s}$$

b. Convert k to m/s

$$k = \left(\frac{2.0\times10^{-2}\text{cm}}{\text{s}}\right)\left(\frac{10^{-2}\text{m}}{\text{cm}}\right) = 2.00\times10^{-4} \text{ m/s}$$

c. S = tan α = 1% = 0.01 m/m

d. Solve Equation for L

$$0.3 = L\left(\frac{1.54\times10^{-8}}{2(2.00\times10^{-4})}\right)^{0.5}\left\{\frac{(2.00\times10^{-4})(0.01)^2}{1.54\times10^{-8}} + 1 - \frac{(2.00\times10^{-4})(0.01)}{1.54\times10^{-8}}\left[(0.01)^2 + \frac{1.54\times10^{-8}}{2.00\times10^{-4}}\right]^{0.5}\right\}$$

$$0.3 = L(6.20\times10^{-3})\left\{\frac{(2.00\times10^{-4})(0.01)^2}{1.54\times10^{-8}} + 1 - \frac{(2.00\times10^{-4})(0.01)}{1.54\times10^{-8}}\left[(1\times10^{-4}) + 7.70\times10^{-5}\right]^{0.5}\right\}$$

$$0.3 = L(6.20\times10^{-3})\left\{1.3 + 1 - (1.3\times10^{2})[1.77\times10^{-4}]^{0.5}\right\}$$

$$0.3 = L(6.20\times10^{-3})\left\{2.3 - (1.3\times10^{2})[1.33\times10^{-2}]\right\}$$

$$0.3 = L(6.20\times10^{-3})\left\{2.3 - 1.73\right\}$$

$$0.3 = L(3.54\times10^{-3})$$

L = 84.8 or 85 m

9-35 Drainage distance using:

Given: Problem 9-34; slopes of 0.5, 1.0, 2.0, and 3.0%; wet season 40.0 cm/mo

Solution:

a. See following spreadsheet calculations

						Wet Season	
Precip. (cm/mo)	4.00					40	
K (cm/s) =	0.02						
S (m/m) =	0.01	0.01	0.02	0.03		0.01	
y_{max} (m) =	0.30	0.30	0.30	0.30		84.59	=L
r =	0.00					0.00	
K (m/s) =	0.00						
r/K =	0.00	0.00	0.00	0.00		0.00	
(r/2K)^0.5	0.01	0.01	0.01	0.01		0.02	
KS(2)/r	0.32	1.30	5.18	11.66		0.13	
KS/r	64.80	129.60	259.20	388.80		12.96	
S(2)	0.00	0.00	0.00	0.00		0.00	
Bracket =	0.67	0.57	0.52	0.51		0.75	
(r/2K^0.5)(Bracket) =	0.00	0.00	0.00	0.00		0.01	
L=	72.19	84.59	92.52	94.65	y(max.) =	1.24	m

9-36 Lower heating value

Given: Cellulose $C_6H_{10}O_5$ with HHV of 32,600

Solution:

a. Compute GMW of cellulose

C = 6(12) = 72
H = 10(1) = 10
O = 5(16) = 80

Total = 162

b. Compute LHV using Eqn 9-15

$$LHV = 32600 - \left[(24290)(9)\left(\frac{10}{162}\right)\right] = 31{,}255.56 \text{ or } 31{,}300 \text{ kJ/kg}$$

9-37 Lower heating value for CH_4

Given: HHV = 888,500 kJ/kg

Solution:

a. Compute GMW of CH_4

C = 12
H = 4(1) = 4

Total = 16

b. Compute LHV using Eqn 9-15

$$LHV = 888500 - \left[(24290)(9)\left(\frac{4}{12}\right)\right] = 881{,}240 \text{ kJ/kg}$$

9-38 LHV of food waste

Given: HHV = 4500 kJ/kg, 6.0% by mass is hydrogen

Solution:

a. Using Eqn. 9-15

$$LHV = 4500 - [(24290)(9)(0.06)] = 3193.2 \text{ or } 3{,}200 \text{ kJ/kg}$$

DISCUSSION QUESTIONS

9-1 Mean time per collection stop

Given: Equation 9-2

Solution:

There is no explicit consideration of crew size in the calculation of t_p' but it may be implicit that a larger crew can empty multiple cans more quickly than a crew of one so t_{bp} would be less. Location of containers at the rear of the house increases collection time linearly as the percentage of rear of house pickups increases.

9-2 Recommending a transfer station

Given: What conditions required

Solution:

The travel time and number of crew members making the trip strongly influence the need for a transfer station. Large crews taking substantial amounts of time (whether because of distance or congestion) favor transfer stations.

9-3 Suitability of soil types

Given: Six soil types and three applications

Solution:

1. Gravel (>2.5 cm diameter) = gas venting
2. Glacial till = not suitable for any of the three uses
3. Clay ($K = 1 \times 10^{-9}$ cm/s) = composite liner
4. Clay ($K = 1 \times 10^{-6}$ cm/s) = not suitable for any of the three uses
5. Sand (K = 0.1 cm/s) = drainage layer
6. Sand (K = 0.001 cm/s) = not suitable for any of the three uses

9-4 Recycling and WTE plant

Given: Proponents claim recycling will not affect performance of WTE

Solution:

Disagree. Recycling is beneficial because it conserves a natural resource. Recycling will affect the incinerator in several ways. First, the reduction in mass of solid waste will permit a reduction in the size of the facility and, hence, the capital cost. In addition, the waste that remains will have a higher energy content. Recycling also reduces waste elements that can damage boilers and remove components that slag and foul the boiler.

9-5 Why yard composting?

Given: Composting of yard waste has little economic value

Solution:

Yard waste uses a considerable volume of landfill space. Composing reduces the volume and makes a useful product to return to the environment.