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INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

FOCUSSED ON MSW, C&D AND E-WASTE MANAGEMENT

Welcome to Week-6

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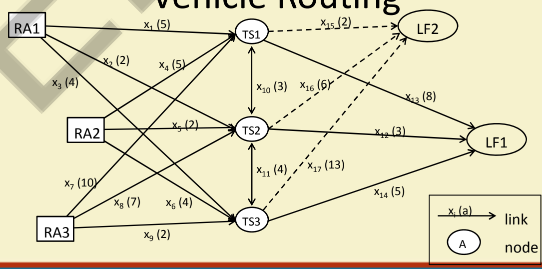
During this week (Week-6)

- Vehicle Routing and Collection System Example Problems
- Review of MSW Management Status of Few of the Proposed Smart Cities in India
- Biological treatment of waste

Vehicle Routing

- factors in designing pick-up routes
  - loading times
  - no U-turns
  - right turns are preferred
  - volume per truck (compaction rating)
  - travel time to the transfer station
- large communities use linear programming, specifically LP network models
  - a network consists of a set of nodes and links that show the direction of flow between various pairs of nodes
  - the optimum solution is one or more paths consisting of a set of connected links between source, intermediate, and sink nodes
  - for each node → flow in = flow out
  - network models can have a multiple sources (residential areas) and sinks (transfer stations and/or landfills)

Vehicle Routing

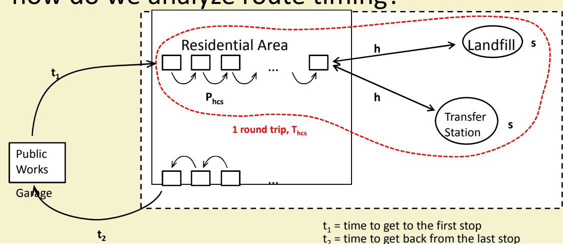


Vehicle Routing

- factors to consider:
  - times to/from the first/last home
  - local routes need input from vehicle drivers (routing coefficients)
  - unloading time at transfer stations/landfill
- there is a need to consider all options
  - the local landfill, or transport to private landfill?
  - the decision variables are routing times through the network
  - the objective → minimize routing time
  - time = money
  - the constraints on the system are travel times along each route, capacities of each transfer station/landfill, conservation of material at nodes, ...
- as more information comes from operating the actual collection system, the process can be refined by trial and error, or through the use of the linear programming model

Pick-up Times

- how do we analyze route timing?



t_1 = time to get to the first stop
t_2 = time to get back from the last stop
P_{hcs} = pick-up time per trip
h = haul time to TS/LF site
s = time at-site emptying the truck

Pick-up Times

- there are equations in the book (library-reference) for pick-up timing
- for example, for hauled container systems:

$$T_{hcs} = (P_{hcs} + s + h)$$

where: T_{hcs} = timing of each round trip, hr/trip
P_{hcs} = pick-up time per trip, hr/trip
s = at-site time (landfill, transfer station) per trip, hr/trip
h = haul time per trip, hr/trip

- pick-up times (P_{hcs}) and at-site times (s) are relatively constant
- but, the haul time (h) depends on both the haul distance and the speed along the route

Pick-up Times

- using field data for various types of collection vehicles, haul time can be approximated by a straight-line relationship:

$$h = (a + bx)$$

where: a, b = empirical constants
x = average round-trip haul distance, mi/trip

- so, time for each round-trip becomes:

$$T_{hcs} = (P_{hcs} + s + (a + bx))$$

- the empirical constants (a, b) are site specific, and consider:
  - speed
  - type of container
  - size of vehicle, number of employees per vehicle
- your new employer will provide these to you, if needed

Number of Trips Per Day

- the number of trips that can be made per vehicle per day, considering an off-route factor, W:

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

where: N_d = number of round trips per day
H = length of a work day, hours/day
W = off-route factor (lunch, pit-stops, ...), expressed as a fraction
t_1 = time to drive from garage to first pick-up, hours
t_2 = time to drive from last pick-up to garage, hours
T_{hcs} = time for one round trip, hr/trip

- this allows us to estimate the number of pick-ups, trips and vehicles that are required for a community collection system

INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

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Design a New Collection System

- let's design a collection system for a sub-division (1000 new homes) and consider two types of vehicles:
  - 1-person side-loaded vehicles
  - 2-person back-loaded vehicles (which also require a separate driver)
- that is, let's determine the number of pick-ups per day, and the size of vehicle
- given the following:
  - number of residents per home = 3.5
  - waste generation (no separation) = 1.2 kg/capita/day
  - density of waste at curb = 110 kg/m^3
  - compaction ratio in the truck = 2.5 (275 kg/m^3)
  - distance to transfer station = 35 miles (we will use miles – for coefficients)
  - number of round trips per day (N_d) = 2
  - length of the work day (H) = 8 hours

Design a New Collection System

- given the following:
  - time to travel – from the garage to first location (t_1) = 0.3 hours
  - time to travel – from the last location back to garage (t_2) = 0.4 hours
  - off-route factor (W) = 0.15 → 15% of time not spent on collection or transport
  - haul constants (based on 55 mph):
    - a = 0.016 hr/trip
    - b = 0.018 hr/mi
  - time at landfill (s) = 0.10 hr/trip

1. determine time available for pick-up per trip (P_{scs})

$$T_{scs} = (P_{scs} + s + (a + bx))$$

$$H(1 - W) = (t_1 + t_2) + N_d(T_{scs})$$

re-arranging:

$$P_{scs} = \frac{[H(1 - W) - (t_1 + t_2)]}{N_d} - (s + a + bx)$$

Design a New Collection System

- the time available per trip (manual loading):

$$P_{scs} = \frac{[8(1-0.15)-(0.3+0.4)]}{2} - (0.1 + 0.016 + 0.018(35)) = 2.3 \text{ hours/trip}$$

2. pick-up time per location (t_p):
   a) 1-person = 0.92 collector-min/location (Table 8-6 for unlimited # bags)
   b) 2-person = 1.35 collector-min/location (from field observations = 0.675*2)

3. number of pick-up locations completed per trip (N_p):

$$N_P = P_{scs}(n/t_p)$$

where: P_{scs} = pick-up time available per trip, hr/trip
n = number of collectors
t_p = pick-up time per pick-up location, collector-min/location

$$\text{min/location} = \left(\frac{t_p}{n}\right) = \left(\frac{\text{collector}\cdot\text{min/location}}{\text{collectors}}\right)$$

a unit analysis →

Design a New Collection System

- the number of pick-up locations:

a) $$N_P = \frac{P_{scs}(n)}{t_p} = \frac{(60 \text{ min/hr})(2.3 \text{ hr/trip})(1 \text{ collector})}{0.92 \text{ collector}\cdot\text{min/location}} = 150 \text{ locations/trip}$$

b) $$N_P = \frac{P_{scs}(n)}{t_p} = \frac{(60 \text{ min/hr})(2.3 \text{ hr/trip})(2 \text{ collector})}{1.35 \text{ collector}\cdot\text{min/location}} = 204 \text{ locations/trip}$$

volume of waste per location (per week):

$$V_P = \frac{(1.2 \text{ kg/pers/d})(3.5 \text{ pers/location})(7 \text{ day/week})}{110 \text{ kg/m}^3} = 0.27 \text{ m}^3\text{/location}$$

Design a New Collection System

5. estimate the volume (v) needed for each type of truck:

$$v = V_P(N_P)/r$$

where: V_P = volume of waste per location, m^3/location
N_p = number of pick-up locations per trip, locations/trip
r = compaction ratio

a) $$v = \frac{V_P(N_P)}{r} = \frac{(0.27 \text{ m}^3\text{/location})(150 \text{ location/trip})}{2.5} = 16 \text{ m}^3\text{/trip}$$

b) $$v = \frac{V_P(N_P)}{r} = \frac{(0.27 \text{ m}^3\text{/location})(204 \text{ location/trip})}{2.5} = 22 \text{ m}^3\text{/trip}$$

– so, a 16 m^3 vehicle can do 1 round trip and pick up waste from 150 locations
– and a 22 m^3 vehicle can do 1 round trip and pick up waste from 204 locations

Design a New Collection System

6. number of truck trips in a week:

a) $$N_T = \frac{(1000 \text{ locations/week})}{(150 \text{ locations/trip})} = 6.67 \text{ trip/week} \rightarrow 16 \text{ m}^3\text{, 1-person vehicle}$$

b) $$N_T = \frac{(1000 \text{ locations/week})}{(204 \text{ locations/trip})} = 4.9 \text{ trip/week} \rightarrow 22 \text{ m}^3\text{, 2-person vehicle}$$

- what is the cost of each system:
  – vehicle size – need to be purchased and operated
  – # of employees – time and wages
  – # trips – fuel cost

Design a New Collection System

- let's look at the labor requirements

a) 1 collector vehicle, assuming the following:
   – 1 employee/vehicle
   – 8 hours/day
   – N_T = 6.67 trips/week (waste pick-up, assuming truck can be partially full)
   – P_{SCS} = 2.3 hours/trip
   – N_T = 7 trips/week (round up for trips to the landfill)

$$\text{Time} = \left(6.67 \frac{\text{trip}}{\text{week}}\right)\left(2.3 \frac{\text{hour}}{\text{trip}}\right) + \leftarrow \text{picking up waste}$$

$$\left(7 \frac{\text{trip}}{\text{wk}}\right)\left(0.1 \frac{\text{hr}}{\text{trip}} + 0.016 \frac{\text{hr}}{\text{trip}} + \left(0.018 \frac{\text{hr}}{\text{mi}}\right)\left(35 \frac{\text{mi}}{\text{trip}}\right)\right) \leftarrow \text{landfill drop-off}$$

$$= (15.33 + 5.22) = 20.6 \frac{\text{hr}}{\text{wk}}$$

Design a New Collection System

a) 1 collector vehicle:
 – having 1 employee per vehicle

$$\text{Labor} = \left\{ \frac{(1 \ \text{collector})\left(20.6 \ \frac{\text{hr}}{\text{wk}}\right)}{(1 - 0.15)\left(8 \ \frac{\text{hr}}{\text{d}}\right)} \right\} = 3.02 \ \text{collector} \cdot \text{day/week}$$

b) 2 person compactor (+ driver)
 – having 3 employees per vehicle

$$\text{Labor} = (3)\left\{ \frac{4.9\,(2.3) + 5\,(0.1 + 0.016 + (0.018 \times 35))}{(1 - 0.15)(8)} \right\} = 6.6 \ \text{collector} \cdot \text{day/week}$$

$$\% \text{ difference} = \left(\frac{(6.6 - 3.02)}{6.6} \right) = 54\%$$

on operating costs, the 1-collector vehicle uses 54% less personnel time

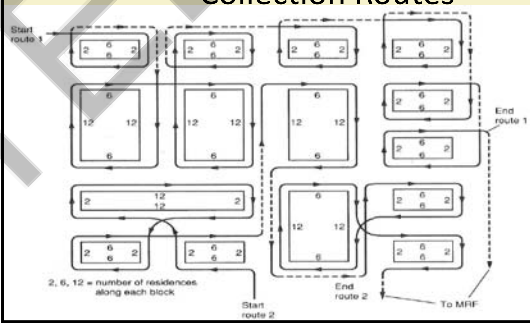
Collection Routes

- heuristic guidelines need to be followed (i.e. rules-of-thumb)
- existing policies on frequency, type of on-site storage (bins, bags)
- crew size and vehicle size & type
- if possible, routes should always start/stop near major intersections
- if possible, trucks should go downhill (hard for 1 man crew)
- last pick-up should be close to TS/LF (reduce travel time)

Collection Routes

- congested areas serviced during low traffic time (e.g. schools)
- large waste volumes picked up first (alertness)
  – think about the piles of bags at low rise apartments
- use new analysis tools as they become available
  – linear programming, GIS, artificial intelligence
- the goal: to minimize resources (time, people, vehicles), and this requires trial & error → experience

Collection Routes



for more information, there are examples in the book

Review of SWM in Proposed Smart Cities

Based on the Field Survey

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स्वच्छ भारत
एक कदम स्वच्छता की ओर

Details of the smart cities surveyed

S. No	State	Name of the City	Waste Generated in tonnes
1	Gujarat	Ahmadabad	4000
2	Andhra Pradesh	Visakhapatnam	1200
3	Madhya Pradesh	Indore	1000
4	Madhya Pradesh	Bhopal	550
5	Rajasthan	Udaipur	230
6	Delhi	New Delhi Municipal Cooperation	250

Ahmadabad Municipal Corporation

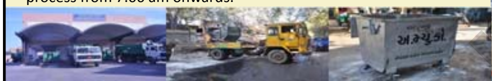
Feature	Description
Name of the City	Ahmadabad, Gujarat
Area	466 sq Km
No. of zones	6
No. of Wards	48
Solid waste (TPD)	4000
Population	63 Lakhs (as on December 2016)

Door to Door Collection → Secondary Collection → Transfer station → Transportation → Processing → Sanitary Landfill

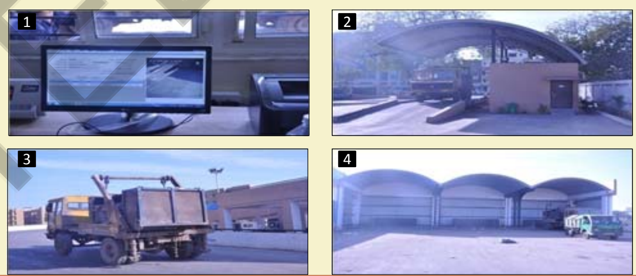
MSWM in Ahmadabad

Waste collection and storage

- Introduced a new concept of Door / Gate to Dump since July 2009
- The waste from these vehicles is transferred to transfer stations from each ward to the treatment plants.
- The project is successfully covering 100% of all residential & commercial units, on all 365 days of the year.
- More than 600 Vehicles have been deployed that start the collection process from 7.00 am onwards.



Transfer station



Controlling of Methane gas

Disposal of waste

Green waste processing unit

Waste processing using composting

Sr. No.	Name of Company	Daily MSW Treatment	Mode of Agreement	Operational Since
1	Excel Industries Ltd	300 Tons into compost	DBFOO * mode No tipping fee	January-2000
2	Bharuch Enviro Engineers Ltd. (UPL Djai Power Ltd.)	250 Tons into compost & RDF	DBFOO * mode No tipping fee	July -2009
3	Creative Eco-Recycle Port Pvt. Ltd.	400 Tons into compost & RDF	DBFOO * mode No tipping fee	December-2012

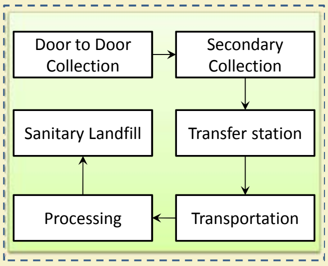
Sanitary landfill for inert disposal

Action Plans for implementation of SWM 2016 rules

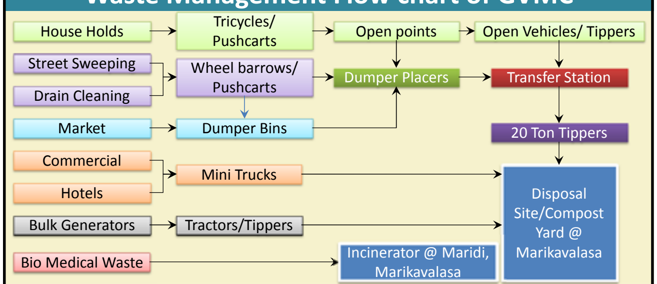
- Roadmap for Zero Waste Ahmedabad by 2031
- Swachhata Jan Model (SJM): Waste segregation at source and inclusion of waste pickers in main stream
- Setting up of Solid Waste Recycling Centre (Material Recovery Facility)
- Scientific Closure of existing Pirana Dump Site
- Implementation of Waste to Energy techniques for treatment of waste

Greater Visakhapatnam Municipal Corporation

Feature	Description
Name of the City	Visakhapatnam, Andhra Pradesh
Area	534 sq Km
No. of zones	6
No. of Wards	72
Solid waste (TPD)	1200
Population	63 lakhs (as on December 2016)



Waste Management Flow chart of GVMC



Data Source: *Revised Master Plan for Visakhapatnam Metropolitan Region – 2021. Report from GVMC*

Waste Collection System

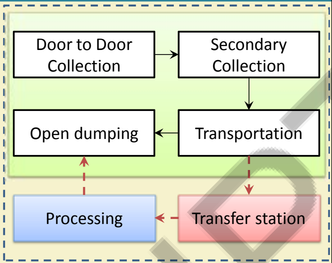
Data Source: *Revised Master Plan for Visakhapatnam Metropolitan Region – 2021, Report from GVMC*

Action Plans for implementation of SWM 2016 rules

- Source Segregation of waste has been introduced in 6 wards as Pilot Project
- Emphasis is being laid on mechanization of garbage handling
- Door to door waste collection has been started in 2 wards from each zone.
- Regular Sweeping (Night sweeping of main roads) and Drain Cleaning
- New landfill sites are being developed as scientific landfill sites.
- Development of Waste to Energy plant in collaboration with Jindal Group for production of energy
- Bio-mining of waste at dump yard in collaboration with Coramandel Groups

Indore Municipal Corporation

Feature	Description
Area	130 Sq. Kms
Population (inLacks)	19,60,630
Solid Waste Generated	1000 Tons
Percentage of Waste Collected	70 - 75 %
Amount of Waste processed	25 - 30 %



Indore Municipal Corporation

Central Workshop for Operation and Maintenance of the vehicles

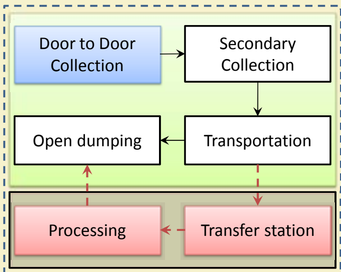
Training and Learning Center developed by the Municipal Corporation for creating awareness among the citizens

Action Plans for implementation of SWM 2016 rules

- The IMC has taken a step towards door to door collection.
- As a part of the program the Solid waste team is creating awareness among the citizens.
- Waste collected from city is disposed at Devguradia trenching ground existing landfill site that is 18 km away from Indore City.
- IMC in collaboration with Private organizations is planning to start up source segregation for residential groups and welfare associations.

Bhopal Municipal Corporation

Particulars	Description
Name of the city	Bhopal, Madhya Pradesh
Area (sq. km)	258
No. of Zones	14
No. of Wards	66
Solid waste (TPD)	550
Population (Lacs)	14



Waste Management System in Bhopal

Action Plans for implementation of SWM 2016 rules

- Cluster based solid waste system is developed for collection and transfer of waste
- Waste processing plant has to be commission and run by M.P. Agro state organization to develop Bio fertilizer of capacity 100MT/day.
- Bio-methanation plant is under construction at the market yard.
- Sanitary landfill is being developed at Agnampudi for disposal of waste.

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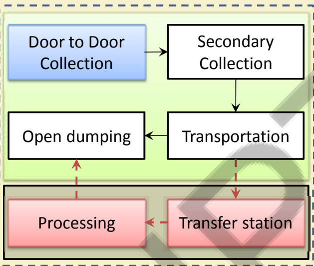
Udaipur Municipal Corporation

Particulars	Description
Name of the city	Udaipur, Rajasthan
Area (sq. km)	64
No. of Zones	5
No. of Wards	55
Solid waste (TPD)	230 (Excluding Industrial & Hospital waste)
Population (Lacs)	4.68



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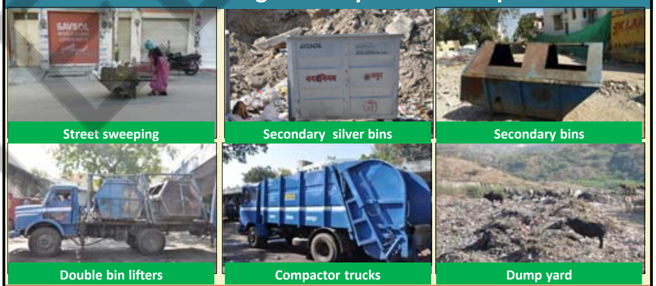
Waste Management System in Udaipur



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Action Plans for implementation of SWM 2016 rules

- The UMC has initiated steps towards door to door collection and Source Segregation of waste as Pilot Project
- Regular Sweeping and Drain Cleaning as the city is a tourist place
- The UMC in association with Hindustan Zinc Ltd., is planning to start up composting and Waste to Energy plants.
- Emphasis is being laid on mechanization of garbage handling

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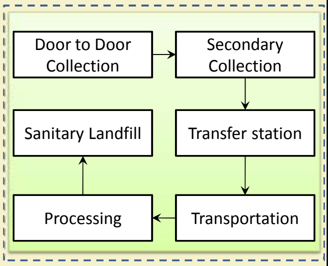
New Delhi Municipal Corporation (NDMC)

Particulars	Description
Name of the city	NDMC, Delhi
Area (sq. km)	42.8
Solid waste (TPD)	250
Population (lacs)	4.5
Landfill (TPD)	170
Composting (TPD)	80



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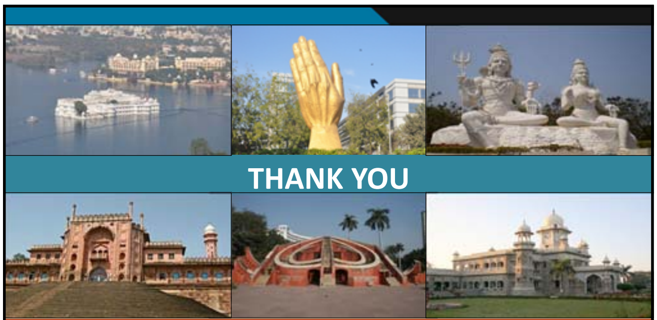
Action Plans for implementation of SWM 2016 rules

- **Collection of garbage:**
  - Door to door collection of garbage has been started at 51 places. NDMC envisages expanding this scheme in its entire area. 1100 pairs of litterbins have been provided at busy places.
- **Collection and transportation of municipal solid waste:**
  - 1600 twin bin trolleys (Blue and Green) along with garbage stations having segregation facilities will be provided.
  - The garbage will be transported in mechanized covered vehicles to the disposal site. The garbage shall be recycled at the disposal site by installing modern compost plant and recycling plant.
- **Disposal of horticulture waste:**
  - Efforts are being made to compost the horticulture waste in situ by local compositing in the NDMC nurseries.



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Biological Treatment of Waste

What is Biological Treatment

- Conversion of organic substrate in the waste to a more stabilized form through the use of biological organisms.
- In this class, we are referring to "solid" solid wastes, not wastewaters.

What Types of Solid Waste are Biologically Treated?

- Municipal Solid Waste
- Sewage Sludge
- Agricultural Waste
- Industrial Waste
- Hazardous Waste

Biological Treatment

- Aerobic
  - Composting
- Anaerobic
  - Anaerobic Digestion
  - Landfills

Municipal Solid Waste composition

Source: EPA

What part of a solid waste is actually treated in a biological treatment process?

- Biodegradable Components
  - Paper
  - Cardboard
  - Food Waste
  - Yard Waste
  - Wood, Leather, Rubber?

Composition of Waste

Type of Biology

- Aerobic
  - Diverse
  - Fungi, bacteria, insects, worms
- Anaerobic
  - Fairly well defined groups of bacteria

Biochemical Processes

- *biochemical processes* transform the organic fraction of MSW into gas, liquid and solid conversion products
- the processes that are most commonly used for the transformation of organic waste include:
  - aerobic composting
  - low-solids anaerobic digestion
  - high-solids anaerobic digestion
  - high-solids anaerobic digestion/aerobic composting
- before looking at these individual processes, some basic principles of biological processes will be introduced

Organic Matter

- organic material composes 30 – 80% of MSW
- a proximate analysis reveals that the organic matter consists of:
  - water content – lost when heated to 105 °C for 1 hour
  - volatile combustible matter – ignition at 450 °C
  - fixed carbon – combustible residue after volatile matter (550 – 950 °C)
  - non-combustible residue – ash
- the principle components of the organic fraction of MSW are:
  - proteins
  - amino acids
  - lipids
  - carbohydrates
  - cellulose
  - lignin
  - ash

Biological Conversion

- the major objective is to convert the organic matter (feedstock) in waste to a stable end-product
- aerobically – it's the composting process
  - a succession of facultative and obligate aerobic microorganisms feed on the organic matter converting it to new cell tissue
- anaerobically – it's the anaerobic fermentation process
  1. enzyme transformation (hydrolysis) – of high MWT compounds into compounds suitable for use as a source of energy and cell tissue
     - basically, anaerobic microbes hydrolyze the organic polymers and lipids into fatty acids, monosaccharides and amino acids

Biological Conversion

2. bacterial conversion – a second set of microorganisms convert these intermediate compounds into lower MWT intermediate compounds
   - acidogens ferment these compounds into simple organic acids (e.g. acetic acid)

3. bacterial conversion – of the lower MWT compound into simple end-products (principally methane and carbon dioxide)

- basically, just like what happens in a landfill

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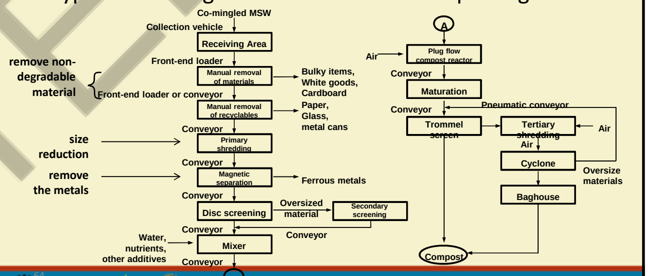
Aerobic Composting

- the aerobic composting process has always occurred in nature:

proteins, amino acids, lipids, carbohydrates, cellulose, lignin, ash + O_2 + Nutrients (N, P, K) + microorganisms → Compost + New Cells (→ Dead Cells → Compost) + CO_2, H_2O, NO_3, SO_4^{2-} + Heat

- the end product remaining after microbial activity is a humus material called "compost"
- the new cells that are produced become part of the active biomass involved in the conversion of the organic matter and, when they die, become part of the compost

A typical flow diagram for commercial composting:



Nutrients

- the most critical environmental factor for composting is the relative proportion of carbon and nitrogen (the C:N ratio)
- the optimal range is between 20:1 and 25:1
  - composting time increases with the C:N ratio above 40:1
- individual components of organic matter have different C:N ratios:
  - digested sludge has a low ratio (15:1)
  - yard waste has a high ratio (40:1 – 80:1)
  - newspaper has a very high ratio (175:1 – 800:1)
- to achieve an optimal ratio, organic waste is blended together
- for example, we might add:
  - newsprint – which is high in carbon and low in nitrogen, and
  - yard waste – which is high in nitrogen
  - and, supplement with manure (15:1) or sludge (15:1) if needed

nominal C:N ratios of selected compostable materials

Table 14-7

Material	Percent N	C/N ratio[a]
Food processing wastes		
Fruit wastes	1.52	34.8
Mixed slaughterhouse waste	7.0–10.0	2.0
Potato tops	1.5	25.0
Manures		
Cow manure	1.7	18.0
Horse manure	2.3	25.0
Pig manure	3.75	20.0
Poultry manure	6.3	15.0
Sheep manure	3.75	22.0
Sludges		
Digested activated sludge	1.88	15.7
Raw activated sludge	5.6	6.3
Wood and straw		
Lumber mill wastes	0.13	170.0
Oat straw	1.05	48.0
Sawdust	0.10	200.0–500.0
Wheat straw	0.3	128.0
Wood (pine)	0.07	723.0
Paper		
Mixed paper	0.25	173
Newsprint	0.05	983
Brown paper	0.01	4490
Trade magazines	0.07	470
Junk mail	0.17	223
Yard wastes		
Grass clippings	2.15	20.1
Leaves (freshly fallen)	0.5–1.0	40.0–80.0
Biomass		
Water hyacinth	1.96	20.9
Bermuda grass	1.96	24

Example of Mixing Wastes

- assume the following properties of leaves and sludge:
  - leaves → C:N ratio of 50:1, water content = 30%, N = 0.7%
  - sludge → C:N ratio of 6:1, water content = 75%, N = 5.6%
- what is the mixing ratio per 1.0 kg to get a C:N = 25:1
- 1 kg leaves:

$$\text{water} = 0.30 \cdot (1.0\ \text{kg}) = 0.30\ \text{kg}$$
$$\text{dry matter} = 0.70 \cdot (1.0\ \text{kg}) = 0.70\ \text{kg}$$
$$N = 0.007 \cdot (0.70\ \text{kg}) = 0.0049\ \text{kg}$$
$$C = 50 \cdot (0.0049\ \text{kg}) = 0.245\ \text{kg}$$

- 1 kg sludge

$$\text{water} = 0.75 \cdot (1.0\ \text{kg}) = 0.75\ \text{kg}$$
$$\text{dry matter} = 0.25 \cdot (1.0\ \text{kg}) = 0.25\ \text{kg}$$
$$N = 0.056 \cdot (0.25\ \text{kg}) = 0.0137\ \text{kg}$$
$$C = 6 \cdot (0.0137\ \text{kg}) = 0.0823\ \text{kg}$$

Example of Mixing Wastes

- take 1 kg leaves and add X kg of sludge:
- the desired C:N ratio is 25:1

$$\frac{25}{1} = \frac{\text{C in 1 kg of leaves} + X \cdot (\text{C in 1 kg sludge})}{\text{N in 1 kg of leaves} + X \cdot (\text{N in 1 kg sludge})}$$
$$25 = \frac{0.245 + X \cdot (0.0823)}{0.0049 + X \cdot (0.0137)}$$
$$0.1225 + 0.3425\,(X) = 0.245 + 0.0823\,(X)$$
$$X = \frac{0.1225}{0.2062} = 0.47$$

- therefore, you need 0.47 kg of sludge per 1.0 kg of leaves

Example of Mixing Wastes

- check the water content for 1.0 kg leaves + 0.47 kg sludge

$$\text{water} = 0.3 + 0.47\,(0.75) = 0.653\ \text{kg}$$
$$\text{dry matter} = 0.7 + 0.47\,(0.25) = 0.818\ \text{kg}$$
$$WC = \frac{\text{mass of water}}{\text{total mass of the system}}$$
$$= \frac{0.653}{0.653 + 0.818} = \frac{0.653}{1.471} = 44\%$$

- this is less than 50% so we need to add water

Example of Mixing Wastes

- check the water content for 1.0 kg leaves + 0.47 kg sludge

$$0.50 = \frac{0.653 + X}{1.471 + X}$$
$$0.50X + 0.736 = 0.653 + X$$
$$0.50X = 0.083$$
$$X = 0.166\ \text{kg water}$$

- so, add 166 mL of water per 1.0 kg of leaves
- also, you should check bulking (increase the porosity of the compost) for air movement
  - add wood chips (changes the C:N ratio), or
  - inert material (like crushed tires)

Temperature

- heat is released in the composting process, and a mass of composting material will retain the heat
- the temperature rise is caused by exothermic reactions associated with microbial respiration
- high temperature is essential for destruction of pathogenic organisms
- composting operates in 2 temperature ranges:
  - mesophilic → 30 – 35°C for the first few days
  - thermophilic → 50 – 60°C for the remainder of the time
  - 60°C for 24 hours will destroy all pathogens
  - it should be kept below 66°C or biological activity is reduced significantly
- to maintain high temperatures, compost must be aerobic
  - in static piles – temperature can be controlled by airflow
  - in windrows – temperature drops for several hours after mixing

pH Control

- pH is the measure of the acidity or alkalinity of the compost
- initially, during the mesophilic stage, pH is between 7.0 and 7.5
- after several days, the pH will naturally drop to 5.0
  - as a result of the production of organic acids
- during thermophilic stage, pH will rise to around 8.0
- to minimize loss of N as ammonia (NH_3^+) gas, the pH should be kept below 8.5
  - this can be managed with aeration
  - the addition of lime to increase pH is discouraged – it causes nitrogen to be released as ammonia gas, which causes odour problems and a reduction in available nitrogen
- mature compost has a pH around 7 (neutral)
- if aeration is insufficient, pH will drop to 4.5 and composting will struggle

Temperature and pH

typical temperature and pH ranges observed during windrow composting

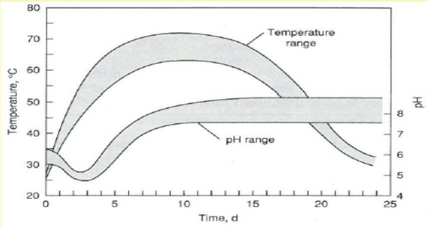


Figure 14-5

Other Environmental Factors

- moisture content
  - should be in the range of 50 – 60% on a wet-weight basis
  - high moisture content displaces air from the pore space
  - sludge is a good source of H_2O
- blending/seeding
  - organisms necessary for decomposition are indigenous to organic material
  - mixing with 5% partially decomposed compost speeds up the process
  - again, sludge is a good source

Other Environmental Factors

- particle size
  - shredded to 25 – 75 mm is beneficial
  - exposes more surface area and allows for easy air movement
- mixing/turning
  - prevents drying, caking or air channeling
  - frequency is a function of the process
  - first turning after 3 days, then every 5th day

INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

FOCUSSED ON MSW, C&D AND E-WASTE MANAGEMENT

End of Week-6

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