IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES | NPTEL

INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

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

BRAJESH KUMAR DUBEY
DEPARTMENT OF CIVIL ENGINEERING

During this week (Week-5)

- Waste Collection, Transport, Segregation and Processing contd....
- Landfill Disposal

Materials Mass Balance

- a materials mass balance is the only way to determine the generation and movement of solid waste with any degree of reliability:

Rate of accumulation of material within the system boundary = Rate of material flow **into** the system boundary − Rate of material flow **out of** the system boundary + Rate of generation of waste material **within** the system boundary

Rate of accumulation → storage

Flow out → products: wastewater, recyclables, leachate, vapors

Generation → accounts for transformations: biological, incineration, ...

- system boundary could be landfill site, manufacturing facility, ...
- can be used to estimate waste per tonne of product
- smart companies work on reducing this ratio

Source Handling and Separation

- handling and separation of solid waste at-source before collection is important in managing residential waste
  - it requires an on-going education program for homeowners to keep them current on what is separated, and what is not
- handling/separation refers to any activity needed to manage solid waste before it is stored for collection or drop-off
  - separating recyclables (blue box, orange drop)
  - separating compostable materials
  - operating the backyard composter
  - separating and disposing of re-usable products
  - dropping off HHW

Designing Collection Systems

- Determining number of vehicles
- Determining vehicles time on the route
- Routing

Collection of Solid Waste

- collection of un-separated waste is difficult due to co-mingling, which combines:
  - residential
  - commercial
  - institutional
  - industrial

  } generation occurs at every home, apartment, facility, ... but also in the streets, parks and even in vacant lots
- as development becomes more diffuse (i.e. lots of suburbs) and total waste quantities increase, the logistics of collection become more complex
- this makes collection a significant cost component
- in 1992, approximately 50 – 70 % of solid waste budgets in the US were spent on the collection phase
- its even more costly now
  - more trucks, more collection streams, more complex cities, ...

Issues with Curbside Pick-up

- who is responsible
  - bags to curb – by resident
  - bins to curb – by resident (or collection crew → increases cost)
  - bins back to home – resident
  - mechanical bins – operated by collection crew
- aesthetic issues
  - bags vs. bins
  - time of day (Guelph by-laws are after 7:00 the night before collection)
  - upset bins/bags – quick clean-up so that they can be picked up
- scavengers – good or bad? … how would you manage it?
- crew size
  - 1-person vehicle
  - multi-person vehicle for back/forth bin handling
- maneuverability – around bags, bins, trucks, alleyways

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES

Issues with Curbside Pick-up

- who gets curbside pick-up
  - single residences
  - duplexes
  - low-rise apartments
  - few medium-rise apartments
- use of large storage containers
  - medium-rise apartments
  - high-rise apartments
  - commercial – off-hours, private haulers
  - institutional
- but these storage containers can be a problem
  - large bins at schools used by nearby residents
  - illegal dumping
  - disposing of incorrect material (e.g. dog owners & stoop and scoop bags)

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES

Issues with Curbside Pick-up

- where the waste is placed
  - at the curb
    - when can you place it,
    - for how long,
    - how to prevent animal damage
  - in the alley
    - access,
    - truck size,
    - maneuverability, …
- think about waste collection in NYC (www.nyc.gov)
  - always people out/about
  - waste can't be there for more than a few hours
  - out of site of tourists
  - 5,150 trucks/week → 54,200 tons res.waste/week

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES

INTEGRATED WASTE MANAGEMENT FOR A SMART CITY
FOCUSSED ON MSW, C&D AND E-WASTE MANAGEMENT

BRAJESH KUMAR DUBEY
DEPARTMENT OF CIVIL ENGINEERING

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES 10

Vehicle Routing

- Manual Techniques
  - Heuristic Routing
  - EPA published 11 rules for heuristic routing
- Computer-assisted Routing
  - This technique will be practiced by most waste collection companies today

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES

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)

IIT KHARAGPUR | NPTEL ONLINE CERTIFICATION COURSES

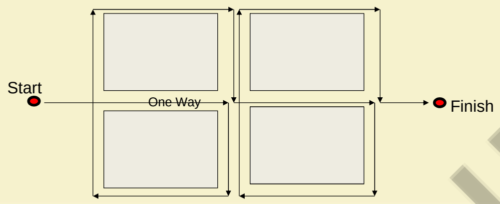
Vehicle Routing

- 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

Typical guideline for routing

1. Routes should not be fragmented or overlapped. Each route should be compact, consisting of street segments clustered in the same geographic area.
2. Total collection plus haul times should be reasonably constant for each route in the community (equalized workloads).
3. The collection route should be started as close to the garage or motor pool as possible, taking into account heavily traveled and one-way streets.
4. Heavily traveled streets should not be collected during rush hours.
5. In the case of one-way streets, it is best to start the route near the upper end of the street, working down it through the looping process.
6. Services on dead end streets can be considered as services on the street segment that they intersect, since they can only collected by passing down that street segment. To keep left turns at a minimum, collect the dead end streets when they are to the right of the truck. They must be collected by walking down, backing down, or making a U-turn.
7. When practical, service stops on steep hills should be collected on both sides of the street while the vehicle is moving downhill for safety, ease, speed of collection, wear on vehicle, and conservation of gas and oil.
8. Higher elevations should be at the start of the route.
9. For collection from one side of the street at a time, it is generally best to route with many clockwise turns around blocks.
10. For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the grid before looping clockwise.
11. For certain block configurations within the route, specific routing patterns should be applied.

Example: One-Way Main Street with Two-Way Arterial Streets

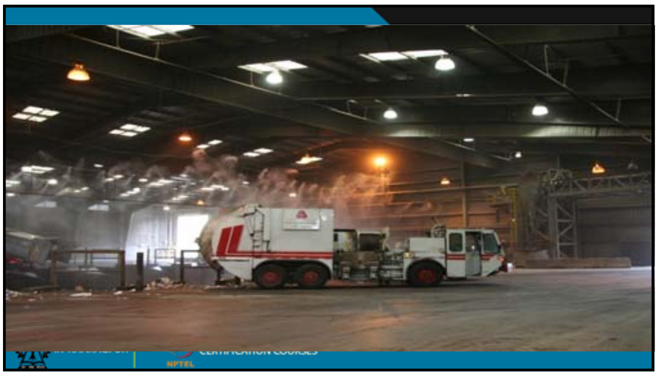


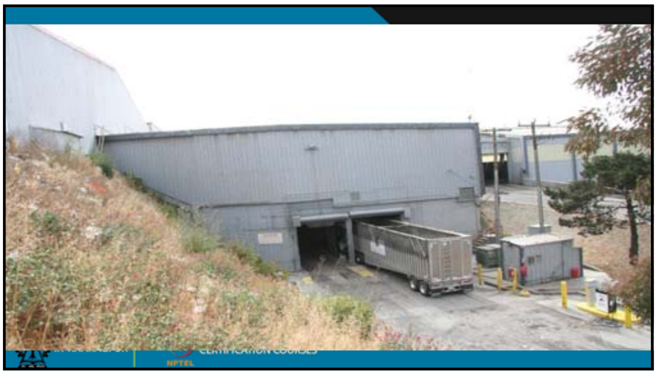
Transfer Stations

- Transfer Stations are used to minimize costs when waste is hauled long distances
- At large distances, it is cheaper to haul waste in larger trucks than smaller trucks

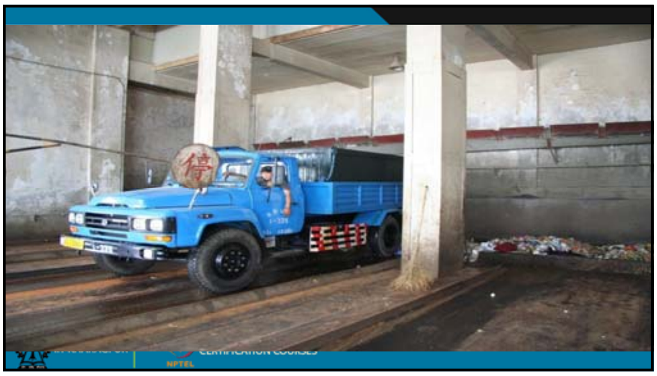
Suwannee County Transfer Station


Transfer station at San Francisco, California

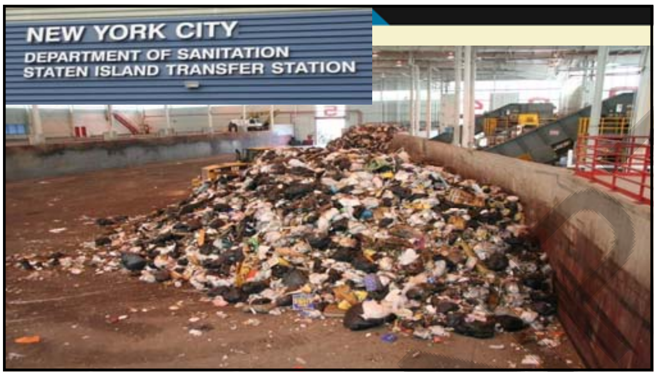


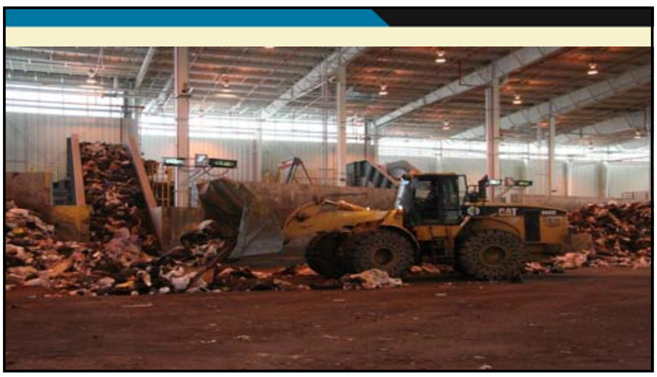


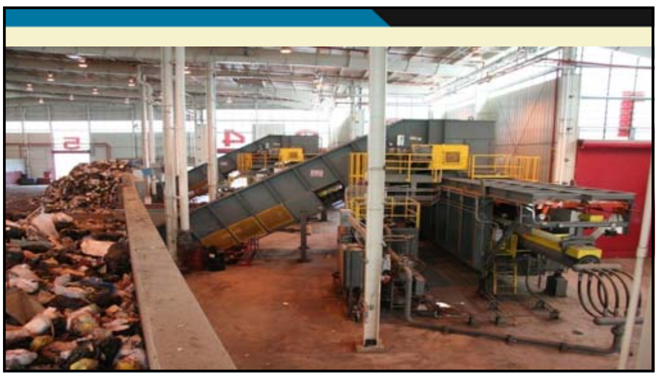

Transfer station in Beijing, China
小武基大型固废分选转运站
Xiao Wu Ji Solid Waste Sorting & Transfer Station

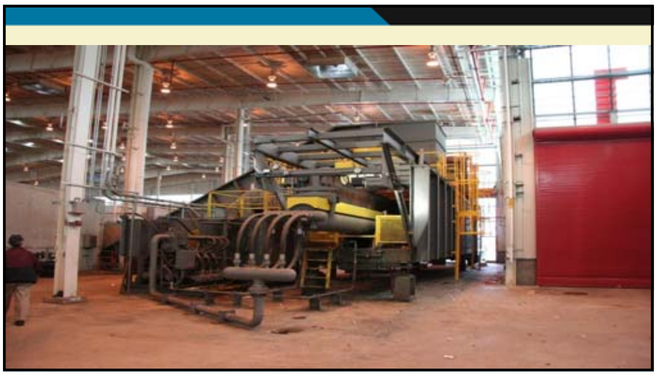


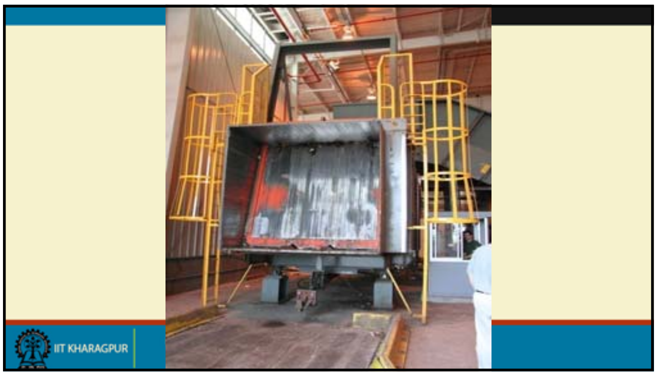

IIT KHARAGPUR


NEW YORK CITY
DEPARTMENT OF SANITATION
STATEN ISLAND TRANSFER STATION





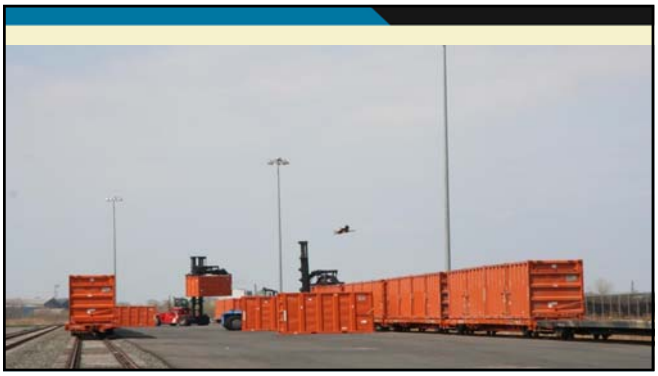



IIT KHARAGPUR


3
4

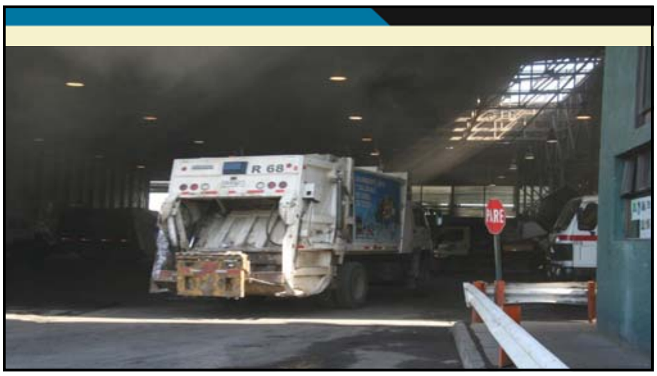

3

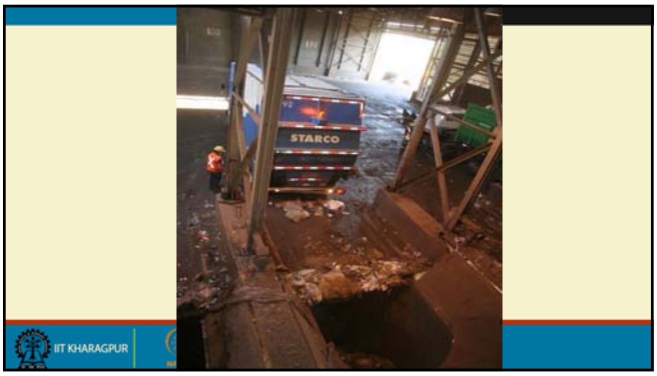

DSEU
70825
EPIX 91329

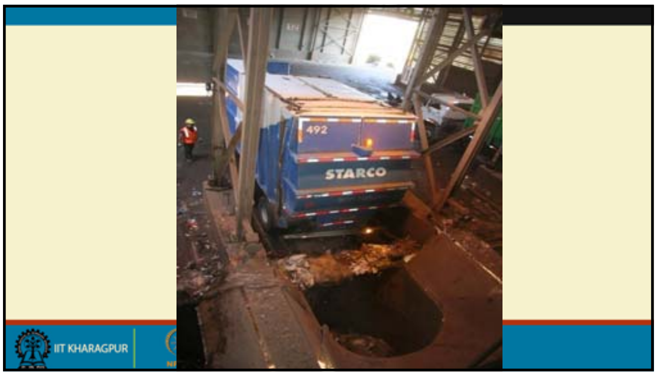



Transfer station in Santiago, Chile
DISAL


UN AMBIENTE LIMPIO
Y SALUDABLE
R
68

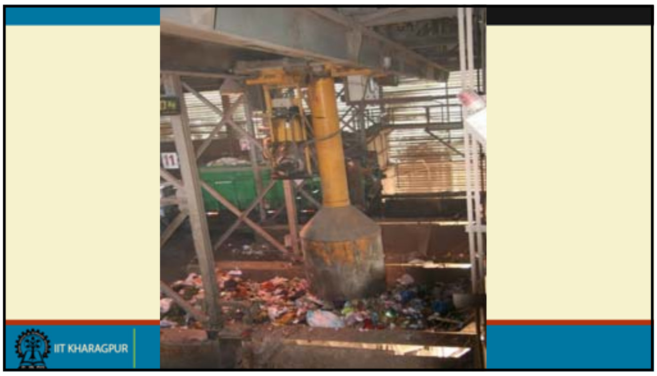

R 68

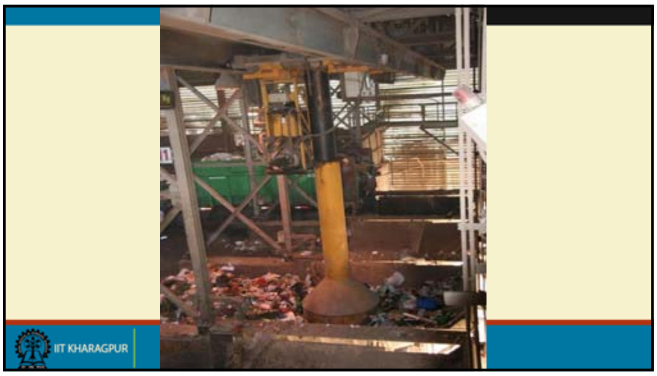

STARCO
IIT KHARAGPUR

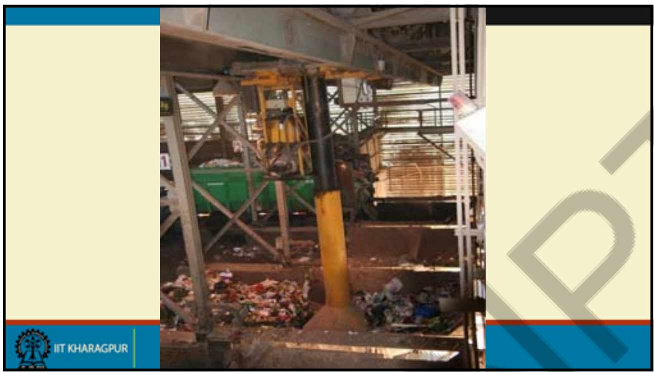

492
STARCO
IIT KHARAGPUR

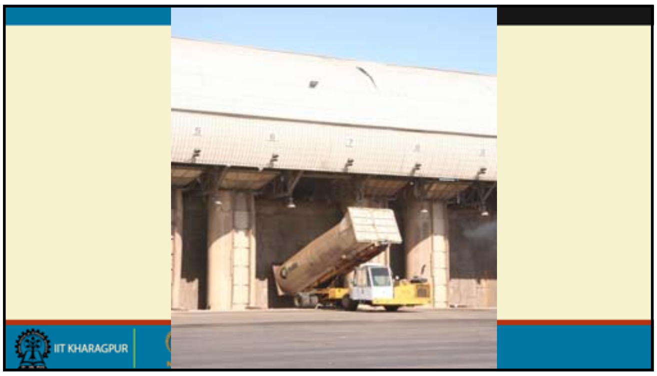

IIT KHARAGPUR

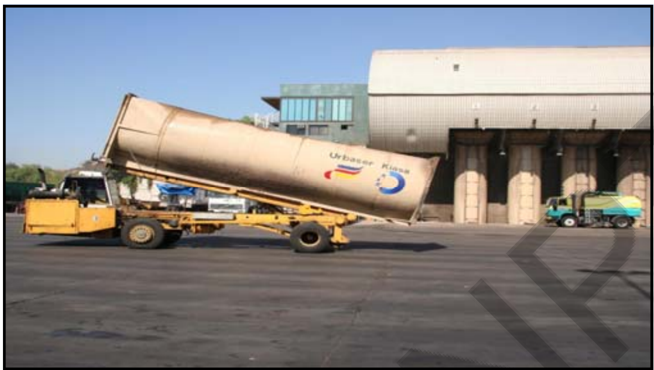

IIT KHARAGPUR


IIT KHARAGPUR


IIT KHARAGPUR


IIT KHARAGPUR


IIT KHARAGPUR




40 TON
kdm


40 TON
kdm


CAR MAX. 40 TON


kdm

Transfer Vehicles

- Trucks and trailers
  - Typical trailer capacity is 65 to 125 cubic yards (50 to 95 cubic meters)
  - Limited by road weight limitations
- Rail cars

Transfer Station Feasibility Calculations

- Assess the cost of direct haul versus transfer
- Find the break-even distance (i.e. the distance at which the cost of owning and operating the transfer station is less that the direct haul option)

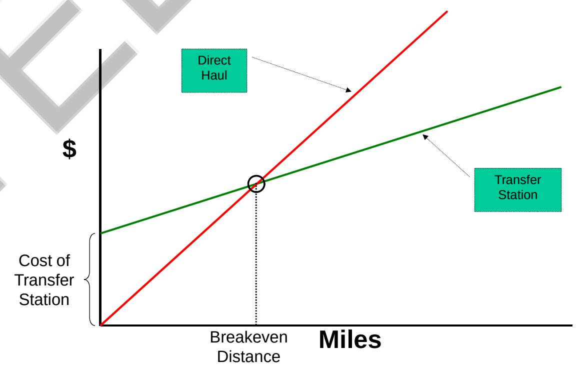
2. Economic comparison of transport alternatives Determine the break-even time for a stationary –container system and a separate transfer and transport system for transporting wastes collected from a metropolitan area to a landfill disposal site. Assume following cost and system data are applicable.

A. Transport costs:
  a. Stationary-container system using an 18-m^3 compactor = \$20/hr
  b. Tractor-trailer transport unit with a capacity of 120 m^3 = \$25/hr

B. Other costs:
  a. Transfer station operating cost, including amortization = \$0.40/m^3
  b. Extra cost for unloading facilities for tractor-trailer transport unit = \$0.05/m^3

C. Other data:
  a. Density of waste in compactor = 325 kg/m^3
  b. Density of wastes in transport units = 150 kg/m^3

Economics of Transfer Stations



Solid Waste Generation and Collection Example problems

Solid Waste Generation Rates

- knowledge of the quantities of solid waste generated, separated and collected for further processing is fundamental to the design of a solid waste management system
- we estimate the quantity of waste generated using available data:
  - load-count analysis
  - weight-volume analysis
  - material balances

  } weight scales are critical
- these are based on amount collected, which is different from the amount generated
- people divert waste before it gets collected
  - backyard composting
  - re-use programs (outside of public collection and disposal)
  - transport between municipalities
    - taking stuff on trips, to the cottage, disposal in other jurisdictions, …

Load Count Analysis

- in this method, the number of individual loads are counted, and the waste characteristics are estimated (type of waste, estimated volume)
- weight is estimated, or, if scales are available, weight data are also recorded
- unit generation rates are determined using the field data:
  - residential area = 1500 homes, average of 3 people per home
  - observations at the scales (transfer station) per week:

11 truck loads, each 20 m^3, total = 40,500 kg/wk

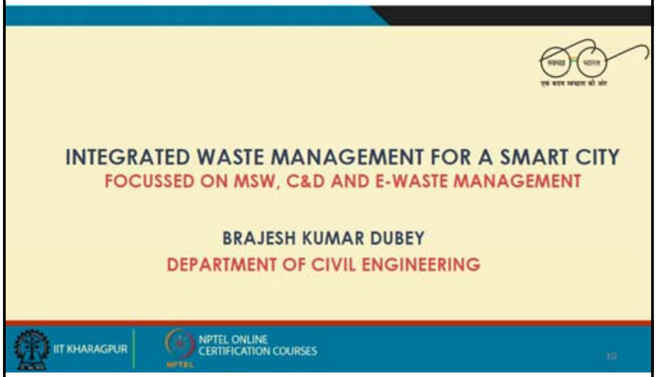
$$\text{S.W.} = \left(\frac{40{,}500}{20(11)}\right) = 184\ \text{kg/m}^3$$

40 private loads, each 300 cm^3, total = 900 kg/wk

$$S.W. = \left(\frac{900}{40(0.3)}\right) = 75\ kg/m^3$$

note the impact of compaction

$$\text{unit rate} = \frac{(40{,}500 + 900)\ \text{kg/wk}}{(1{,}500 \times 3)\ \text{person}} = 9.2\ \text{kg/capita/wk} = 1.31\ \text{kg/capita/day}$$



Materials Mass Balance

- a materials mass balance is the only way to determine the generation and movement of solid waste with any degree of reliability:

Rate of accumulation of material within the system boundary = Rate of material flow **into** the system boundary − Rate of material flow **out of** the system boundary + Rate of generation of waste material **within** the system boundary

- Rate of accumulation → storage
- Rate of material flow out → products: wastewater, recyclables, leachate, vapors
- Rate of generation → accounts for transformations: biological, incineration, …

- system boundary could be landfill site, manufacturing facility, …
- can be used to estimate waste per tonne of product
- smart companies work on reducing this ratio

Example: Mass Balance

- a cannery processes fresh produce, cans it and packages it to be sent to market, with the following materials received daily:
  - raw produce = 12.0 tonne/day
  - cans = 5.0 tonne/day
  - cartons = 0.5 tonne/day
  - miscellaneous material = 0.3 tonne/day
- and, they do the following processing:
  - 10.0 tonnes of final product are made
  - 1.2 tonnes of produce wasted and fed to cattle
  - 0.8 tonnes of produce ends up as wastewater
  - 4.0 tonnes of cans stored internally for future use
  - 1.0 tonnes of cans used for packaging
  - 3% of cans used are damaged and recycled

Example: Mass Balance

- also we have the following processing:
  - all cartons are used for packaging the final product
  - 3% of cartons are damaged during processing and recycled
  - 25% of the miscellaneous material is stored for future use
  - 25% of miscellaneous material ends up as mixed waste
  - the remaining 50% of miscellaneous material becomes waste paper
  - 35% of this waste paper is recycled
  - the rest is sent out as mixed waste
- determine a materials mass balance on production at the cannery plant
- we have 4 inputs to the system:
  - produce
  - cans
  - cartons
  - miscellaneous material

Example: Mass Balance

- which becomes either:
  - final product (produce + cans + cartons)
  - product sent to feed cows (produce)
  - wastewater stream (produce)
  - recycled material (cans + cartons + miscellaneous material)
  - stored material for future use (cans + miscellaneous material)
  - mixed waste (miscellaneous material)
- let's start with a mass balance of the entire system
- process input:

$$\begin{aligned}\text{total} &= (\text{raw produce} + \text{cans} + \text{cartons} + \text{miscellaneous})\\ &= (12.0 + 5.0 + 0.5 + 0.3)\ \text{tonne/day}\\ &= 17.8\ \text{tonne/day}\end{aligned}$$

- so, we have to account for 17.8 tonnes of material on a daily basis

Example: Mass Balance

- material stored internally:

$$\text{cans} = 4.0 \text{ tonnes}$$
$$+ \ \text{miscellaneous} = 25\% \cdot (0.30) = 0.075 \text{ tonne/day}$$
$$\text{total} = (4.0 + 0.075) = 4.075 \text{ tonnes/day}$$

- final product produced:

$$\text{final product} = 10.0 \text{ tonnes/day}$$
$$+ \ \text{cans used} = (1.0 - 0.03) = 0.97 \text{ tonne/day}$$
$$+ \ \text{cartons used} = (0.97)(0.50) = 0.485 \text{ tonnes/day}$$
$$\text{total} = (10.0 + 0.97 + 0.485) = 11.455 \text{ tonnes/day}$$

- waste product discharged as wastewater (to WWTP)

$$\text{produce wasted to WWTP} = 0.80 \text{ tonnes/day}$$
$$\text{total} = 0.80 \text{ tonnes/day}$$

13

Example: Mass Balance

- material recycled:

$$\text{cans} = 3\% \cdot (1.0 \text{ tonne}) = 0.03 \text{ tonnes}$$
$$+ \text{cartons} = 3\% \cdot (0.50 \text{ tonnes}) = 0.015 \text{ tonne/day}$$
$$+ \ \text{miscellaneous paper} = (0.50)(0.35)(0.30 \text{ tonnes}) = 0.0525 \text{ tonne/day}$$
$$\text{total} = (0.03 + 0.015 + 0.0525) = 0.0975 \text{ tonnes/day}$$

- mixed waste:

$$\text{miscellaneous} = (0.65)(0.50)(0.30 \text{ tonnes}) = 0.0975 \text{ tonne/day}$$
$$+ \ \text{miscellaneous} = (0.25)(0.30 \text{ tonnes}) = 0.075 \text{ tonne/day}$$
$$\text{total} = (0.0975 + 0.075) = 0.1725 \text{ tonnes/day}$$

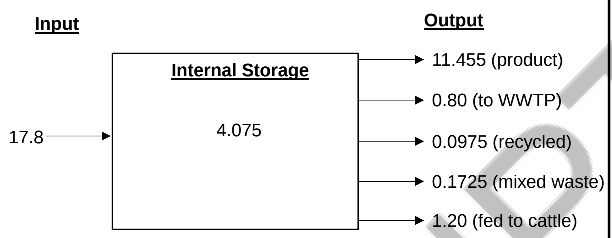
- produce fed to cattle:

$$\text{total} = 1.2 \text{ tonnes/day}$$

14

Example: Mass Balance

- materials mass balance on **the entire system**:

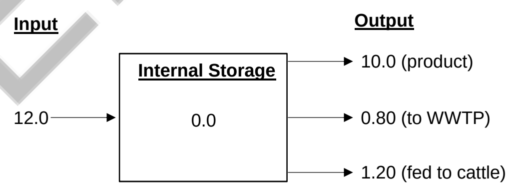


17.8 = 4.075 + 13.725

15

Example: Mass Balance

- materials mass balance on **produce**:

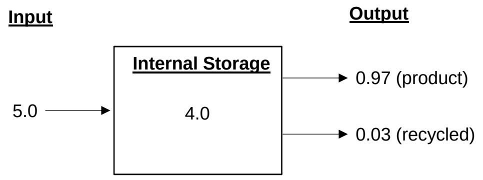


12.0 = 0.0 + 12.0

16

Example: Mass Balance

- materials mass balance on **cans**:

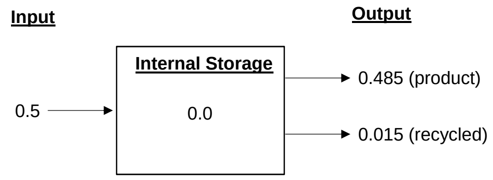


5.0 = 4.0 + 1.0

17

Example: Mass Balance

- materials mass balance on **cartons**:



0.5 = 0.0 + 0.5

18

Example: Mass Balance

- materials mass balance on **miscellaneous material**:

Input

Output

Internal Storage

0.075

0.3 → [Internal Storage 0.075] → 0.0525 (recycled)

→ 0.1725 (mixed waste)

0.3 = 0.075 + 0.225

Impact of Backyard Composting

- backyard composting also impacts (reduces) collection rates
  - food waste – no meats
  - they attracts pests and flies; takes a long time to break down
  - yard waste – some cities require residents to compost leaves
- what does one need:
  - a composting unit → home made: - wire mesh, boards; commercial: - drum, plastic, …
  - water
  - air → for oxygen
  - mixing – to maintain contact with air

- provides good, stabilized material for gardens (soil bulking)
- but, can cause odour problems – good mixing prevents this
- some communities provide central facilities for large-scale composting – others allow central drop-off
- mulching is considered composting – excellent for recycling

Impact of Compaction

- at-source compaction impacts collection rates
- for example, a high-rise container volume collects typical waste, all collected in one bag (co-mingled) with no recycling:
  - 200 units, 3.5 people/unit, generation rate of 1.35 kg/person/day
  - un-compacted specific weight = 100 kg/m^3
  - after compaction, specific weight= 250 kg/m^3
  - determine the # of 7.5 m^3 containers before/after compaction
    - total mass $= (200 \times 3.5 \times 1.35 \times 7) = 6{,}615 \text{ kg/week}$
    - before compaction, volume $= \left(\frac{6{,}615 kg}{100 \, kg/m^3}\right) = 66.2 m^3 /week$

      # containers $= \left(\frac{66.2 \text{ m}^3}{7.5 \text{ m}^3 / cont.}\right) = 8.8 \; containers \rightarrow$ 9 trips/week
    - after compaction, volume $= \left(\frac{6{,}615 \text{ kg}}{250 \; kg/m^3}\right) = 26.5 \text{ m}^3 / week$

      # containers $= \left(\frac{26.5 \text{ m}^3}{7.5 \text{ m}^3 / cont.}\right) = 3.5 \; containers \rightarrow$ 4 trips/week

Source Separation Impacts on Energy Content

- separation of solid waste components at-source is one way to reduce the mass/volume sent to collection, but it also affects the composition of the waste
- if the remaining wastes are to be combusted, what is the energy content of the residual solid waste?

1. using Table 3.4 from the solid waste book (Tchobanoglous et al.,) and converting the percentages to 100 kg of waste (~ 1.5 months of waste), calculate the total energy in the waste
2. then apply recycling and calculated the change in energy

Impact of Source Separation on Energy Content

based on Table 3-4

converted from Table 4-5

Component	Solid Waste kg	Energy KJ/kg	Energy MJ
Organic			
food	9.0	4652	41.9
paper	34.0	16747	569.4
cardboard	6.0	16282	97.7
plastics	7.0	32564	227.9
textiles	2.0	17445	34.9
rubber	0.5	23260	11.6
leather	0.5	17445	8.7
yard waste	18.5	6513	120.5
wood	2.0	18608	37.2
Inorgancs			
glass	8.0	140	1.1
tin cans	6.0	698	4.2
aluminum	0.5		
other metals	3.0	698	2.1
dirt, ash, etc…	3.0	6978	20.9
Total	**100.0**		**1178.2**

from the labels, coatings, and attached material

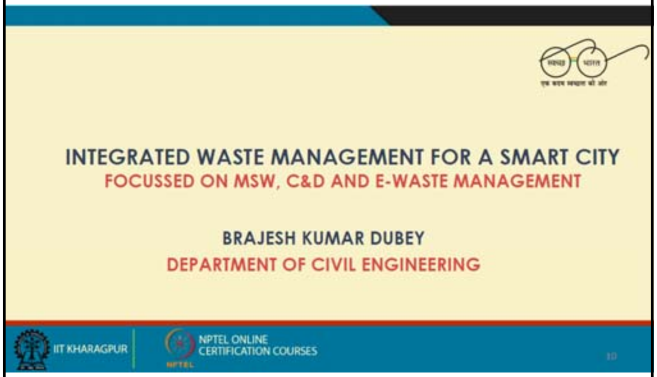
- total energy is 1178.2 KJ for 100.0 kg of waste

Impact of Source Separation on Energy Content

- through recycling we can remove:
  - 80% of the paper
  - 90% of the cardboard
  - 50% of the plastic
- the loss of energy

Component	Percentage Removed %	Weight Removed kg	Loss of Energy MJ
paper	80	27.2	455.5
cardboard	90	5.4	87.9
plastic	50	3.5	114.0
Total		**36.1**	**657.4**

- weight loss = (36.1 / 100.0) = 36%
- energy loss = (657.4 / 1178.2) = 56%



25

Impact of Source Separation on Energy Content

- why such a large loss of energy from the co-mingled waste stream? → because you are removing the highest energy content materials (outside of yard waste)
- we need to compare/consider the extra energy needed to collect the recycled material separately
- is it worth it?
  - extra trucks
  - air pollution, noise, congestion associated with them
  - extra costs of collection vs. efficiencies at a separation facility
- seems that a more complete assessment of the cost and operation of the system should be done to provide useful data that can be discussed in a public forum
- This is something part of what we call Life cycle analysis (LCA)

26

Impact of Home Compactors on Collection

- assume that home compactors are installed in a residential area
- assume that there is 100 kg of waste

- estimate the volume reduction that could be achieved if compacted density = 320 kg/m^3
- take each component and determine initial volume:
  . food = (9.0 kg / 290 kg/m^3) = 0.031 m^3
  . paper = (34.0 / 90) = 0.378 m^3
  .
  .
  .

27

Impact of Home Compactors on Collection

- from Table 3.4 of Tchobanoglous book, calculate the pre-compacted waste volume:

Component	Solid Waste kg	Specific Weight kg/m3	Volume m3
Organic			
food	9.0	290	0.031
paper	34.0	90	0.378
cardboard	6.0	50	0.120
plastics	7.0	65	0.108
textiles	2.0	65	0.031
rubber	0.5	130	0.004
leather	0.5	160	0.003
yard waste	18.5	100	0.185
wood	2.0	240	0.008
Inorgancs			
glass	8.0	200	0.040
tin cans	6.0	90	0.067
aluminum	0.5	160	0.003
other metals	3.0	745	0.004
dirt, ash, etc...	3.0	480	0.006
Total	100.0		**0.988**

generally not compacted

- total volume <u>before</u> compaction is 0.988 m^3

28

Impact of Home Compactors on Collection

- there are 2 streams of household waste
  - yard waste, wood, other metals and ash are not usually compacted
    - initial volume (un-compacted mat.) = (0.185 + 0.008 + 0.004 + 0.006) = <u>0.204</u> m^3
  - everything else is compacted
    - initial volume (compactable mat.) = (0.988 – 0.204) = <u>0.784</u> m^3
- now, lets use the compactor:
  - mass of un-compacted material = (18.5 + 2.0 + 3.0 + 3.0) = <u>26.5</u> kg
  - mass of compactable material = (100 – 26.5) = <u>73.5</u> kg
  - volume after compaction = (73.5 / 320) = 0.230 m^3
- waste volume after compaction
  - volume reduction (compactable) = (0.784 – 0.230) = 0.554 m^3
  - percent reduction (compactable) = $\left(\frac{0.784 - 0.230}{0.784}\right) = 70.7\ \%$
  - percent reduction (total) = $\left(\frac{0.988 - 0.434}{0.988}\right) = 56.1\ \%$

(0.204 + 0.230)
(0.204 + 0.784)

29

Impact of Home Compactors on Collection

- while the use of compactors reduces the bulk volume of the waste to be handled, the weight remains the same
  - it can complicate the collection process, as there are maximum weight guidelines on waste containers for collection personnel
  - generally, 15.0 kg per bag
- typically, the compacted volume will vary from 20 – 60% of the original volume
- this complicates processing at recycling facilities
  - they have to break up the compacted waste to recover recyclable material or combustible material
  - unless they are removed prior to compaction

30

Impact of Home Separation on Waste Collection

- a community is purchasing specialized vehicles for curbside collection of source separated wastes
- three containers will be provided:
  1. newspaper and cardboard
  2. plastic and glass
  3. aluminum and tin cans
- separated and placed by the curb once per week
- estimate the capacity requirements for each material separated
- assume:
  - 80% of recyclable material will be separated
  - newsprint represents 20% of the paper waste
  - number of homes = 1,500 @ 3.5 person/home
  - garbage truck 30 m^3
  - each recyclable vehicle = 12 m^3
  - per capita generation = 2.0 kg/person/week

Impact of Home Separation on Waste Collection

- total waste generated = $(2.0 \times 1500 \times 3.5 \times 7) = 73{,}500$ kg
- set up a table with waste component weights and volumes

based on the percentages from Table 3.4

Component	Solid Waste kg	Specific Weight kg/m3	Volume m3
Organic			
food	6615	290	22.8
paper	24990	90	277.7
cardboard	4410	50	88.2
plastics	5145	65	79.2
textiles	1470	65	22.6
rubber	368	130	2.8
leather	368	160	2.3
yard waste	13598	100	136.0
wood	1470	240	6.1
Inorgancs			
glass	5880	200	29.4
tin cans	4410	90	49.0
aluminum	368	160	2.3
other metals	2205	745	3.0
dirt, ash, etc...	2205	480	4.6
Total	73500		725.9

* big volume low density

Impact of Home Separation on Waste Collection

- determine the volume of each component:
  - volume of cardboard recycled = $(0.80 \times 88.2) = 70.6$ m^3
  - volume of newsprint recycled = $(0.80 \times (277.7 \times 0.2)) = 44.4$ m^3
  - volume of plastic recycled = $(0.80 \times 79.2) = 63.3$ m^3
  - volume of glass recycled = $(0.80 \times 29.4) = 23.5$ m^3
  - volume of tin cans recycled = $(0.80 \times 49.0) = 39.2$ m^3
  - volume of aluminum recycled = $(0.80 \times 2.3) = 1.8$ m^3
- number of trips:
  - volume of recyclables = $(70.6 + 44.4 + 63.3 + 23.5 + 39.2 + 1.8) = 242.9$ m^3
  - 12 m^3 per vehicle (no compaction)
  - number of trips = $(242.9 / 12) = 20.2$
- so, we need to make ~ 21 trips each week for recyclables
- note: total mass of collected recyclables = 20,168 kg

Impact of Home Separation on Waste Collection

- what about the remaining solid waste:
  - volume of waste at the curb = 483.1 m^3
- MSW vehicles:
  - back loading compactors (rating of 170 – 400 kg/m^3)
  - 30 m^3 per vehicle
  - compact the waste to a density = 300 kg/m^3
  - mass of waste at curb = $(73{,}500 - 20{,}168) = 53{,}332$ kg
  - volume waste in the truck = $(53{,}332 / 300) = 177.8$ m^3
  - number of trips = $177.8 / 30 = 5.9$ $\rightarrow$ 6 trips/wk
- points to ponder:
  - if we were just hauling solid waste $\rightarrow$ 9 trips/wk (1 set of MSW vehicles)
  - with the new recyclables $\rightarrow$ 6 trips/wk (MSW vehicles)
    $\rightarrow$ 21 trips/wk (recyclable vehicles)
  - one crew? – 1 day of waste collection, 4 days of recyclables?
  - this needs much more refined planning of waste collection routes

Impact of Home Separation on Waste Collection

- what if we separate the wet waste (green bag) as well:
  - volume of green (food) = 22.8 m^3 (from the previous table)
  - volume of recyclables = 242.9 m^3
  - 20 m^3 per double loading (green + blue) vehicle (10 m^3 blue, 10 m^3 green)
  - number of trips (green) = $(22.8 / 10) = 2.28 \rightarrow 3$ trips/wk
  - number of trips = $(242.9 / 10) = 24.3 \rightarrow 25$ trips/wk

  this defines the number of (blue+green) trip
- MSW vehicles:
  - mass of waste at curb = $(73{,}500 - 20{,}168 - 6{,}615) = 46{,}717$ kg
  - volume waste in the truck = $(46{,}717 / 300) = 155.7$ m^3
  - number of trips = $155.7 / 30 = 5.2 \rightarrow$ still 6 trips/wk
- points to ponder:
  - with the white + blue + green $\rightarrow$ 6 trips/wk (MSW vehicles)
    $\rightarrow$ 25 trips/wk (blue + green vehicles)
  - and, the 20 m^3 double loading compactors would be more expensive
  - could we purchase vehicles with a better blue/green volume capacity?