Q2) Calculate energy content

FW	15 %
Paper	45 %
Cardboard	10 %
Plastics	10 %
Garden trimmings	10 %
wood	5 %
Tin Cans	5 %

Using the approximate formula:

$$HHV = 53.5\,(F + 3.6\,CP_1) + 372\,P_2 L R$$

$F = 15$

$\left.\begin{matrix} C = 10 \\ P_1 = 45 \end{matrix}\right\} 55$

$\left.\begin{matrix} P_2 = 10 \\ L = 0 \\ R = 0 \end{matrix}\right\} 10$

$$\underbrace{HHV}_{\text{as\_discarded basis.}} = 53.5\,(15 + (3.6 \times 55)) + 372\,(10) = 15{,}116 \text{ kJ/kg}$$

→ Estimating moisture content from typical data on slide # 6 _ Lecture _ 2.

Component	% mass	% moisture	moisture mass
FW	15	70	10.5
Paper	45	6	2.7
Cardboard	10	5	0.5
Plastics	10	2	0.2
garden	10	60	6
wood	5	20	1
tin cans	5	3	0.15
	100		21.05

$$P)\ \%_{\text{wet-basis}} = \left[\frac{21.05}{100}\right] \times 100 = 21.05\,\%$$

$$HHV)_{\text{dry-basis}} = HHV \times \left[\frac{100}{100 - 21.05}\right] = 19146 \text{ kJ/kg}$$

Assuming a typical ash-content of 6% as given in slide # 17 _ Lecture _ 2

$$HHV)_{\substack{\text{ash-free}\\ \text{dry-basis}}} = 15116 \times \left[\frac{100}{100 - 6 - 21.05}\right] = 20{,}721 \text{ kJ/kg.}$$

The HHV obtained with the approximate formula can be compared with the typical data in slide # 9_ Lecture _2 _ Appendix

FW	15	4650
Paper	45	16750
Cardboard	10	16300
Plastics	10	32600
garden trimmings	10	6500
wood	5	18600
tin cans	5	700

$HHV)_{as-discarded}$

$= (0.15 \times 4650) + (0.45 \times 16750) + (0.10 \times 16300) + (0.10 \times 32600) + (0.1 \times 6500) + (0.05 \times 18600) + (0.05 \times 700)$

$HHV)_{as-discarded} = 14,740 \ kJ/kg$

$$HHV)_{dry-basis} = 14740 \times \left(\frac{100}{100-21.05}\right) = 18,670 \ kJ/kg.$$

$HHV)_{ash-free-dry-basis} = 20205 \ kJ/kg.$

Q3) Hauled- Container System (HCS)

$t_1 = 20$ min

$t_2 = 25$ min

$d_e = 8$ min

$$h = \frac{60 \text{ km}}{90 (\text{km/hr})} = 0.67 \text{ hr} = 40 \text{ min}$$

$H = 8$ hrs

$W = 0.15$

$\left.\right\} (1-W) H = 6.8$ hrs

For HCS $t_{net} = m + u + d_e + s + h$

Assuming typical values for $(m+u) = 0.4$ h/trip

$s = 0.133$ h/trip

$t_{net} = 0.4 + (8/60) + 0.133 + (0.67)$

$(t_{net} = 1.34 \text{ hrs})$

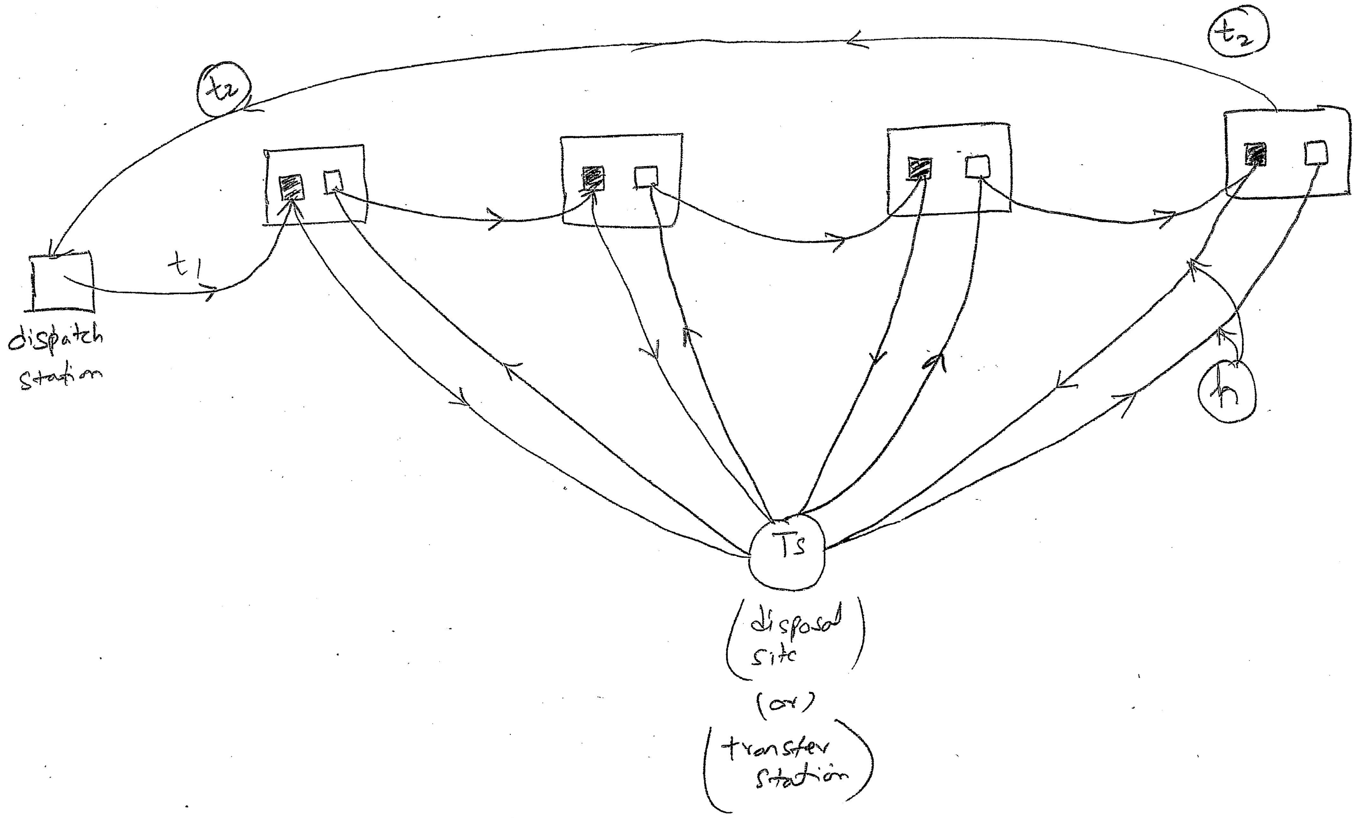
As $t_{net} = 1.34$ hrs

$$N_t = \frac{(1-W)H - t_1 - t_2}{t_{net}}$$

$$N_t = \left[\frac{(6.8) - (20/60) - (25/60)}{1.34}\right]$$

$$N_t = 4.5 \text{ trips}$$

So, plan for $N_t \approx \boxed{4 \text{ trips}}$



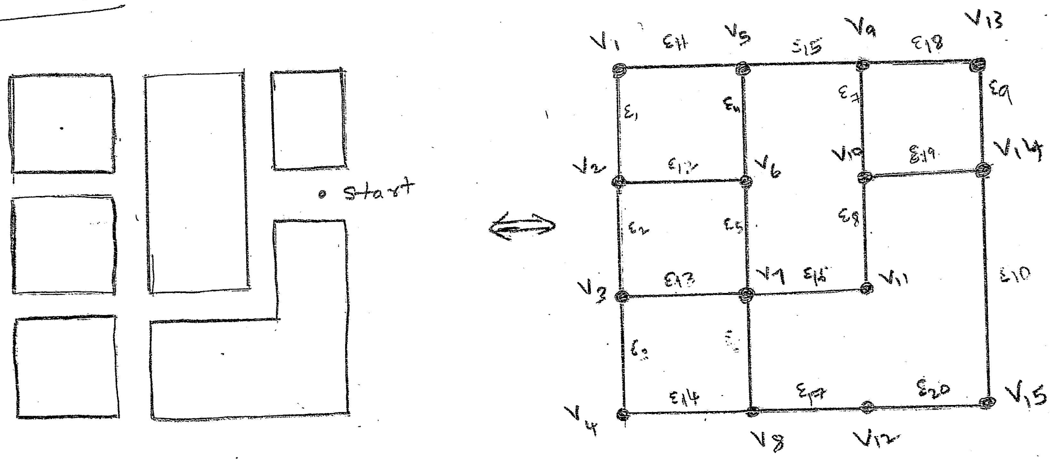
4 container locations in a day can be serviced as it is a HCS.

Actual hours spent on a collection day $= 4(1.34) + \left(\frac{20+25}{60}\right) + (0.15)8$

$= 7.31$ hrs

* Not-part of solution ; only for information

(Q3_Appendix) Convert given street network into a graph with (nodes and links)
V (nodes), $\mathcal{E}$ (links)



(undirected graph)
[~ 2-sided pickup]

$G = (V, E)$

V = set of nodes/vertices

E = set of edges/links

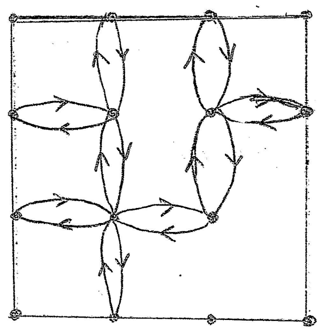
$V = \{v_i\}_{i=1}^{15} = \{V_1, V_2 \cdots\cdots V_{15}\}$

$E = \{\mathcal{E}_j\}_{j=1}^{20} = \{\mathcal{E}_1, \cdots\cdots \mathcal{E}_{20}\}.$

$$\begin{bmatrix} \mathcal{E}_1 = \{V_1, V_2\} \\ \mathcal{E}_2 = \{V_2, V_3\} \\ \vdots \\ \mathcal{E}_{20} = \{V_{12}, V_{15}\} \end{bmatrix}$$

As 8 nodes $\{V_2, V_3, V_5, V_6, V_8, V_9, V_{10}, V_{14}\}$ have odd number of links, Euler's tour is <u>not possible</u>

<u>If</u> <u>only</u> <u>1-sided pickup is possible</u> then the graph would be modified as:



$G = (V, E)$

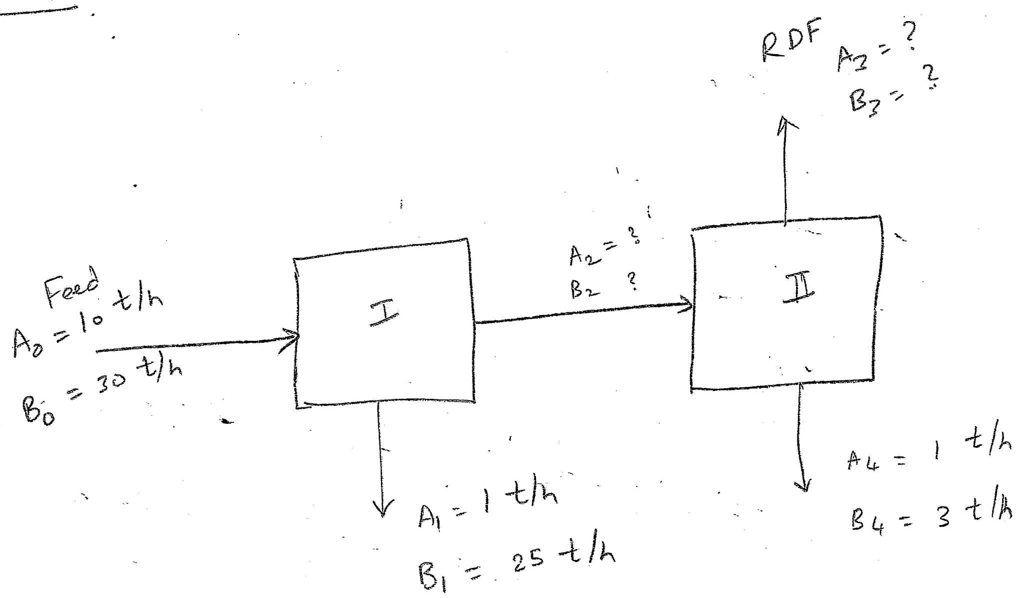
$V = \{v_i\}_{i=1}^{15}$

$E = \{\mathcal{E}_j\}_{j=1}^{29}$

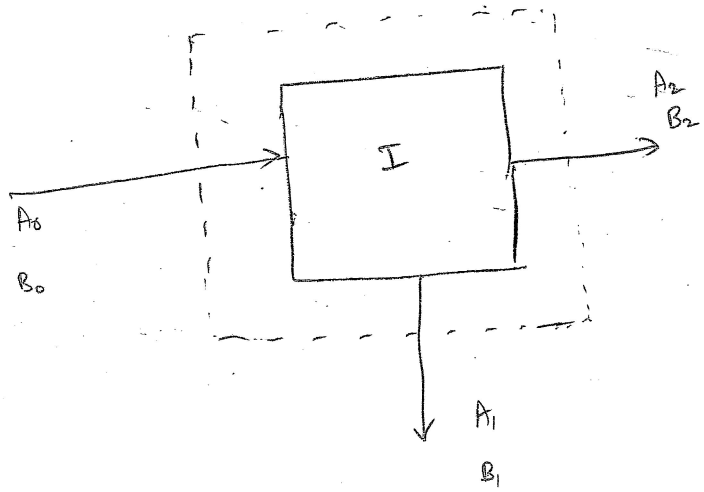
All nodes have even number of edges.

So, Euler's tour <u>is possible</u>

Q3 (2))



Let us consider control volume around classifier (I) and balance the mass-flow rate for organics (A) and inorganics (B) seperately.



$$\begin{bmatrix}\text{mass}\\ \text{acc.}\\ \text{rate}\end{bmatrix} = \begin{bmatrix}\text{mass}\\ \text{input}\\ \text{rate}\end{bmatrix} - \begin{bmatrix}\text{mass}\\ \text{output}\\ \text{rate}\end{bmatrix} + \begin{bmatrix}\text{mass}\\ \text{Production}\\ \text{rate}\end{bmatrix} - \begin{bmatrix}\text{mass}\\ \text{consumption}\\ \text{rate}\end{bmatrix}$$

At steady-state $\begin{bmatrix}\text{mass}\\ \text{acc}\\ \text{rate}\end{bmatrix} = 0$; For conservative substance $\left\{\begin{matrix}\begin{bmatrix}\text{mass}\\ \text{production}\\ \text{rate}\end{bmatrix} = 0\\ \begin{bmatrix}\text{mass}\\ \text{Consumption}\\ \text{rate}\end{bmatrix} = 0\end{matrix}\right\}$

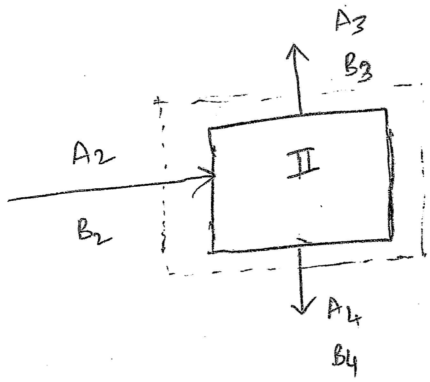
$\Rightarrow \quad A_0 - A_1 - A_2 = 0$

$\Rightarrow \quad A_2 = A_0 - A_1 = 10 - 1 = 9$ t/h.

Similarly $\quad B_0 - B_1 - B_2 = 0 \quad \Rightarrow B_2 = 30 - 25 = 5$ t/h

$\boxed{\begin{matrix}A_2 = 9 \text{ t/h}\\ B_2 = 5 \text{ t/h}\end{matrix}}$

Consider Control volume around classifier II



$A_2 = A_3 + A_4 \Rightarrow A_3 = A_2 - A_4 = 9 - 1 = 8$ t/h

$B_2 = B_3 + B_4 \Rightarrow B_3 = B_2 - B_4 = 5 - 3 = 2$ t/h

$$\boxed{\begin{array}{l} A_3 = 8 \text{ t/h} \\ \hline B_3 = 2 \text{ t/h} \end{array}}$$

Recovery of component A is $\left[\frac{A_3}{A_0}\right] \times 100 = \left[\frac{8}{10} \times 100\right] = 80\%$

Purity of RFD $= \left[\frac{A_3}{A_3 + B_3}\right] = \left[\frac{8}{8+2}\right] \times 100 = 80\%$

Q4) Given SCS ; we have to calculate break-even time b/n direct hauling and building a transfer station.

(I) Direct - hauling

$$\text{unit-cost} = \frac{\$\,20}{hr} \times \frac{1}{18\ m^3} \times \frac{1}{325\ (\cancel{kg}/m^3)} \times 1000 \left(\frac{\cancel{kg}}{tonne}\right)$$

$$\text{unit-cost} = \frac{\$\ 3.42}{tonne-hr} \quad \left(\frac{\$}{mass-time}\right)$$

(II) Transfer - station (TS)

$$\text{hauling cost (HC)} = \frac{\$\ 25}{hr} \times \frac{1}{120\ m^3} \times \frac{1}{150\ kg/m^3} \times 1000 \left(\frac{\cancel{kg}}{\cancel{tonne}}\right)$$

$$HC = \frac{\$\ 1.39}{tonne-hr} \quad \left(\frac{\$}{mass-time}\right)$$

Fixed costs (a) O/c $\frac{\$\ 0.40}{m^3} \times \frac{1}{150\ (kg/m^3)} \times \left(1000\ \frac{kg}{\cancel{tonne}}\right)$

$$O/c\ (\text{operating cost of TS}) = \frac{\$\ 2.67}{tonne} \quad \left(\frac{\$}{mass}\right)$$

(b) extra costs : $\frac{\$\ 0.05}{m^3} \times \frac{1}{150\ \cancel{kg}/m^3} \times 1000 \left(\frac{\cancel{kg}}{tonne}\right)$

$$e/c = \frac{\$\ 0.33}{tonne} \quad \left(\frac{\$}{mass}\right)$$

$$\text{total cost for TS} = (HC \times time) + (o/c + e/c)$$

$$\text{TS cost} = \left[\frac{\$\ 1.39}{tonne-hr} \cdot t^*\right] + \left[\frac{\$\ 2.67 + \$\ 0.33}{tonne}\right]$$

$$\boxed{\text{TS cost} = 1.39\, t^* + 3} \rightarrow (1)$$

Direct hauling cost $= \left[\dfrac{\$\,3.42}{\text{tonne\_hr}}\right]\left(\dfrac{\$}{\text{mass\_time}}\right)$

DH Cost @ break-even time (t^*) $= \boxed{3.42\, t^*} \rightarrow (2)$

Equating both DH and TS costs @ $\underline{t^*}$ (break-even time)

$$3.42\, t^* = 1.39\, t^* + 3$$

$$\Rightarrow \boxed{t^* = 1.478 \text{ hrs} = 88.7 \text{ min}}$$

Check with $t = 100$ min

@ $t = 100$ min

DH cost $= \$\,3.42 \times \left(\dfrac{100}{60}\right)$ per tonne $= \dfrac{\$\,5.7}{\text{tonne}}$

TS cost $= \$\,1.39 \times \left(\dfrac{100}{60}\right) + 3 = \dfrac{\$\,5.3}{\text{tonne}}$

For $t > t^*$ $\boxed{\text{TS Cost} < \text{DH cost}}$

@ $t = 80$ min

DH Cost $= \$\,3.42 \times \left(\dfrac{80}{60}\right) = \dfrac{\$\,4.56}{\text{tonne}}$

TS cost $= \$\,1.39 \times \left(\dfrac{80}{60}\right) + 3 = \dfrac{\$\,4.85}{\text{tonne}}$

For $t < t^*$ $\boxed{\text{TS cost} > \text{DH Cost}}$

Q5_1) $C_{50}H_{100}O_{40}N$

$$C_aH_bO_cN_d + \frac{4a+b-2c-3d}{4} O_2 \rightarrow a\,CO_2 + \left(\frac{b-3d}{2}\right) H_2O + d\,NH_3$$

1 mole of $C_{50}H_{100}O_{40}N$ requires $\left(\frac{(4\times 50)+(100)-(2\times 40)-(3\times 1)}{4}\right)$ moles of O_2

$(a=50\ b=100\ c=40\ d=1)$

$\Rightarrow$ 54.25 moles of O_2

1 mole of organic requires $\Rightarrow$ $54.25 \times \left(\frac{1}{0.21}\right)$ moles of air

1 mole of organic requires $\Rightarrow$ (Assuming Air is 78% N_2, 21% O_2 by volume.)

$\Rightarrow$ Calculating the molecular wt. of the organic

$MW)_{organic} = (12\times 50) + (1\times 100) + (16\times 40) + (14\times 1) = 1354 \left(\frac{g}{mole}\right)$

$\Rightarrow$ Calculating the molecular wt. of air

$MW)_{air} = (0.78\times 28) + (0.21\times 32) \simeq 29 \left(\frac{g}{mol}\right)$

1354 g organic requires $\Rightarrow$ $54.25 \times \left(\frac{1}{0.21}\right) \times 29$ g air

1 g organic requires $\Rightarrow$ 5.533 g air

1 tonne organic requires $\Rightarrow$ 5.533 tonnes of air

But it is better to estimate air requirements in volume

ρ_{air} @ NTP $(20^\circ C,\ 1 atm) = 1.2041 \frac{kg}{m^3}$

$\Rightarrow$ 1 tonne organic requires $\Rightarrow$ $5.533\times 10^3\ kg \times \frac{1}{1.2041} \left(\frac{m^3}{kg}\right)$

$\Rightarrow$ 4595 m^3 of air @ NTP $(20^\circ C,\ 1 atm)$

If we include NH_3 oxidation also:

$$NH_3 + 2O_2 \longrightarrow H_2O + HNO_3$$

1 mole NH_3 $\Rightarrow$ 2 moles O_2

17 g NH_3 $\Rightarrow$ $2 \times \left(\frac{1}{0.21}\right) \times 29$ g air

$\Rightarrow$ 1 tonne NH_3 $\Rightarrow$ $2 \times \frac{1}{0.21} \times 29 \times \left(\frac{1}{17}\right)$ tonnes of air

$\Rightarrow$ 1 tonne NH_3 $\Rightarrow$ $= 16.25$ tonnes of air

1 tonne NH_3 $\Rightarrow$ $= 13493$ m^3 of air @ NTP

But 1 tonne of solid waste organic results only in 0.0126 tonnes of NH_3

$\Rightarrow$ Air required for ammonia $= (0.0126 \times 13493) m^3$ @ NTP

$\simeq 169.4$ m^3

total Air $\simeq$ $4595 + 169.4$ m^3 $=$ $\boxed{4764.4 \ m^3}$

* Instead of density, an easier conversion is:

1 mole of gas occupies 24.05 L volume @ NTP $\left(\begin{matrix}20°C \\ 1 atm\end{matrix}\right)$

1 mole of gas occupies 22.4 L volume @ STP $\left(\begin{matrix}0°C \\ 1 atm\end{matrix}\right)$