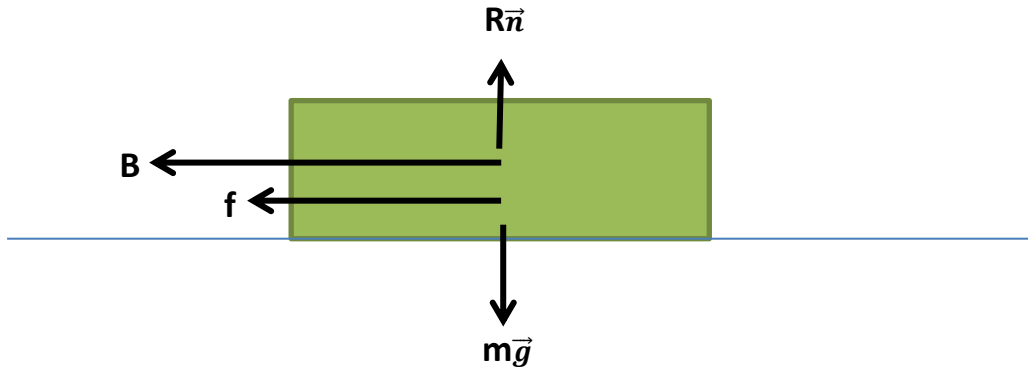


**APPENDIX D**

**LINE 4 – PARIS METRO**

**D.1. Determine the braking acceleration**

Determining the braking acceleration will be done by the mechanical model. The step of determining the braking acceleration will be examined by dividing the mechanical form of the train.



The equation as follow :

$$-B - f + R\vec{n} - m\vec{g} = m.a$$

Braking forces = 1900 N/ton

Mass train = 126.4 ton =  $12.64 \cdot 10^4$  kg

$$B = 1900 \text{ N/ton} \cdot 126.4 \text{ ton} \\ = 240,160 \text{ N}$$

Friction forces = 100 N/ton

$$f = 100 \text{ N/ton} \cdot 126.4 \text{ ton} \\ = 12640 \text{ N}$$

Then :

$$-B - f = m.a \\ -240,160 \text{ N} - 12,640 \text{ N} = 12.64 \cdot 10^4 \cdot a \\ a = -2 \text{ m/s}^2$$

Result : The acceleration (negative) after the braking point is  $-2 \text{ m/s}^2$ . In this research negative acceleration symbolized by  $-K$ .

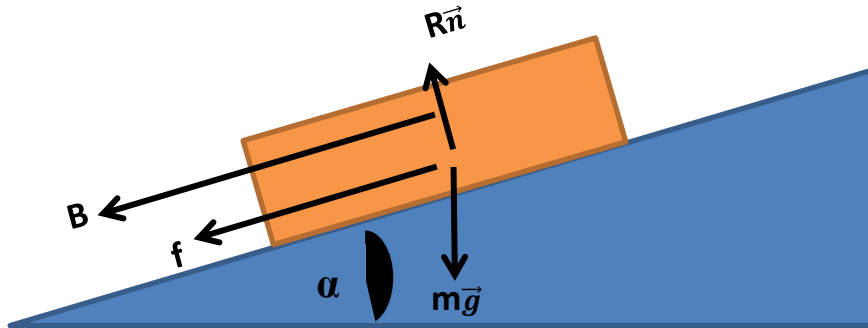
## D.2. Determine braking state

The velocity after the braking is 20 km/h which is 5.56 m/s. But in this process the braking velocity will be re-determined if the braking velocity do not utilize on the maximum state.

There is 3 state of the train when the brakes applied which is  $(t_b, d_b, v_b)$ . So to determine the braking point is following the equation below :

$$d_b = \frac{v_b^2}{2(K+a_g)}$$

$a_g$  = acceleration due to the gradient of the track, in this research the assumption of there is no gradient will be applied.



So, the braking point will be :

$$d_b = \frac{v_b^2}{2(K+a_g)}$$

$$= \frac{5.56^2}{2(2+0)}$$

$$= 7.7284 \text{ m}$$

To recheck if the velocity of the brake is at the maximum state can use the following equation :

$$v_b = \sqrt{2(K+a_g) \cdot d_b}$$

$$= \sqrt{2(2+0) \cdot 7.7284}$$

$$= 5.56 \text{ m/s}$$

Result : The braking point before the next station is 7.7284m with braking velocity 5.56m/s.

**D.3. Determine the coasting phase**

To determine the coasting point we can use the following equation :

$$V_t = V_0 + a.t$$

$$19.44 = 0 + 1.3 .t$$

$$t_{\text{acceleration}} = 14.95 \text{ s}$$

So the distance that has been travelled during the acceleration phase is :

$$\begin{aligned} S &= V_0.t + 0.5.a.t^2 \\ &= 0. 14.95 + 0.5 . 1.3 . 14.95^2 \\ &= 145.35 \text{ m} \end{aligned}$$

The travelled distance during the coast phase as following equation :

$$S_c = \text{Total length interstation} - S - db$$

$$\begin{aligned} S_c &= 424\text{m} - 145.35\text{m} - 7.7284\text{m} \\ &= 270.92 \text{ m} \end{aligned}$$

**D.4. Determine the acceleration of the coasting phase**

The acceleration of the coasting during the coasting phase will be varies as the following equation

$$\begin{aligned} S_c &= \frac{V^2 - V_b^2}{2ac} \\ 270.92 &= \frac{19.44^2 - 5.56^2}{2ac} \\ a_c &= 0.64 \text{ m/s.} \end{aligned}$$

**D.5. Proposed Model**

There are several point on this proposed model which is :

1. The duration time
2. The energy consumption
  - Energy using during the acceleration phase for 1 station
  - Energy using during the coasting phase for 1 station
  - Energy using during the braking phase for 1 station
  - Total energy using for 1 station
  - Total energy using for 1 line which is LINE 4
3. Implementation and analysis for the proposed model

**D.5.1. The duration time**

The duration of the brake phase is :

$$\begin{aligned} T_b &= \frac{V_b}{K+a_g} \\ &= \frac{5.56}{2} \\ &= 2.78s \end{aligned}$$

The coasting time will be

$$S = V_0 t + 0.5 \cdot a \cdot t^2$$

$$270.92 = 19.44 \cdot t + 0.5 \cdot 0.64 \cdot t^2$$

$$t_{\text{coasting}} = 11.68s$$

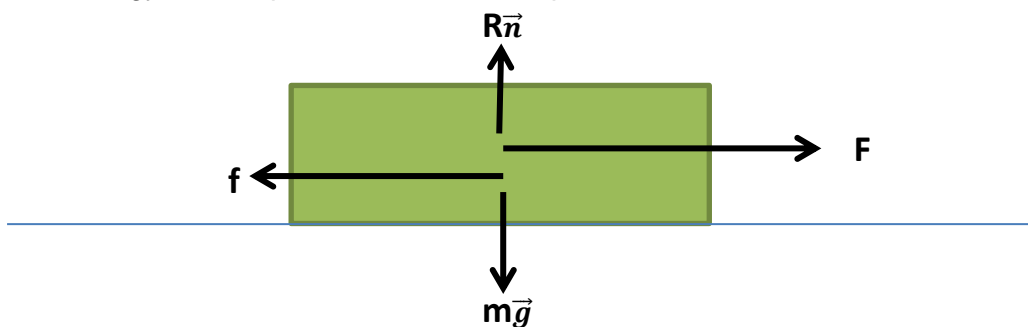
$$\text{Total time for the journey} = t_{\text{acceleration}} + t_{\text{coasting}} + t_{\text{braking}}$$

$$= 14.95 + 11.68 + 2.78$$

$$= 29.41 \text{ s}$$

**D.5.2. The energy consumption**

- The energy consumption for acceleration phase for 1 station



$$F - f + R\vec{n} - m\vec{g} = m \cdot a$$

$$F = f + m \cdot a$$

$$= 100 \cdot 126.4 + 126,400 \cdot 1$$

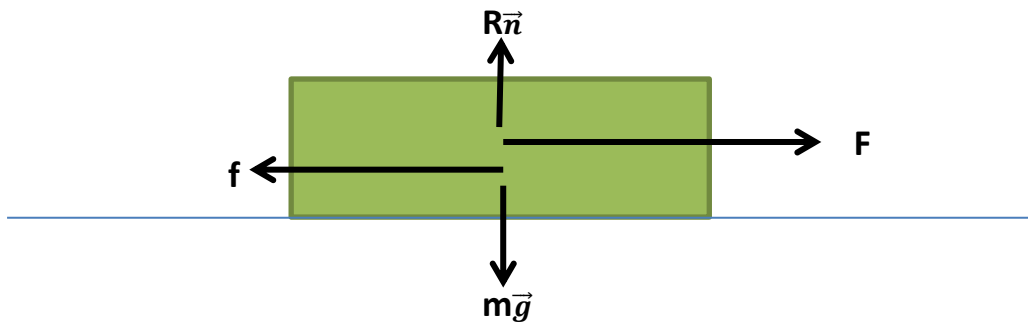
$$= 139,040 \text{ N}$$

$$\text{Energy} = F \cdot S$$

$$= 139,040 \cdot 145.35$$

$$= 20,209,464 \text{ J}$$

- The energy consumption for coasting phase for 1 station



$$F - f + R\vec{n} - m\vec{g} = m.a$$

$$F = f + m.a$$

$$= 100 \cdot 126.4 + 126,400 \cdot 0.64$$

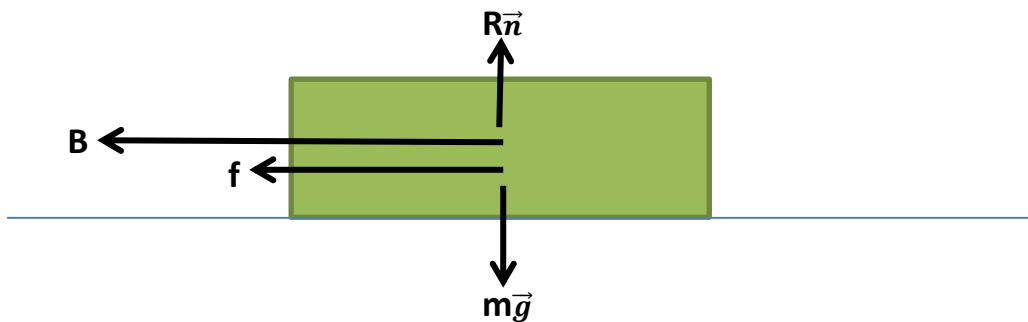
$$= 93,536 \text{ N}$$

$$\text{Energy} = F.S$$

$$= 93,536 \cdot 270.92$$

$$= 25,340,773.12 \text{ J}$$

- The energy consumption for braking phase for 1 station



$$-B - f + R\vec{n} - m\vec{g} = m.a$$

$$-B = m.a + f$$

$$= 126,400 \cdot 2 + 1,900 \cdot 126.4$$

$$= 492,960 \text{ N}$$

$$\text{Energy} = |B| \cdot d$$

$$= 492,960 \cdot 7.7284$$

$$= 3,809,792.064 \text{ J}$$

- Total energy using for 1 station

$$\begin{aligned}
 \text{Energy Total} &= \text{Energy}_{\text{acceleration}} + \text{Energy}_{\text{coasting}} + \text{Energy}_{\text{braking}} \\
 &= 20,209,464 \text{ J} + 25,340,773.12 \text{ J} + 3,809,792.064 \text{ J} \\
 &= 49,360,029.18 \text{ J}
 \end{aligned}$$

- Total energy consumption for line 4

$$\begin{aligned}
 \text{Total energy consumption} &= 26 \text{ station} \cdot \text{Energy Total} \\
 &= 26 \cdot 49,360,029.18 \text{ J} \\
 &= 1,283,360,759 \text{ J}
 \end{aligned}$$

### D.5.3. Implementation and Analysis

The power consumption for the initial system is 1760KW. So the energy consumption for the line 1 with 4 station is 1760 kW x 26 menit = 762.66 kWh = 2,745,576,000Joule. With the proposed model, we can save the energy up to 1,462,215,241 J or 406.17 kWh.

From the [www.carbontrust.co.uk/energy](http://www.carbontrust.co.uk/energy) , we can convert the energy into Carbon and CO<sub>2</sub> emission. The carbon and CO<sub>2</sub> emission saving can be seen in Table D.1

Table D.1 Carbon and CO<sub>2</sub> emission

Fuel		4	
		kg C	kg Co2
Grid electricity	Delivered	47,52189	174,6531
	Primary	424,5695	67,46484
Natural gas		21,03961	77,1723
Coal		33,18409	121,851
Coke		41,02317	150,2829
Petroleum Coke		37,65196	138,0978
Gas / diesel oil		27,61956	101,5425
Heavy fuel oil		28,79745	105,6042
Petrol		26,60414	97,4808
LPG		23,27354	85,2957
Jet Kerosene		26,60414	97,4808
Ethane		22,13627	81,234
Naphtha		28,79745	105,6042
Refinery gas		22,13627	81,234