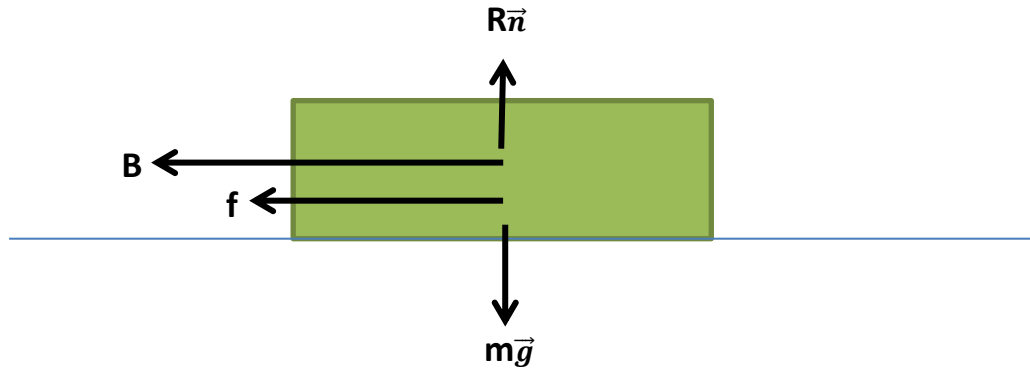


APPENDIX K
LINE 10 – PARIS METRO

K.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 = 106 ton = $10.6 \cdot 10^4$ kg

$$\begin{aligned} B &= 1900 \text{ N/ton} \cdot 106 \text{ ton} \\ &= 201,400 \text{ N} \end{aligned}$$

Friction forces = 100 N/ton

$$\begin{aligned} f &= 100 \text{ N/ton} \cdot 106 \text{ ton} \\ &= 10600 \text{ N} \end{aligned}$$

Then :

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

$$-201,400 \text{ N} - 10,600 \text{ N} = 10.6 \cdot 10^4 \cdot a$$

$$a = -2 \text{ m/s}^2$$

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

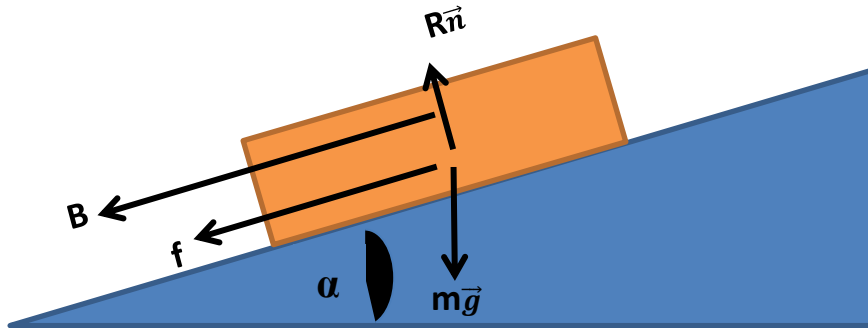
K.2. Determine braking state

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.

K.3. Determine the coasting phase

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

$$V_t = V_0 + a.t$$

$$19.44 = 0 + 1 . t$$

$$t_{\text{acceleration}} = 19.44 \text{ s}$$

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

$$\begin{aligned} S &= V_0.t + 0.5.a.t^2 \\ &= 0. 19.44 + 0.5 . 1 . 19.44^2 \\ &= 188.18 \text{ m} \end{aligned}$$

The travelled distance during the coast phase as following equation :

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

$$\begin{aligned} S_c &= 532\text{m} - 188.18\text{m} - 7.7284\text{m} \\ &= 336.0916 \text{ m} \end{aligned}$$

K.4. Determine the acceleration of the coasting phase

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

$$\begin{aligned} S_c &= \frac{V^2 - V_b^2}{2ac} \\ 336.0916 &= \frac{19.44^2 - 5.56^2}{2ac} \\ a_c &= 0.52 \text{ m/s.} \end{aligned}$$

K.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 10
3. Implementation and analysis for the proposed model

K.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

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

$$336.0916 = 19.44 \cdot t + 0.5 \cdot 0.52 \cdot t^2$$

$$t_{\text{coasting}} = 14.48s$$

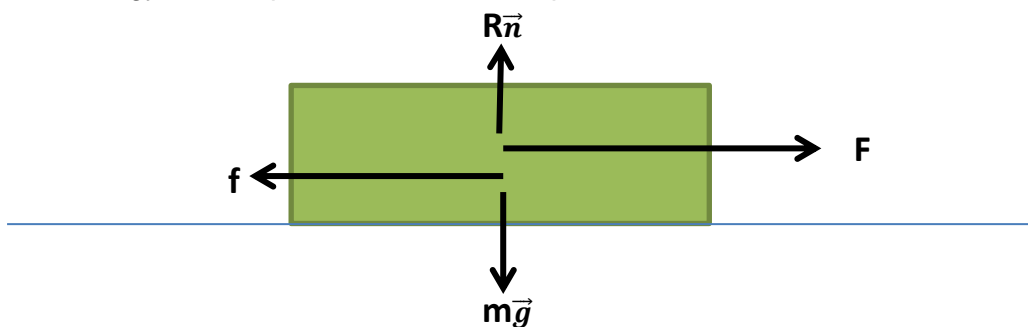
$$\text{Total time for the journey} = t_{\text{acceleration}} + t_{\text{coasting}} + t_{\text{braking}}$$

$$= 19.44 + 14.48 + 2.78$$

$$= 36.7 \text{ s}$$

K.5.2. The energy consumption

- The energy consumption for acceleration phase for 1 station



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

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

$$= 100 \cdot 106 + 106000 \cdot 1$$

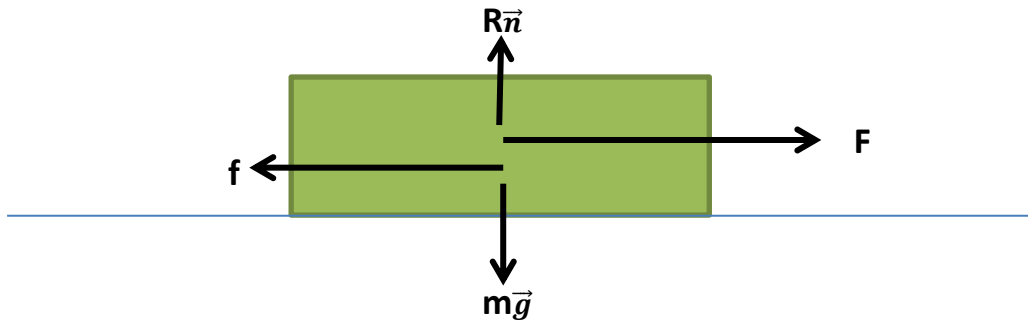
$$= 116,600 \text{ N}$$

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

$$= 116,600 \cdot 188.18$$

$$= 21,941,788 \text{ J}$$

- The energy consumption for coasting phase for 1 station



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

$$F = f + m.a$$

$$= 100 \cdot 106 + 106,000 \cdot 0.52$$

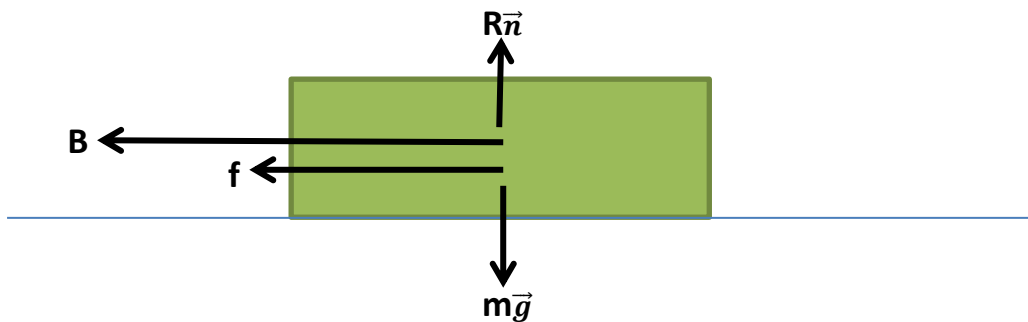
$$= 65,720 \text{ N}$$

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

$$= 65,720 \cdot 336.0916$$

$$= 22,087,939.95 \text{ J}$$

- The energy consumption for braking phase for 1 station



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

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

$$= 106,000 \cdot 2 + 1,900 \cdot 106$$

$$= 413,400 \text{ N}$$

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

$$= 413,400 \cdot 7.7284$$

$$= 3,194,920.56 \text{ J}$$

- Total energy using for 1 station

$$\begin{aligned}\text{Energy Total} &= \text{Energy}_{\text{acceleration}} + \text{Energy}_{\text{coasting}} + \text{Energy}_{\text{braking}} \\ &= 21,941,788 \text{ J} + 22,087,939.95 \text{ J} + 3,194,920.56 \text{ J} \\ &= 47,224,648.51 \text{ J}\end{aligned}$$

- Total energy consumption for line 10

$$\begin{aligned}\text{Total energy consumption} &= 23 \text{ station} \cdot \text{Energy Total} \\ &= 23 \cdot 47,224,648.51 \text{ J} \\ &= 1,086,166,916 \text{ J}\end{aligned}$$

K.5.3. Implementation and Analysis

The power consumption for the initial system is 1080KW. So the energy consumption for the line 1 with 23 station is 1080 kW x 23 menit = 414kWh = 1,490,400,000 Joule. With the proposed model, we can save the energy up to 404,233,084 J or 112.28 kWh.

From the www.carbontrust.co.uk/energy , we can convert the energy into Carbon and CO₂ emission. The carbon and CO₂ emission saving can be seen in Table K.1

Table K.1 Carbon and CO₂ emission

Fuel		10	
		kg C	kg Co2
Grid electricity	Delivered	13,13676	48,2804
	Primary	117,3663	18,64971
Natural gas		5,816104	21,3332
Coal		9,173276	33,684
Coke		11,34028	41,5436
Petroleum Coke		10,40836	38,1752
Gas / diesel oil		7,63504	28,07
Heavy fuel oil		7,960652	29,1928
Petrol		7,35434	26,9472
LPG		6,433644	23,5788
Jet Kerosene		7,35434	26,9472
Ethane		6,11926	22,456
Naphtha		7,960652	29,1928
Refinery gas		6,11926	22,456