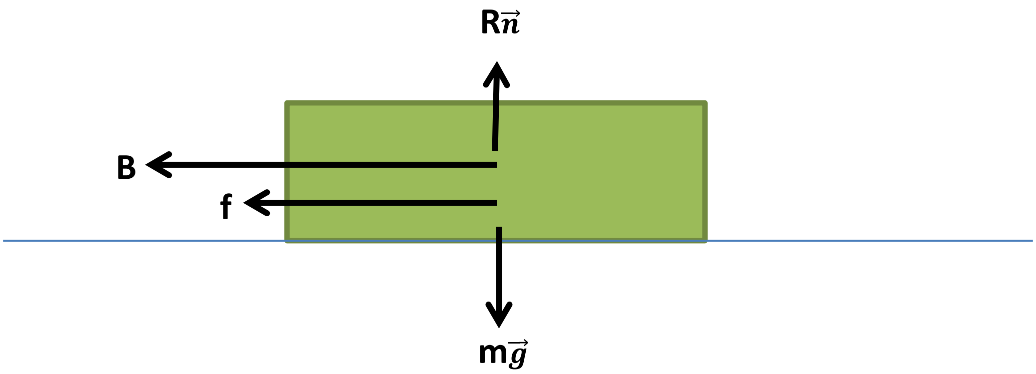
APPENDIX A

LINE 2 – PARIS METRO

A.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 examine by dividing the mechanical form of the train.



The equation as follow :

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

Braking forces = 1900 N/ton

Mass train = 125.7 ton = 12.57 . 10^4 kg

B = 1900N/ton. 125.7 ton

= 238,830 N

Friction forces = 100 N/ton

f = 100 N/ton. 125.7 ton

= 12,570 N

Then :

$-B - f = m.a$

- 238,830 N – 12,570 N = 12.57 . 10^4. a

$a = -2\ m/s^2$

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

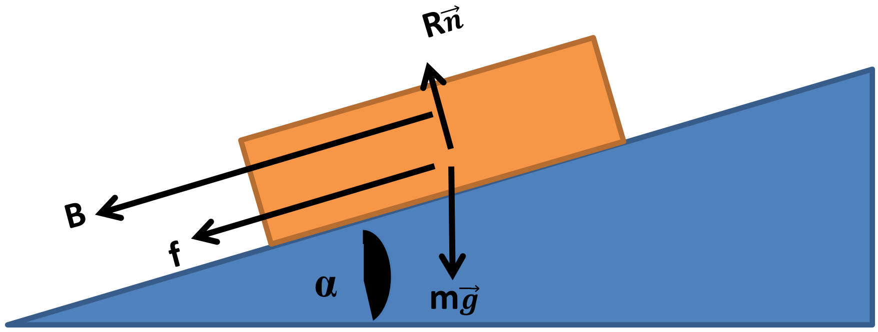
A.2. Determine braking state

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 :

$$V_b = \sqrt{2(K + a_g).d_b}$$

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

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

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

A.3. Determine the coasting phase

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

$V_{t} = V_0 + a.t$

$19.44 = 0 + 0.9 .t$

$t_{acceleration} = 21.6$ s

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

$S = V_{o}.t + 0.5.a.t^2$

$= 0.21.6 + 0.5 . 0.9 . 21.6^2$

$= 209.952$ m

The travelled distance during the coast phase as following equation :

$S_c =$ Total length interstation – S – db

$S_c = 513m – 209.952m – 7.7284m$

$= 295.3196$ m

A.4. Determine the acceleration of the coasting phase

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

$$S_c = \frac{V^2 - V_b^2}{2ac}$$

$$295.3196 = \frac{19.44^2 - 5.56^2}{2ac}$$

$a_c = 0.59$ m/s.

A.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 2
3. Implementation and analysis for the proposed model

A.5.1. The duration time

The duration of the brake phase is :

$\tau_b = \frac{V_b}{K+a_g}$

$= \frac{5.56}{2}$

= 2.78s

The coasting time will be

$S = Vot + 0.5.\ a.\ t^2$

$295.3196 = 19.44.t + 0.5.\ 0.59.\ t^2$

$t_{coasting} = 12.73s$

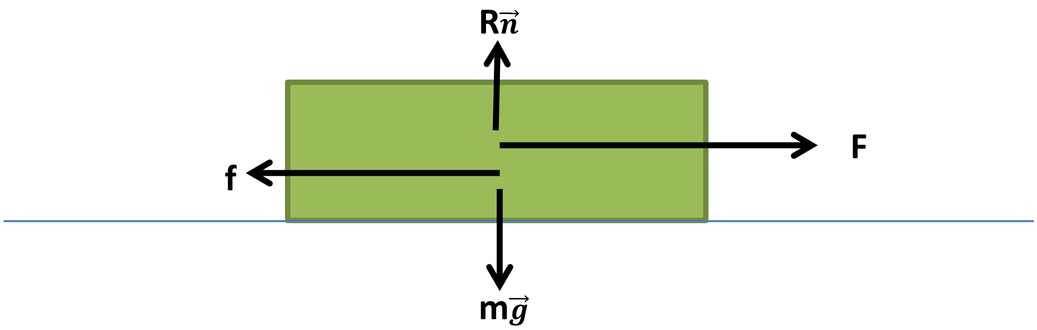
Total time for the journey = $t_{acceleration} + t_{coasting} + t_{braking}$

= 21.6 + 12.73 + 2.78

= 37.11 s

A.5.2. The energy consumption

- The energy consumption for acceleration phase for 1 station



$F – f + R\vec{n} - m\vec{g} = m.a$

F = f + m.a

= 100 . 125.7 + 125700 . 0.9

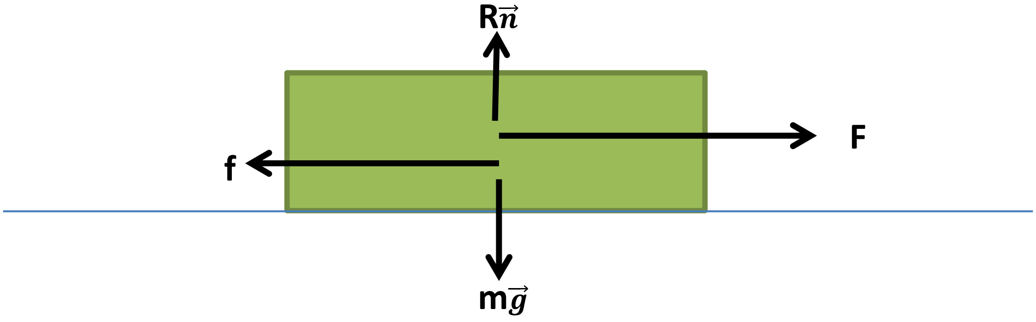
= 125,700 N

Energy = F.S

= 125,700 . 209.952

= 26,390,966 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 . 125.7 + 125,700 . 0.59

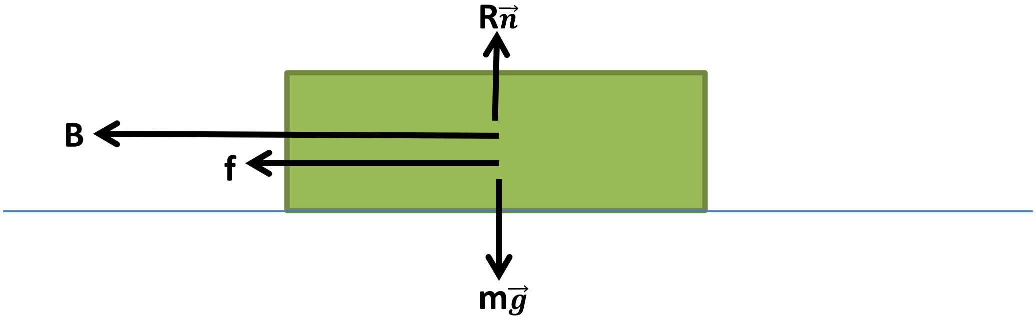
= 86,733 N

Energy = F.S

= 86,733 . 295,3196

= 25,613,954.87 J

- The energy consumption for braking phase for 1 station



-B –f + $R\vec{n}$ - $m\vec{g}$ = m.a

-B = m.a +f

= 125,700 . 2 + 1,900 . 125,7

= 490,230 N

Energy = $|B|$. d

= 490,230 . 7.7284

= 3,788,693.532 J

- Total energy using for 1 station

Energy Total = $Energy_{acceleration} + Energy_{coasting} + Energy_{braking}$

= 26,390,966 J + 25,613,954.87 J + 3,788,693.532 J

= 55,793,614.4 J

- Total energy consumption for line 2

Total energy consumption = 25 station . Energy Total

= 25. 55,793,614.4 J

= 1,394,840,360 J

A.5.3. Implementation and Analysis

The power consumption for the initial system is 1800KW. So the energy consumption for the line 1 with 25 station is 1800 kW x 25 menit = 750kWh = 2,700,000,000 Joule. With the proposed model, we can save the energy up to 1,305,159,640 J or 362.54 kWh.

From the www.carbontrust.co.uk/energy , we can convert the energy into Carbon and CO_2 emission. The carbon and CO_2 emission saving can be seen in Table A.1

Table A.1 Carbon and CO_2 emission

Fuel		Line 2	
		kg C	kg Co2
Grid electricity	Delivered	42,41718	155,8922
	Primary	378,963062	60,217894
Natural gas		18,779572	68,8826
Coal		29,619518	108,762
Coke		36,61654	134,1398
Petroleum Coke		33,607458	123,2636
Gas / diesel oil		24,65272	90,635
Heavy fuel oil		25,704086	94,2604
Petrol		23,74637	87,0096
LPG		20,773542	76,1334
Jet Kerosene		23,74637	87,0096
Ethane		19,75843	72,508
Naphtha		25,704086	94,2604
Refinery gas		19,75843	72,508