CHAPTER III

COLLECTING AND PROCESSING DATA

Collecting and processing data in this chapter begin with the process description. Process description examining how do the train control works. This process is more to the learning activity from the literature. Collecting data will be begin by checking the sources from the internet as the researcher cannot have the access to the paris metro, however the data that could be collect shows only how effective it would be for the proposed approach. If there is no data, we can use the variable to determine and count the effectiveness of the proposed approach. Processing data is the part where the researcher testing the hypothesis of the proposed approach whether it will make an efficient energy consumption or not. After processing data the researcher will compare the proposed approach with the initial model.

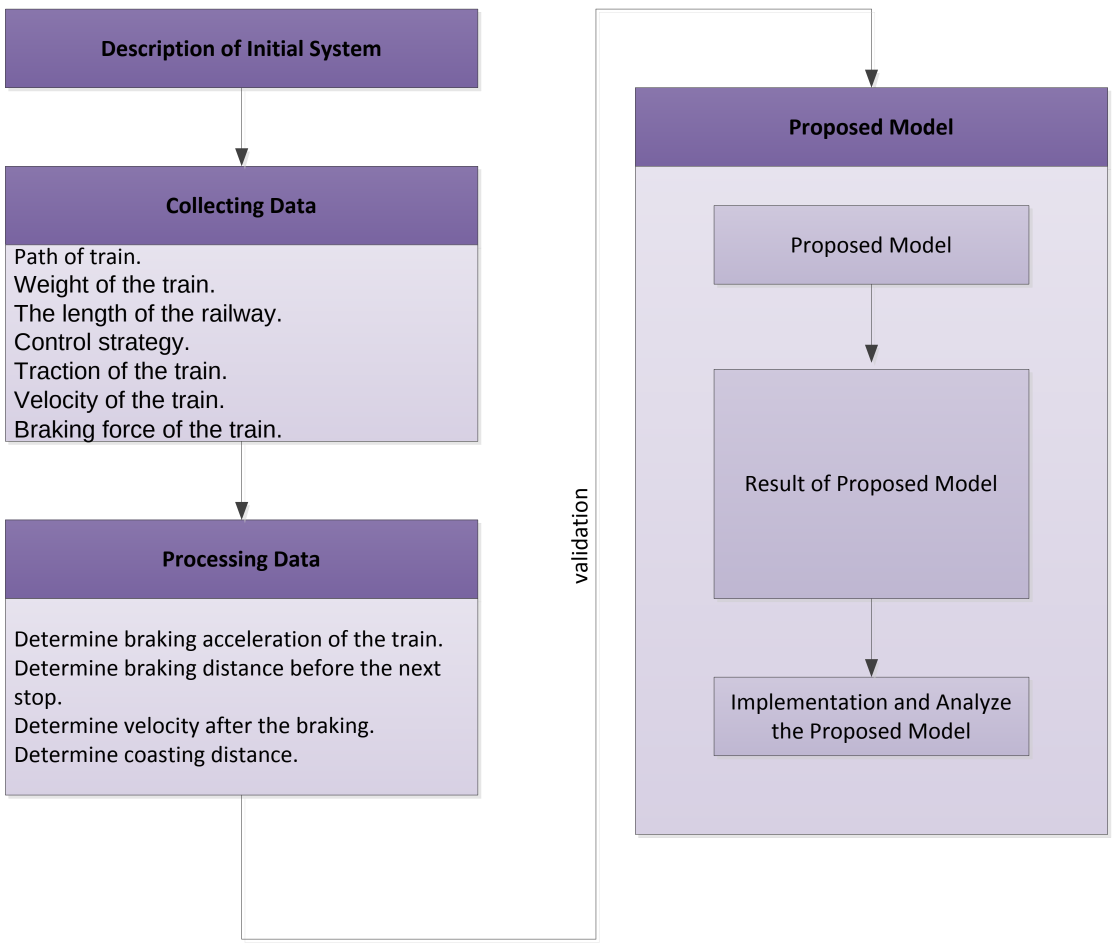


Figure III.1 Collecting and Processing Data Diagram

III.1 Description of Initial System

The research is focusing on the Paris Metro subway tunnel. There are 16 lines for the subway metro. Paris Metro serves the commuter with the ticket and smart card, the commuters has to put the single way ticket or smart card on the entrance gate. There is no demand for the ticket at the exit gate but the controller will ask for the ticket or the smart card at any station randomly. The ticket pass is €1.70 for single way fare and €12.50 for 10 way fare. The first train leaves the terminal on 5.30 am but some lines the train leaves at the intermediate station. The last train will leaves from the terminal at 1.15 am and leaves at 2.15 am for Saturday night and the night before holiday.

The process of the train would be the train comes to the terminal station, open the doors, load the passengers, close the doors, driver start to accelerate the train, driver change the train to coasting mode, driver decide where is the braking point and the train arrive at the next stop at the target time and so on until the last terminal. The model can be see on the Figure III.2

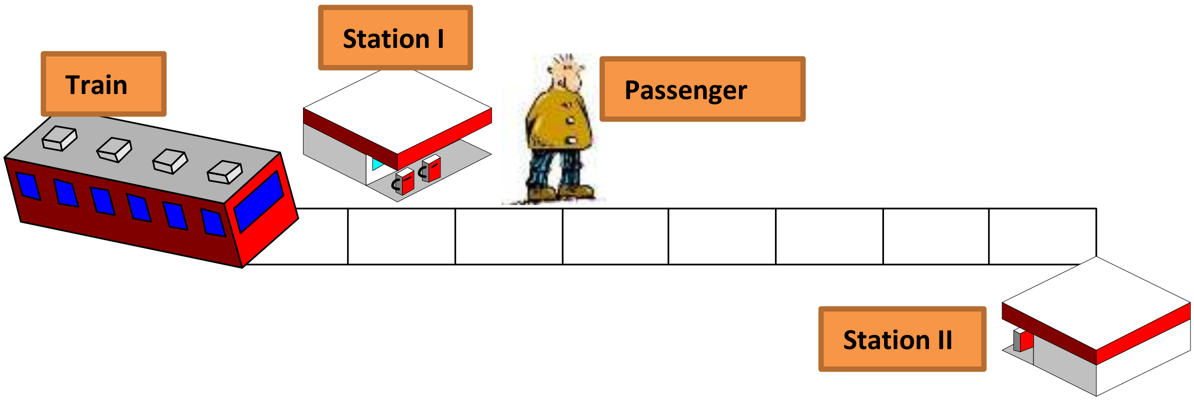


Figure III.2 Initial System Model

The process of the passengers being served in the Paris Metro system would be the passenger comes to the any station, get the ticket (can be buy in automated machine or on the spot teller), get into the entrance gate (put the ticket into the gate or presenting the smart card), the passenger choose the line according to the destination station, the passenger wait for the train, get into the train, go to the destination station or connecting station, get out of the entrance gate. The passengers process can be seen in Figure III.3

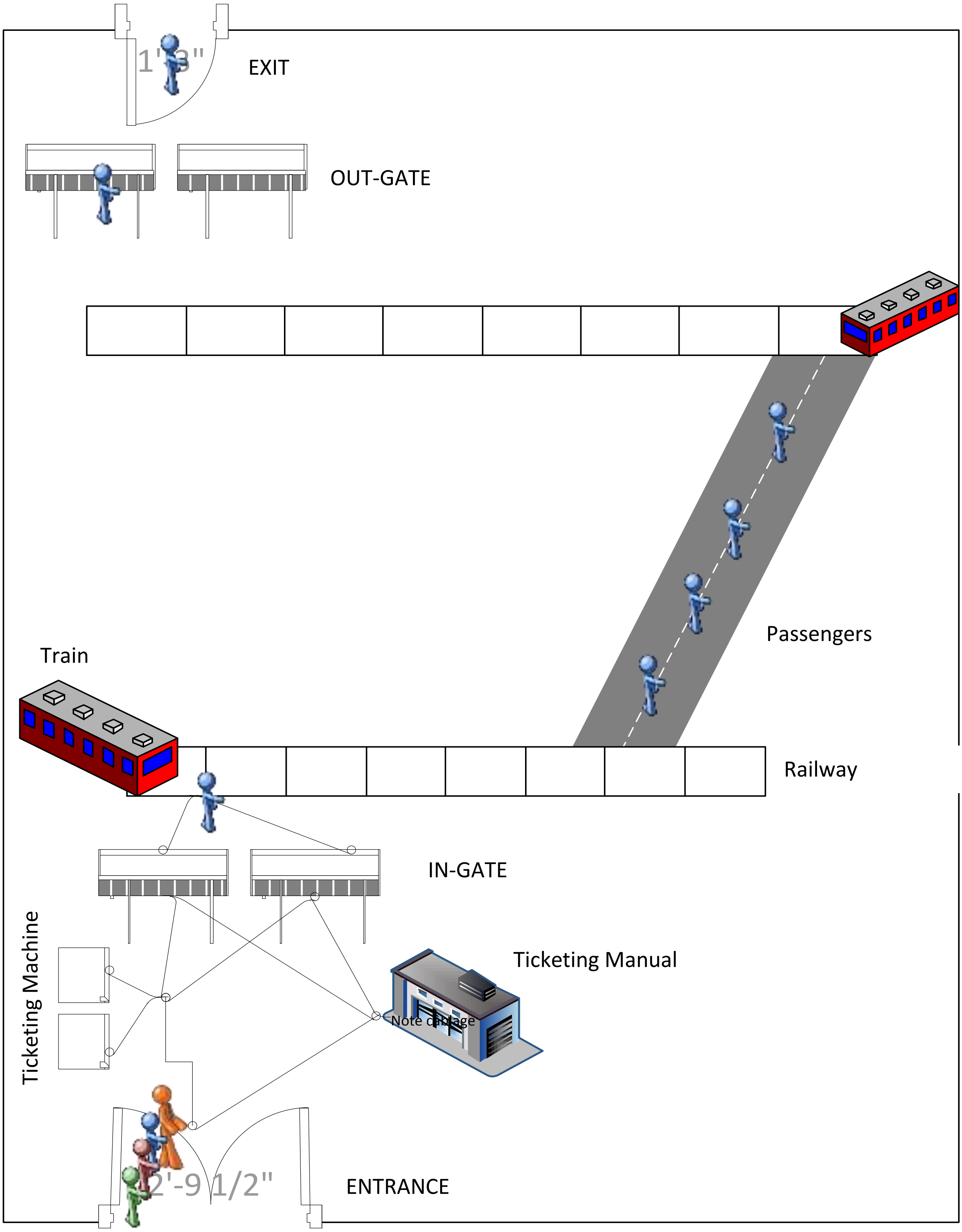


Figure III.3 Passengers Process

III.2 Collecting the data

In this part the researcher collecting the data that will be useful to compare the energy efficiency.

There are several data that will be need in this research which:

1. Path of train.
2. Weight of the train.
3. The length of the railway.
4. The number of the train.
5. Velocity of the train.
6. Acceleration of the train.

III.2.1. Path of the train

The path of the train data following the map of the paris metro which is available on www.ratp.fr. The map can be seen in Figure III.4

Figure III.4 Map of Paris Metro

III.2.2. Weight of the train

The weight of the train will determine how is the acceleration and the gravitation of the railway effect. There are several train model that can be seen on the Table III.1.

Table III.1 Mass of the train

Types of train	mass (ton)
MP 89-CC	144,2
MP 89-CA	135
MP 05	140
MF 01	125,7
MF 67	106
MF 59	126,4
MP 73	132,5
MF 77	130,8
MF 88	74,2

The explanation of the types of the train as following below :

1. MP = a subway system that the vehicles are equipped with the pneumatics wheels.
2. MF = a subway system that are equipped with the rolling material on the rail.
3. Series number of 59, 67, 73, 77, 88, 89, 01, 05 represents the date of the train produces which is 1959, 1967, 1973, 1988, 1989, 2001 and 2005.
4. CC = Drives manually
5. CA = Drives automatically

III.2.3. The length of the railway

The length of the railway depends on the line. Each line has the different long of railway and the length of each station to another station is different. However for this research, the researcher will based on the average interstation to simplify the mathematical procedure. The length of the interstation can be seen on Table III.2.

Table III.2 The length of the railway

Ligne	Number of stations	Length (km)	Average interstation (m)
1	25	16,6	692
2	25	12,3	513
3	25	11,7	488
3 bis	4	1,3	433

Table III.2 The length of the railway (continued)

Ligne	Number of stations	Length (km)	Average interstation (m)
4	26	10,6	424
5	22	14,6	695
6	28	13,6	504
7	38	22,4	605
7 bis	8	3,1	443
8	37	22,1	614
9	37	19,6	544
10	23	11,7	532
11	13	6,3	525
12	28	13,9	515
13	32	24,3	776
14	9	9	1129

III.2.4. The number of the train

The number of the train is depends on the railway line. Its depend on the traffic and how many customers that could be served on each line. The number of the train can be seen on Table III.3.

Table III.3 Number of the train

Types of train	Number of train
MP 89-CC	52
MP 89-CA	21
MP 05	49
MF 01	161
MF 67	220
MF 59	56
MP 73	46
MF 77	66
MF 88	9

III.2.5. The velocity of the train

The velocity of the train is needed to determine the travelling time of the train. The velocity of the train depends on the types of the train. The velocity of the train can be seen on the Table III.4

Table III.4 The velocity of the train

Types of train	Speed (km/h)	Maximum Speed (km/h)
MP 89-CC	70	80
MP 89-CA	80	
MP 05	80	80
MF 01	70	80
MF 67	70	80
MF 59	70	80
MP 73	70	80
MF 77	80	100
MF 88	40	80

III.2.6. The acceleration of the train

The acceleration of the train is used to determine the time to reach the Velocity of the train for the coasting phase. The acceleration of the train at start can be seen on the Table III.5.

Table III.5 The acceleration of the train

Types of train	Acceleration at start (m/s^2)
MP 89-CC	1,25
MP 89-CA	
MP 05	1,35
MF 01	0,9
MF 67	1
MF 59	1,3
MP 73	1,3
MF 77	0,81
MF 88	0,95

III.3 Processing the data

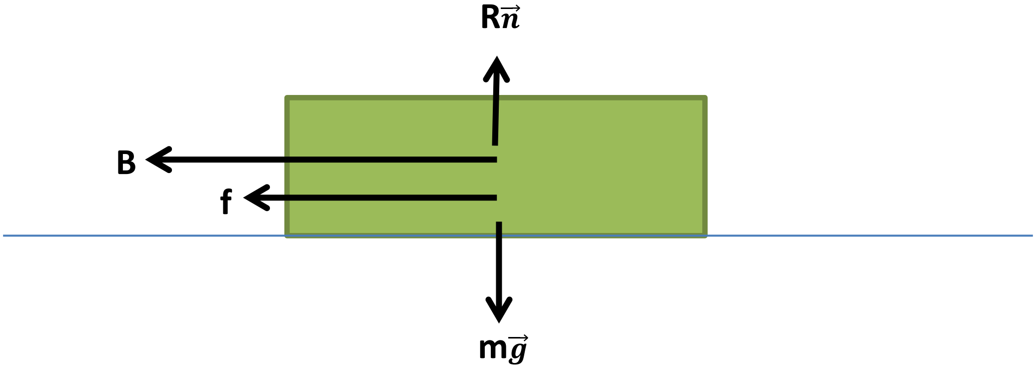
On this part of the research, the researcher will give the example of the line. The result on the other line will be determine on the Appendix. The following procedure will follow the formula that been conducted by Howlett and Pudney (1995)[26] .Processing data part will follow the following step :

1. Determining the braking acceleration (negative acceleration)
2. Determining the distance where the braking should be applied and the velocity of the train after the braking.

3. Determining the length for the coasting phase.
4. Determining the acceleration for the coasting phase.

III.3.1 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 :

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

Braking forces = 1900 N/ton

Mass train = 140 ton = $14 \cdot 10^4$ kg

B = 1900N/ton. 140 ton

= 266,000 N

Friction forces = 100 N/ton

f = 100 N/ton. 140 ton

= 14,000 N

Then :

$-B - f = m.a$

$-266{,}000\ N - 14{,}000\ N = 14 \cdot 10^4 \cdot a$

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

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

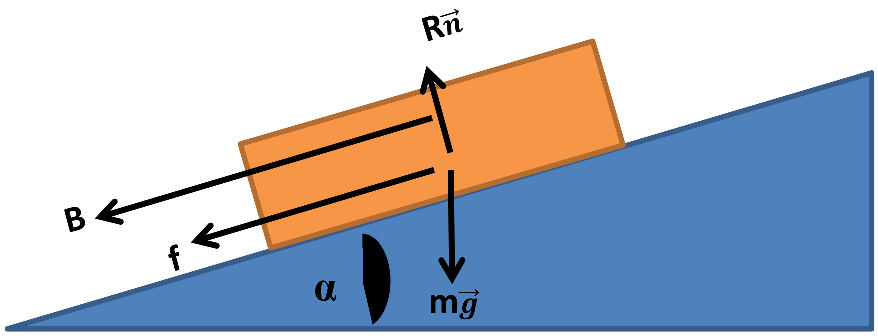
III.3.2 Determine braking state

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 m

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

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

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

= 5.56 m/s

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

III.3.3 Determine the coasting phase

The coasting phase is the phase where the train works on the maximum speed of the acceleration- coasting- braking phases. It can be seen on the Figure III.5. The point x<0.1 is the acceleration point. The point 0.1 ≤x≤0 0.9 is the coasting phase and the point x >0.9 is the braking phase.

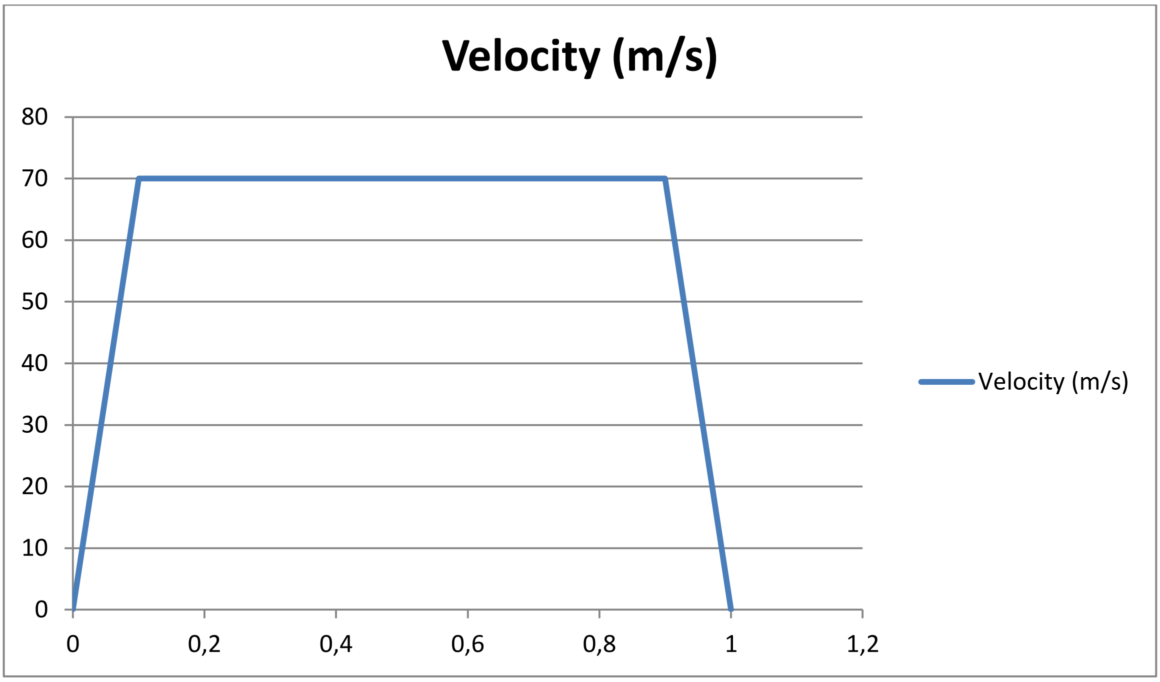


Figure III.5 Acceleration – Coasting – Braking chart

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

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

$22.22 = 0 + 1.35.t$

$t_{acceleration} = 16.46$ s

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

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

$= 0.16.46 + 0.5 \,.\, 1.35 \,.\, 16.46^2$

$= 182.878$m

The travelled distance during the coast phase as following equation :

$S_{c\,=}$ Total length interstation – S – db

S_c = 692m – 182.878m – 7.7284m

= 501.3936 m

III.3.4 Determine the acceleration of the coasting phase

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

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

$$501.3936 = \frac{22.22^2 - 5.56^2}{2ac}$$

a_c = 0.461 m/s.

III.4 Proposed Model

On this part the researcher will put all the result and implementate it all together. The comparison with the initial system will be on the next chapter.

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 1
3. Implementation and analysis for the proposed model

III.4.1. The duration time

The duration of the brake phase is :

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

$$= \frac{5.56}{2}$$

= 2.78s

The coasting time will be

S = Vot + 0.5. a. t^2

501.3936 = 22.22.t + 0.5. 0.461. t^2

$t_{coasting}$ = 18.87s

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

= 16.46 + 18.87 + 2.78

= 38.11 s

III.4.2. The energy consumption

By following the Chang and Sim formulation in Yang et.al (2010)[24]. The energy consumption will be expressed as following equation :

$$E^k_{(i,j)}(X) = \mu_k \int_0^{T^k_{(i,j)}(X)} F^k_{(i,j)}(X,t).V^k_{(i,j)}(X,t)dt + A_k T^k_{(i,j)}(X) + \xi_k \int_0^{T^k_{(i,j)}(X)} B^k_{(i,j)}(X,t).V^k_{(i,j)}(X,t)dt$$

On the equation its include 3 factor which is :

- Tractive power
- Auxiliary energy
- Braking power

On the equation $F^k_{(i,j)}(X,t).V^k_{(i,j)}(X,t)$ represents the exported tractive power of train k at time t. The first integral over interval [0, $T^k_{(i,j)}(X)$] is the total work by traction on link (i,j). Multiplied by $\hat{I}\,{}^1/_4\,k$, the first part then denotes the totral energy consumption by traction operations. The second part, namely $A_k T^k_{(i,j)}(X)$, represents the total auxiliary energy consumption on the link. In the third part, equation $B^k_{(i,j)}(X,t).V^k_{(i,j)}(X,t)dt$ is the exported power of train k at time t. The integral over interval [0, $T^k_{(i,j)}(X)$] denotes the total work consumed by braking on link (i,j). With multiplier $\hat{I}\,{}^3/_4\,k$, the third part represents the total energy consumed in the braking operation.

It is worth noting that, owing to the uncertain environment of real-world operations, some performance parameters in equation, such as $\hat{I}\,{}^1/_4\,k$, A_k and $\hat{I}\,{}^3/_4\,k$, are not necessarily fixed indeed. The uncertainties of these parameters can be reflected by the fluctuation of their values, or alternatively, the detailed characteristics cannot be captured accurately. For example, $\hat{I}\,{}^1/_4\,k$ represents the multiplier of converting the work to energy consumption during the traction operation. Nevertheless, it can be impacted to a great degree by some additional factors (such as the current track voltage, the age of a locomotive, etc.) so as to cause the occurrence of uncertainty.For this reason, a more suitable assumption is to treat this parameter as an uncertain variable instead of a constant. Besides, according to driving habits of drivers, more auxiliary energy Ak is generally required in the accelerating operation of a train than that needed in the coasting operation. Thus, this parameter can be expressed as an uncertain variable in the mathematical formulation to capture its complex characteristics. To handle the existed uncertainties in a mathematical way, performance parameters, including $\hat{I}\,{}^{1}/_{4}\,k$, A_k and $\hat{I}\,{}^{3}/_{4}\,k$, will be reexpressed as fuzzy variables and rewritten as $\hat{I}\,\widetilde{{}^{1}/_{4}}\,k$, $\widetilde{Ak}$ and $\hat{I}\,\widetilde{{}^{3}/_{4}}\,k$, respectively, in the following discussion. These fuzzy parameters can be predetermined by experiential estimations or professional judgements in real-world applications.

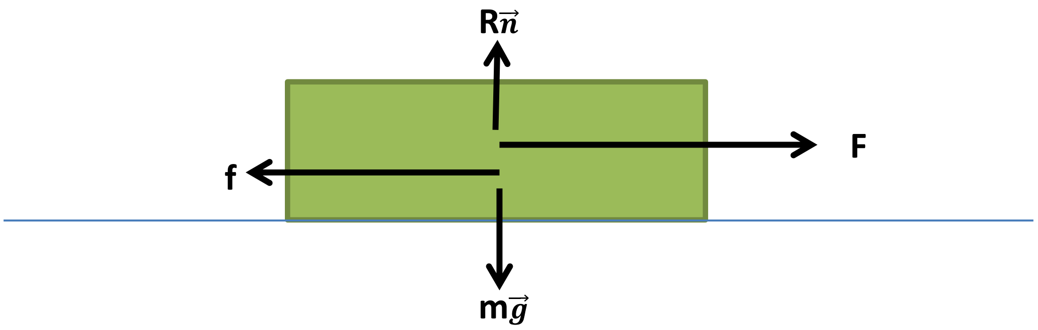
To put the element of gravitation, the researcher put another equation and the energy equation will be as follow :

$$E_{(i,j)}^{k}(X) = \mu_k \int_0^{T_{(i,j)}^{k}(X)} F_{(i,j)}^{k}(X,t).V_{(i,j)}^{k}(X,t)dt + A_k T_{(i,j)}^{k}(X) + \xi_k \int_0^{T_{(i,j)}^{k}(X)} B_{(i,j)}^{k}(X,t).V_{(i,j)}^{k}(X,t)dt$$

$$+ \int_0^{T_{(i,j)}^{k}(X)} G_{(i,j)}^{k}(X,t).V_{(i,j)}^{k}(X,t)dt$$

In the equation $G_{(i,j)}^{k}(X,t).V_{(i,j)}^{k}(X,t)$ represents the energy consumed to push the train on the railway with the gradient.

- The energy consumption for acceleration phase for 1 station



F –f + R$\vec{n}$ - m$\vec{g}$ = m.a

F = f + m.a

= 100 . 140 + 140000 . 1,35

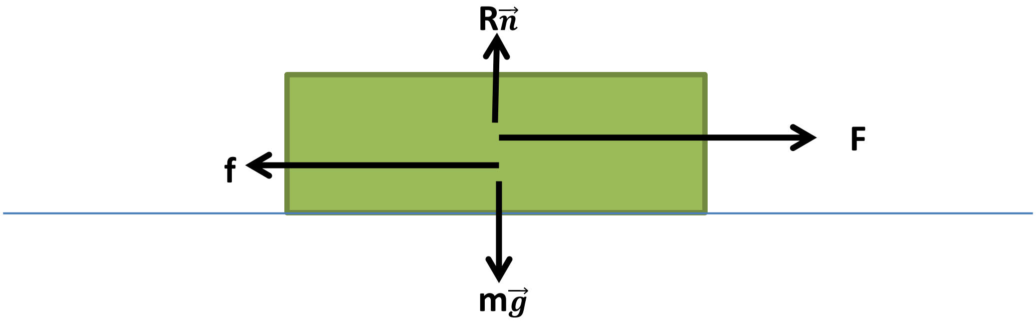
= 203000 N

Energy = F.S

= 203000 . 182,878

= 37,124,234 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 . 140 + 140000 . 0.461

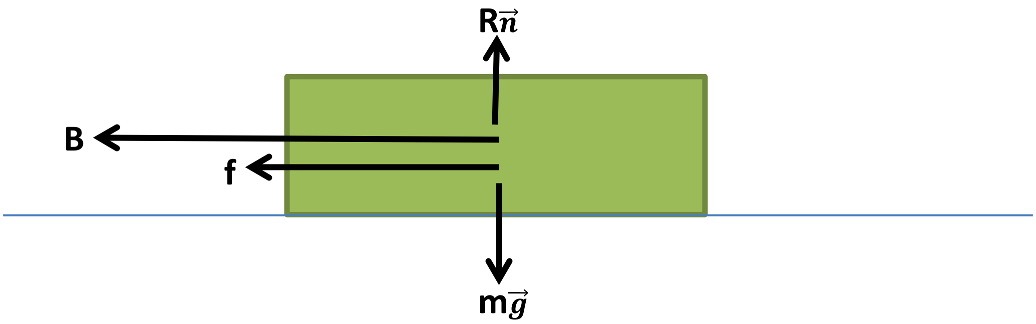
= 78,540 N

Energy = F.S

= 78,540 . 501,396

= 39,379,453.34 J

- The energy consumption for braking phase for 1 station



-B –f + $R\vec{n}$ - $m\vec{g}$ = m.a

-B = m.a +f

= 140,000 . 2 + 1,900 . 140

= 546,000 N

Energy = $|B|$. d

= 546,000 . 7.7284

= 4,219,706.4

- Total energy using for 1 station

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

= 37,124,234 J + 39,379,453.34 J + 4,219,706.4 J

= 80,723,393 J

- Total energy consumption for line 1

Total energy consumption = 25 station . Energy Total

= 25. 80,723,393

= 2,018,084,825 J

III.4.3. Implementation and Analysis

The power consumption for the initial system is 2400KW. So the energy consumption for the line 1 with 25 station is 2400 kW x 25 = 1000kWh = 3,600,000,000 Joule. With the proposed model, we can save the energy up to 1,581,915,175 J or 439.42 kWh.

From the www.carbontrust.co.uk/energy , we can convert the energy into Carbon and CO_2 emission. The carbn and CO_2 emission saving can be seen in Table III.6

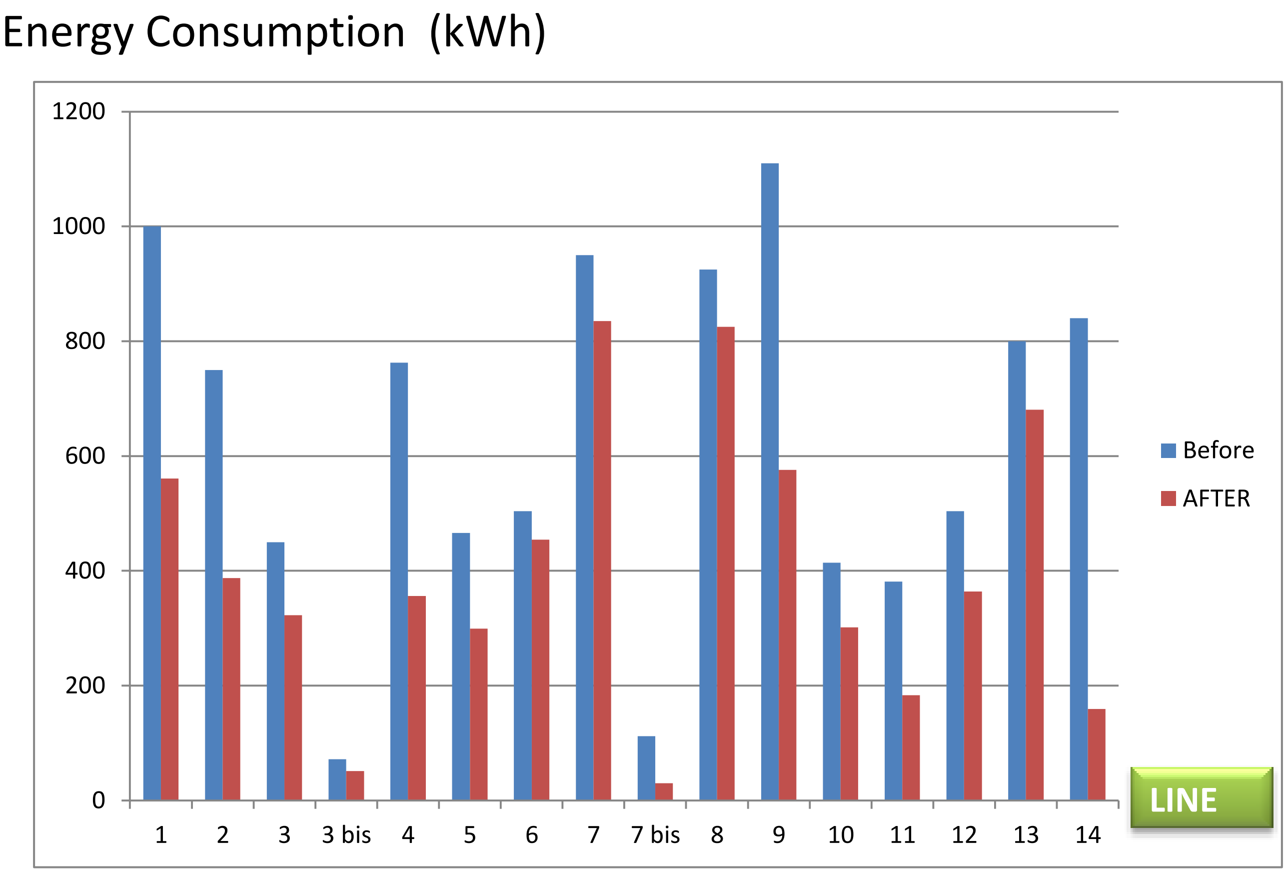
Table III.6 Carbon and CO_2 emission

Fuel		Carbon emission factor		Line 1	
		kg C/kWh	kg CO2/kWh	kg C	kg Co2
Grid electricity	Delivered	0,117	0,43	51,41214	188,9506
	Primary	1,0453	0,1661	459,3257	72,98766
Natural gas		0,0518	0,19	22,76196	83,4898
Coal		0,0817	0,3	35,90061	131,826
Coke		0,101	0,37	44,38142	162,5854
Petroleum Coke		0,0927	0,34	40,73423	149,4028
Gas / diesel oil		0,068	0,25	29,88056	109,855
Heavy fuel oil		0,0709	0,26	31,15488	114,2492
Petrol		0,0655	0,24	28,78201	105,4608

Table III.6 Carbon and CO_2 emission (continued)

Fuel	Carbon emission factor		1	
	kg C/kWh	kg CO2/kWh	kg C	kg Co2
LPG	0,0573	0,21	25,17877	92,2782
Jet Kerosene	0,0655	0,24	28,78201	105,4608
Ethane	0,0545	0,2	23,94839	87,884
Naphtha	0,0709	0,26	31,15488	114,2492
Refinery gas	0,0545	0,2	23,94839	87,884

The Comparison of the Energy Consumption before and after proposed approach can be see in Picture III.6



Picture III.6 Energy Consumption Comparison Before and After the Proposed Approach