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# Optimization Technique for Reducing Energy Consumption of Rapid Transit Mode

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***Abstract: Since the time, our mother earth was created, energy was taken from the universe(System),now energy is being depleted as non-renewable source. Energy can neither be created nor be destroyed as it transforms in one form to another. So researchers came up with renewable source of energy as the solution like solar, wind and tidal waves. The world is experiencing an energy crisis and the prices of petroleum products like petrol and diesel has gone up. So its time to come forward and save the future of our mother earth. The paper deals in reducing energy consumption of rail rapid transit mode i.e. of metro. It shows how driving behaviour can be controlled using optimized speed profile and efficiency can be managed. It states round trip data taken of Mumbai(India) metro from Versova to Ghatkopar and viceversa. Speed data was taken from GPS(Global Postioning System) embedded in Smart watch Software. Time interval was noted and distance, acceleration data was formulated using Newtons Equations of Motion. Energy Consumed was drawn out from tractive effort data. Then efficiency, energy lost and regenerative braking energy was calculated using Work Energy Theorem. Maximum efficiency of 88.27% was obtained between Asalpha to Jagruti Nagar Station while between Western Express Highway to Andheri Station a 72.66% efficiency was analysed. This affects the time interval of metro trains arriving at station, also the amount of boarding and alighting passengers from the train. A model was designed and simulated using results obtained. The paper also deals with the prototype of Regenerative energy which can either be used in braking systems but also for acceleration and cruising purpose. The idea can benefit a developing country like India where 6.3% GDP is from Transportation Industry.***
***Keywords: optimized speed profile, efficiency, regenerative braking energy***

## I. INTRODUCTION

Energy conservation is the prime focus of the paper. Especially where rapid rail transit mode is concerned as 20 to 50 kW-hr of energy is consumed in a single trip of a metro as it covers a distance of 11.5 km with 15000 ridership travelling in peak hour. Why the word optimum is used in the title? It is used so as to maximise the benefit of what energy is being used to run the system. While writing the paper the thought of replacing the metro model with Solar train or Maglev train could be arrived in your mind but the paper deals with changes that can be applied to the existing metro model in efficient way. The paper will give you the comparison between different aspects like distance Vs time, speed Vs time, acceleration Vs time, tractive effort Vs distance, optimized speed profile graphs when train runs from Versova to Ghatkopar and viceversa. It also compares that between which station the efficiency is maximum. It also compares between station, the energy lost and regenerative braking energy using histograms.

All the data can be easily found when a case study is taken into consideration. The regenerative braking energy model is widely used in many locomotives but what if we try to recover every energy consumed during acceleration, cruising, coasting and braking. It can be easily understood with a model where the traction motor rotates the axle and mounted on it a Dynamo(small generator) which converts mechanical energy into electrical energy can be used to recharge the battery. Effectiveness can be improved by reducing headway by optimizing timetable strategies so to increase traffic capacity. If driver drives at optimum speed analyzed in results, efficiency will be improved and energy consumption will be less.

## II. LITERATURE REVIEW

Researchers from various institutes have tried to comply with energy reduction management when it comes to urban rail rapid transit mode. Author A. Gonzalez-Gil *et al*.[1] states energy reduction consumption of 25-35% in his paper. Parameters that they investigated was Regenerative braking model, Energy metering, Smart power management, Renewavble energy micro-generation.To ensure environmental best performance, service quality urban rail rapid transport should minimize its energy use. The principal measures of energy breakdown was used by this author. Practical logical methodology for qualitative assessment and control driving behaviour, energy optimized timetables could approximately reduce enegy consumption by 30%.Another researcher Bwo-Ren Ke *et al*.[2] optimized train speed trajectory.

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Signalling control system can control mass rapid transit system(MRTS) between successive stations. Parameters in their research were optimal speed codes, geometric variables like track gradient, average speed, acceleration, jerk along with fuzzy-PID gain scheduler which controlled acceleration. MMAS finds the optimal speed code of each section. Tracking performance managed by fuzzy-PID gain scheduler under specific speeds. Command tracking is more effective rather than excessive acceleration or deceleration with fuzzy-PID gain scheduler. Researcher Ning Zhao *et al.*[3] main objective was to minimize substation energy consumption. They took variables like driving speed profile and timetable configuration. They concluded optimal train trajectory and timetable have huge impact on substation energy consumption and load can be reduced significantly. Stability and Performance of system is improved thereby reducing investment cost for new metros. Energy saving operation methodologies for urban rail transit systems, Ziyou GAO[4] and Lixing YANG[4] authors main aim was to reduce energy consumption and operation cost using advanced optimized ways. They mentioned train speed profile optimization, utilization of regenerative energy and integrated optimization of timetable and speed profile. They remarked that passenger demand effect train weight, due to which acceleration and braking rates gets affected. This affected traction energy consumed. Research on regenerative ESDs techniques can be further applied. Train scheduling with energy management at network is new research direction. Energy saving and service quality improvement was given by authors Yeran Huang *et al.*[5].They followed passenger travel time, boarding and alighting passengers, regenerative braking energy, adjusting headway, binary encoding method to obtain timetables of high quality. The paper ended with effective model designed for optimizing timetable with headway to increase Capacity. Demonstrated data from Beijing Yizhuang subway line taken to obtain effectiveness of proposed approaches. Analysis were made on impact of track alignment on energy consumption level by author B. Sarsembayev *et al.*[10].

## III. THEORETICAL CONSIDERATION

Sir Isaac Newton, the renowned physicist and mathematician gave his own 3 equations of Motion which is used in the paper.James Prescott Joule, the physicist gave the formula of work done or energy consumed. Work-energy theorem can be derived from Newton's 2$^{nd}$ Law.

### A. Newtons Equation of Motion

$v = u + (a)x(t)$ ……………………………………………………………..(1)

$s = (u)x(t) + 0.5x(a)x(t^2)$ …………………………………………..………(2)

Where $v$ is final velocity, $u$ is initial velocity, $a$ is acceleration, $t$ is time taken and $s$ is distance covered.

These above equations were used to get acceleration(1) and distance(2) from speed data obtained.Time was also noted how much time the metro took between stations,neglecting the dwell time at station.

### B. Newton's 2$^{nd}$ Law

$F = (m)x(a)$……………………………………………………………………..(3)

Where $F$ is Tractive force, $m$ is mass of system, $a$ is acceleration.

Dead load of the metro was taken.Alighting and Boarding passengers data was taken from the final report of Mumbai MRTS Project-MMRDA which was in peak hour.Tractive effort was calculated using total mass of train with passengers by acceleration.

### C. Work(Energy Consumed)

$W = F.s$ ……………………………………..…………………………..(4)

Where $W$ is Work done, $F$ is tractive force applied,$s$ is distance covered.Dot product of tractive effort with displacement gives energy consumed by metro.The area under Tractive effort with distance gives also the work done.

### D. Work Energy Theorem

$\Sigma W = (0.5x(m)x(v_1^2)) - (0.5x(m)x(v_2^2)$…………………………………(5)

Where $v_1$ is final velocity,$v_2$ is initial velocity.W is work done by all forces.The net work done by all forces is change in kinetic energies.

### E. Efficiency

$\eta\% = ((Energy\ output)/(Energy\ input))x100$……………………………(6)

After getting the ratio of energy given out from the system to energy given to the system,we can get efficiency.

## IV. METHODOLOGY

The methodology adopted is based on theoretical consideration taken in order to find the required optimized speed profile which the driver must adopt between stations. First the speed values are collected using smartwatch at every 10 seconds. The train moves from Versova to Ghatkopar and the data is collected. Then the acceleration is calculated using eq.(1) for example

$v = u + (a)x(t)$

16.9x(5/18)=0+ax10

a=0.4694m/s$^2$

Likewise for whole time and speed data acceleration data is formulated. Then comes distance which is calculated by eq.(2)

$s = (u)x(t) + 0.5x(a)x(t^2)$

s=(16.9x10/3600)+0.5x(0.4694)x(10x10/1000)

s=0.0704km

Likewise the distance data is collected and noted. Then dead load is noted as 1 rake load is 50 tonnes then for 4 rake load is 4x50=200 tonnes. At every station passengers alights and boards the train so net amount of passengers load is added to dead load. For example,

200+14.22=214.22 tonnes

Now this converted to mass will be 214.22/9.18=21837kg. Knowing acceleration data multiplied by mass will give tractive effort. For example,

F=21837x0.4694=10.25kN

After multiplying by distance we get energy consumed i.e.,

W=10.25x0.0704=0.36MJ

After getting every data and summing it we will get energy consumed in kW-hr.For efficiency i.e.

$\eta\%=((0.5x(m)x(v_{max}^2))/(\Sigma F.s))x100$

$\eta\%=((0.5x(21837)x(50.36x5/18)^2)/(0.36+1.52+1.17+0.57+0.18-0.02+0.01-0.04-0.24)x1000000)x100$

$\eta\%=60.87\%$

Likewise efficiency is known. Then comes energy lost and regenerative braking energy. It is assumed that energy lost is due to friction, air resistance, eddy currents, heat until maximum speed is reached. Regenerative braking energy starts from maximum speed reduces to zero. These are the main assumptions while calculating Energy lost and Regenerative braking energy.

$$\Sigma W = (0.5x(m)x(v_1^2)) - (0.5x(m)x(v_2^2)$$

$\Sigma F.s$ - Energy lost=$0.5x(m)x(v_{max}^2) - 0$ ……………………………………(6)

$\Sigma F.s$ – Regenerative braking energy=$0 - 0.5x(m)x(v_{max}^2)$ ……………………(7)

Eq(6) is applied from acceleration to cruising while Eq(7) is applied from coasting to braking.

Table1.Recorded Data Collected in Excel Sheet

| Station | Time(sec) | Distance(k | Speed(km/ | Accelerati | Dead load | Boarding P | Alighting P | Net Weigh |
|---|---|---|---|---|---|---|---|---|
| Ghatkopar | 0 | 0.0000 | 0 | 0.0000 | 4*50=200 | 12694 | 0 | 12694 |
| | 10 | 0.0894 | 21.46 | 0.5961 | | | | |
| | 20 | 0.1569 | 23.34 | 0.0522 | | | | |
| | 30 | 0.2239 | 23.86 | 0.0144 | | | | |
| | 40 | 0.2898 | 23.79 | -0.0019 | | | | |
| | 50 | 0.3552 | 23.62 | -0.0047 | | | | |
| | 60 | 0.4203 | 23.5 | -0.0033 | | | | 12694*60= |
| | 70 | 0.4860 | 23.59 | 0.0025 | | | | |
| | 80 | 0.5538 | 24.14 | 0.0153 | | | | |

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### *A. Regenerative Energy*

Regenerative energy is different from regenerative braking energy as regenerative energy is obtained during the whole process in acceleration, cruising, coasting and braking. It can be easily obtained by placing dynamo over the axle of motor and generated torque from motor will rotate the dynamo which will produce electrical energy. This can be easily understood with the prototype shown below.

Fig.1 Side view of Prototype

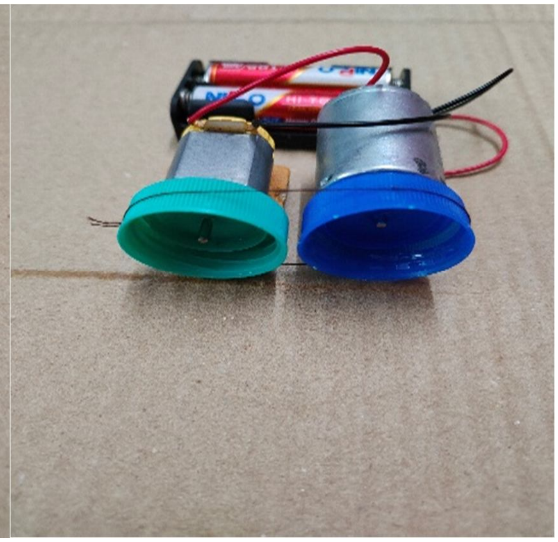


Fig.2 Front view of Prototype

## V. ANALYSIS

The data collected in excel table is analysed and curves are drawn. It is noted that as the total mass of the train with passengers decreases, efficiency increases. It means that amount of passengers boarding the passenger should be less than alighting passengers. This will increase acceleration and hence gain optimum speed with less amount of energy consumed. This is called optimum energy management. In other words the boarding passengers will be less only when the frequency of trains is more at peak hours.

1) *Distance Vs Time:* Train moving from Versova to Ghatkopar distance data is shown in Fig.3 in the form of graph while train from Ghatkopar to Versova is shown in Fig.4.

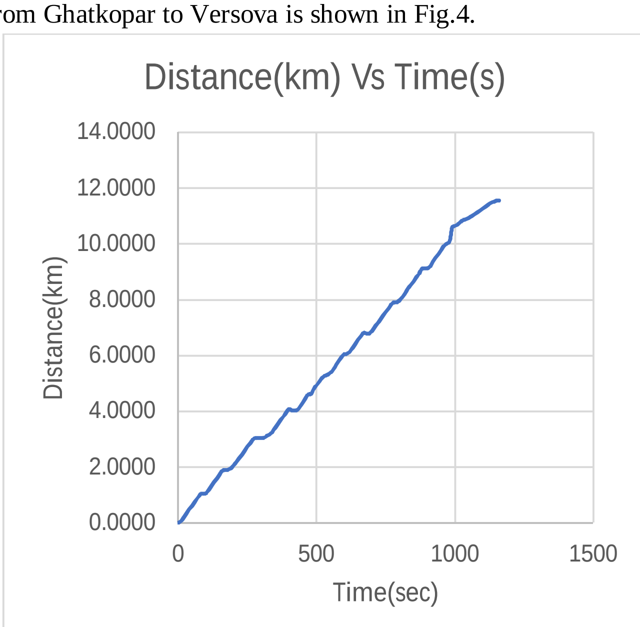



Fig.3 Variation of Distance(km) with Time(s)

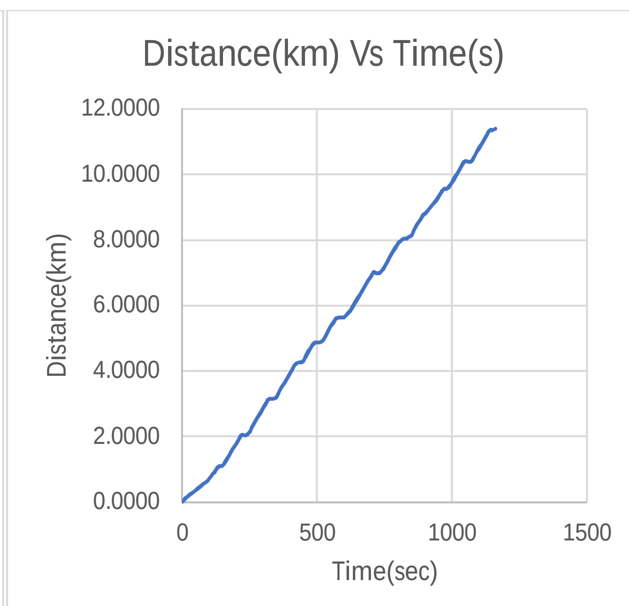
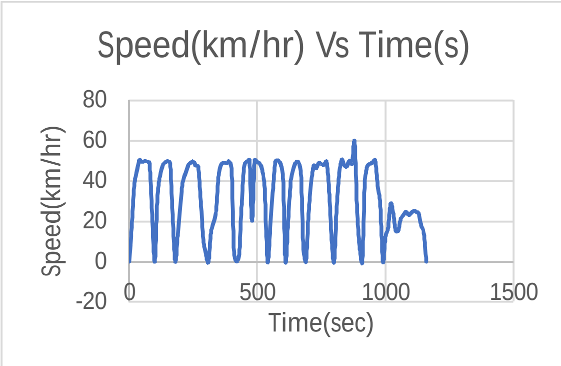



Fig.4 Variation of Distance(km) with Time(s)

2) *Speed Vs Time:* Train moving from Versova to Ghatkopar speed data is shown in Fig.5 in the form of graph while train from Ghatkopar to Versova is shown in Fig.6.



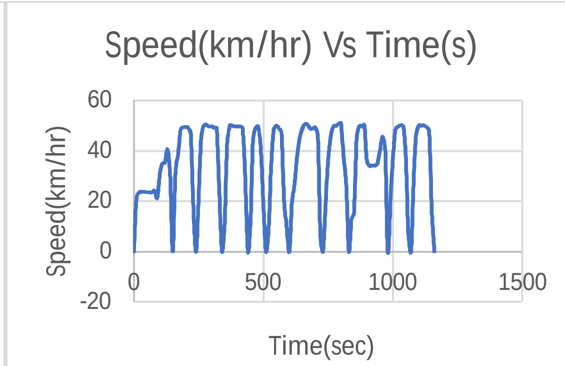
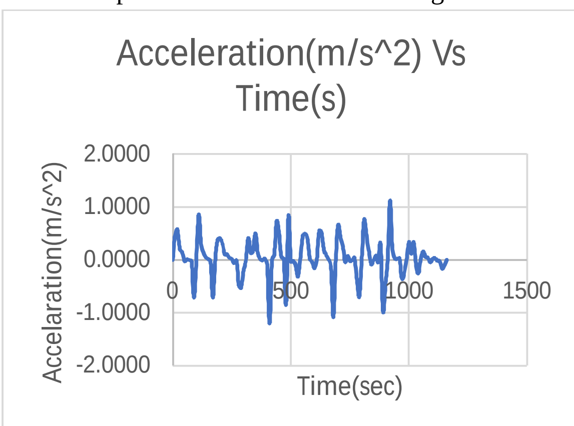




Fig.5 Variation of Speed(km/hr) with Time(s) Fig.6 Variation of Speed(km/hr) with Time(s

3) *Acceleration Vs Time:* Train moving from Versova to Ghatkopar acceleration data is shown in Fig.7 in the form of graph while train from Ghatkopar to Versova is shown in Fig.8.



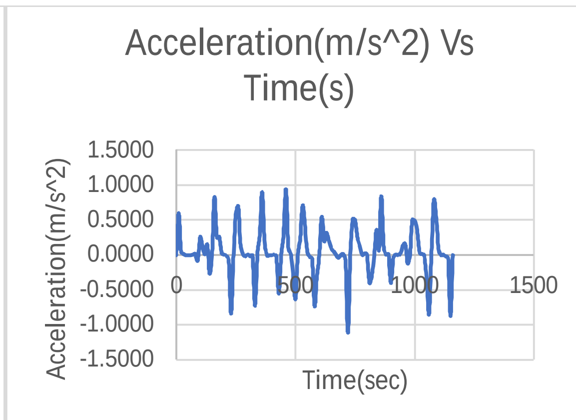
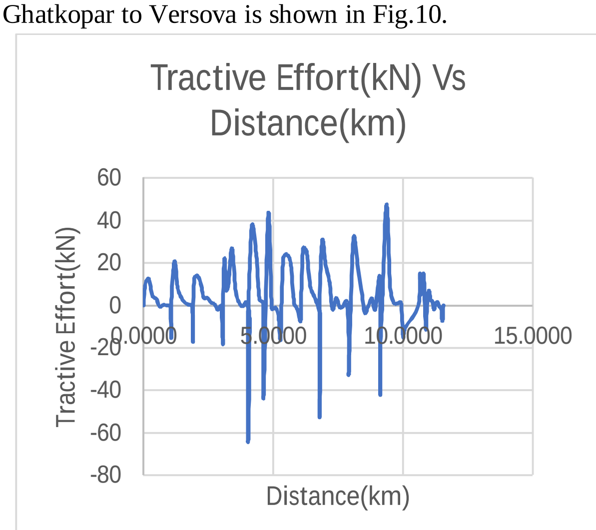




Fig.7 Fig.8
Variation of Acceleration(m/s^2)with Time(s) Variation of Acceleration(m/s^2)with Time(s)

4) *Tractive effort Vs Distance:* Train moving from Versova to Ghatkopar data is shown in Fig.9 in the form of graph while train from Ghatkopar to Versova is shown in Fig.10.



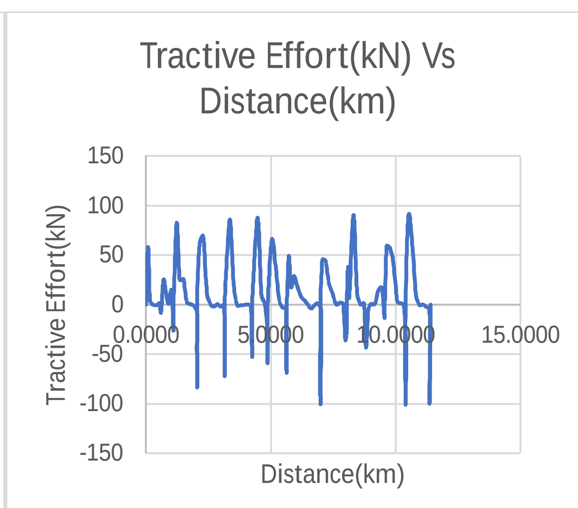




Fig.9 Fig.10
Variation of Tractive Effort with Distance Variation of Tractive Effort with Distance

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5) *Efficiency:* Train moving from Versova to Ghatkopar data is shown in Fig.11.

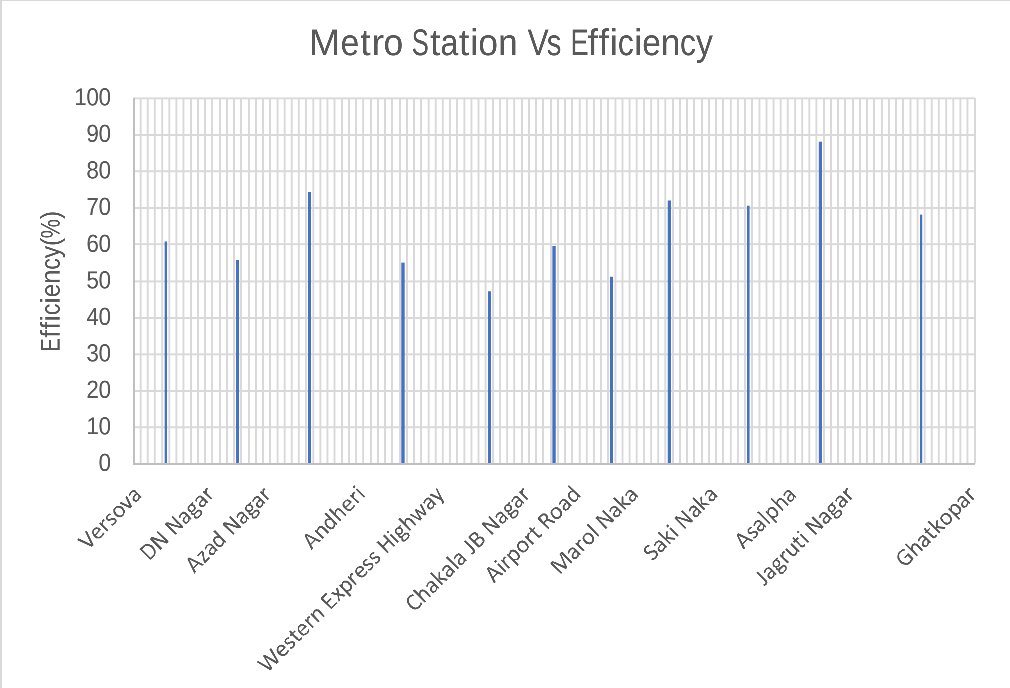


Fig.11 Efficiency(%) data with Metro station

While train from Ghatkopar to Versova data is shown in Fig.12.

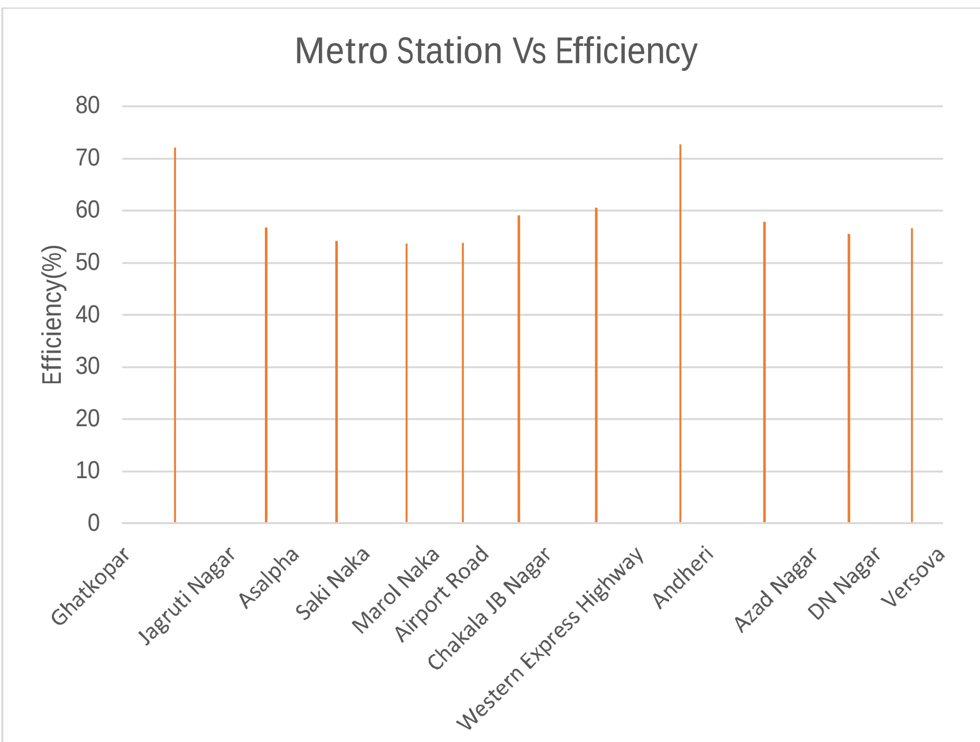


Fig.12 Efficiency(%) data with Metro station

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6) *Optimized Speed Profile:* Train moving from Versova to Ghatkopar data is shown in Fig.13 in the form of graph while train from Ghatkopar to Versova is shown in Fig.14.

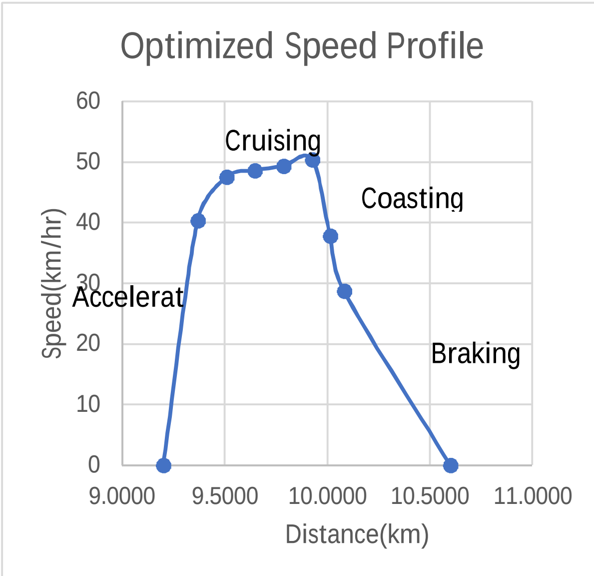


Fig.13 Optimized speed profile

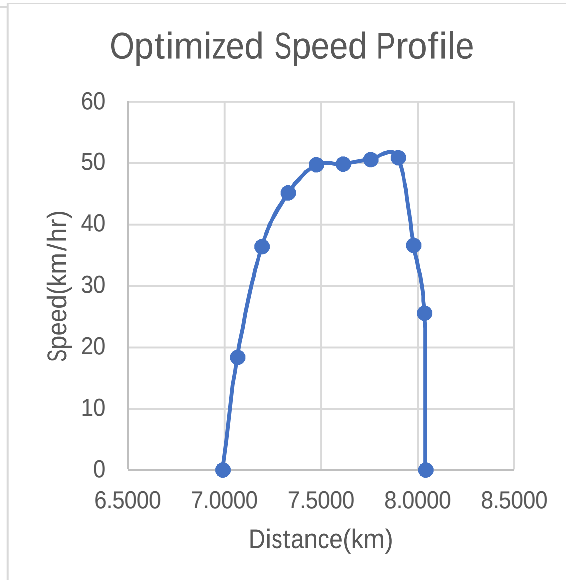


Fig.14 Optimized speed profile

7) *Energy lost and Regenerative Braking Energy:* Train moving from Versova to Ghatkopar data is shown in Fig.15

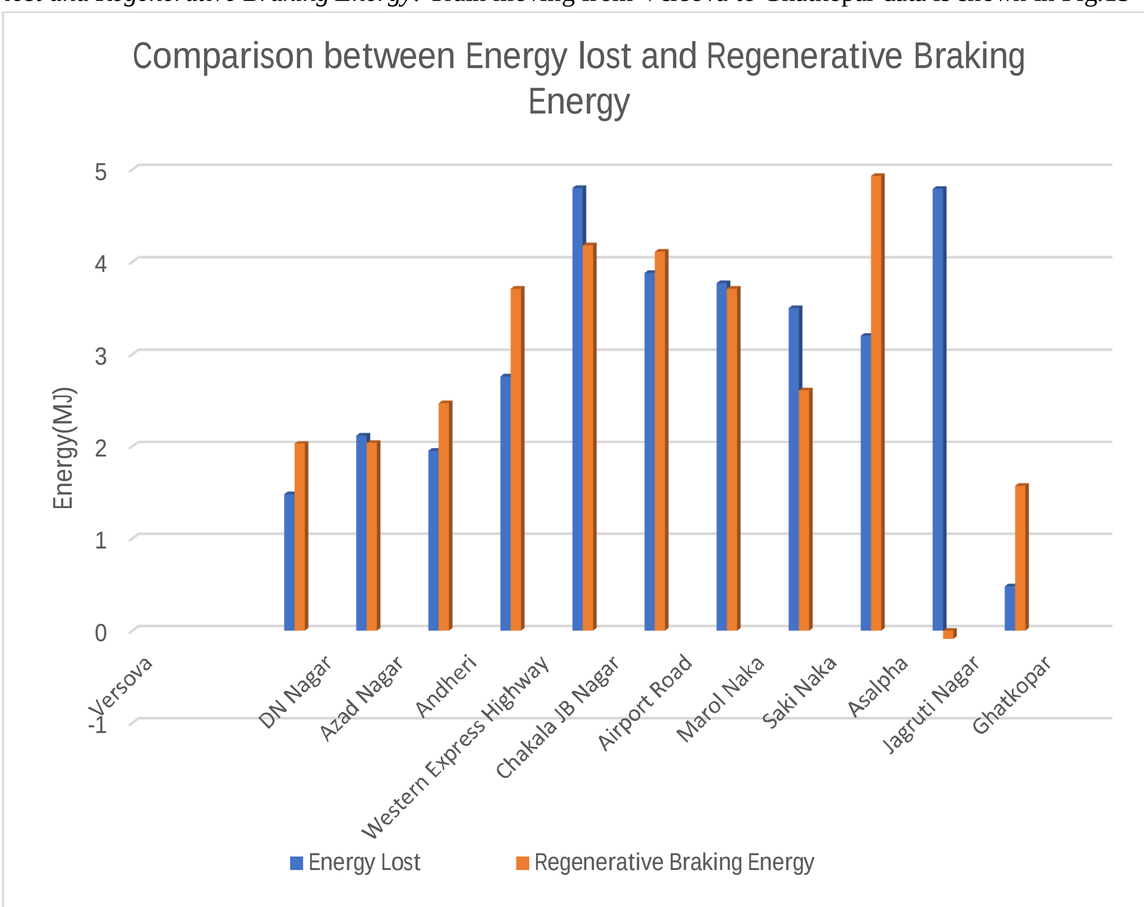


Fig.15 Comparison between Energy Lost and Regenerative Braking Energy

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While train from Ghatkopar to Versova data is shown in Fig.16.

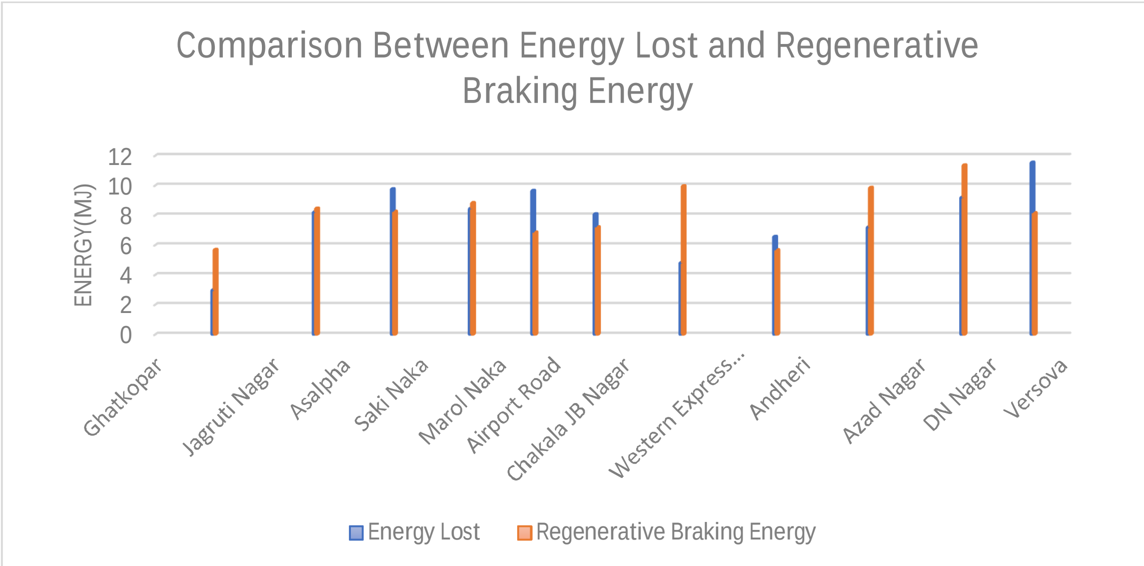


Fig.16 Comparison between energy lost and regenerative braking energy

## VI. SUMMARY AND DISCUSSION

*1)* Less number of passengers in train means more number of trains arrive at stations.
*2)* Frequency will be more when time interval will be less between successive trains. For example the time interval of metro is 6 minutes. It should be reduced to 3 minutes during peak hours.
*3)* When time interval is less that means headway is less which means the traffic capacity in one trip of metro increases.
*4)* Optimizing speed profiles using maximum efficiency between stations will help the driver to run train economically.
*5)* Regenerative braking energy will surely be used for lighting, cooling the coaches of metro thereby conserving energy.
*6)* Regenerative energy model as discussed above will make sure that during acceleration, cruising also the energy can be restored.

## VII. RESULT AND CONCLUSION

*1)* It is found that energy consumed by train when it travels from Versova to Ghatkopar is 18.91kW-hr while viceversa is 49.26kW-hr.This is due to more number of passsengers travelling from Ghatkopar to Versova than from Versova to Ghatkopar.
*2)* The efficiency of the train between station Asalpha to Jagruti Nagar is 88.27% so speed profile corresponding to this gives optimized speed profile as shown in Fig.11 while between station Western Express Highway to Andheri is 72.66% so speed corresponding to this data gives optimized speed profile as shown in Fig.12.
*3)* As the mass of passengers inside the train increases,energy lost and regenerative braking energy also increases as in Fig.13 the average passengers travelling is less while in Fig.14 the average passengers travelling is more.
*4)* It is noticed that in this case that regenerative braking value is more than energy lost value in Fig.13 and Fig.14.So train operation was more economical.
*5)* The optimized speed profile of Fig.11 is more economical as compared to in Fig.12 because in Fig.11 the speed covers a larger distance than in Fig.12.
*6)* Simulated model on PTV Vissim runs smoothly taking Optimized speed profile.

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