High Speed Train Simulation and Optimisation for Accidental Delay induced Single Line Assembly

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Abstract- This report aims to model train simulation between London and Birmingham station. The model simulates n number of trains with K number of blocks to safely drive train given maximum speed of 86.1 m/s, while max acceleration of 0.76 m/s^2 and safely decelerating at 0.38 m/s^2. There is a five second delay after a train passes a signal before it changes back to green. The model is further optimised to maximum number of trains per hour given an accidental delay of half hour introduced at 9.00 am to 9.30 am. The report yields that maximum 20 trains per hour can transit given the number of blocks is 2 to maximise the transport. Three methods of optimisation were used namely random hill climbing, Greedy hill climbing and Monte-Carlo simulation. Monte-Carlo gave the best result for optimisation on all three.

Keywords- Random hill, Monte-Carlo, Greedy hill, Simulation, Optimisation

1. Introduction

Train transport is one of the most prominent mode of transport since last century. It is still the most widely used mode of public transport. High number of public are dependent on it for their daily travel. Running the train on their full capacity is much needed. The trains can easily run on full speed that would not only reduce the travel time but also maximize the number of trains per hour thus reducing the load on railways and maximizing its profits. The problem associated with this is incident. As rail runs on track that is a parallel mode one small incident can bring the whole system to standstill causing trains before to stop. These incidents should also be avoided as it is directly responsible for public life. These associated problems motivated us to reconsider the existing system and optimize it by simulating the whole process.

2. Literature Review

There are many government organizations trying to optimize rail network since many years. The main hurdles are minimizing incidents while maximizing operations and profits. Biggest issue associated with rail network is public life, any minor mishap can result in number of casualties. Alex lander et al. [1] planning proper traveling speed can not only increase profits but also decrease incidents. The author introduces concept of headway time and buffer time. They calculate most conventional velocity of train by taking into picture interlock assembly and stopping time. It calculates buffer time by calculating the time, rail-line is spare. The application of this model on Copenhagen railway showed that by reducing their current maximum speed by six percent they increased capacity by eleven percent.

Rodriguez et al. [2] use of track length to optimize the capacity of the system. The author concludes that slowing of trains while arrival and departure added with the time taken by public to get on and off the train limits the track capacity. They also conclude that closer the station more time is wasted as slowing time adds load to the normal time. The number of tracks do not influence the results as time is highly influenced by freeing of station. Increasing distance between station allows the train to run to its full capacity eliminating effect of slowing time and optimizing the circuit. They also recommend speed control at particular part of tracks as this may reduce line interval making it independent of distance between stations.

Incidental delay caused would change all optimized planning of the model. [3] The author analyses delay distribution on high speed train circuits. Eleven classification of events causing delay is done and various models for distribution function of delay is studied. Kolmogorov–Smirnov test is used to evaluate the model fit and report the result. Lognormal, Gamma and normal distribution was applied to delay events. The maximum difference between theoretical distribution and empirical distribution of dataset is calculated and hypothesis testing at 95% significance level is done to evaluate whether the delay distribution fits the model or not is observed. All three models passed the test at 0.05 alpha level and hence concluded that these functions can be used to fit delay distribution of high-speed trains. Uniform distribution model failed the test, owing to its dependency on accurate data scale and non-fitting of random data. Lognormal model of this paper is used to fit delay in this report giving mean as 3.378 and standard deviation as 0.751.

3. Modelling and simulation

The simulation problem is to find most optimized number of trains running per hour given K number of signaling blocks located equidistant along the 145 Km line between London and Birmingham.

- Acceleration time and distance covered

Max a = 0.76 m/s^2 giving time to accelerate maximum velocity of 86.1 m/s as time = v-u/a = 86.1/0.76 = 113.3 s and distance travelled till max speed is reached is given by s = u t + 0.5 a t^2 since u or initial velocity is 0 equation becomes s = 0.5 a t^2 = 0.5*0.76*113.3**2 = 4878 m

- Energy efficient deceleration time and distance covered

Energy optimal deceleration time = 86.1/0.38 = 226.6 s and distance =86.1*226.6 – 0.5*0.38*226.6**2 = 9751 m

- Emergency deceleration time and distance covered

Emergency deceleration time = 86.1/2.5 = 34.44 s and distance = 86.1*34.44 – 0.5*2.5*34.44**2 = 1483 m

The above scenario indicates that we will have to design blocks atleast 9751*1.5 = 14626 m for safer and energy efficient stop between trains.

The total distance is 145 km and needs equal distance between blocks limiting the choice for k= {1,2, 4, 5, 8, 10, 20, 25, 29, 40, 50…}. But minimum distance between 2 blocks are said to be 14000 m stating maximum block as {1,2,4,5,8,10,14}

This limits the simulation as range of K is between 1 to 10.

- Calculating maximum number of trains per hour

Assuming maximum number of signal block installed in line that is 10

The distance between each block comes to around 14500 meters so for a train to safely travel we need the first train to cross this block hence we can say that by the time the first train has crossed the first signal we cannot send the second train.

Calculating the time required for the first train to cross the first block

s= u*t + 0.5*a*t**2 since initial velocity is zero the equation becomes

s=0.5*a*t**2

14500=0.5*0.76*t**2

resolving the equation for t we get time taken for first train to cross the first block is 195 seconds and the delay in signal to turn green is 5 seconds making the total time to 200 seconds this indicates that the second train can only leave after 200 seconds which is nearly 3 mins making maximum number of train possible in 1 hour as 60/3 = 20 trains.

Hence maximum number of trains per hour is 20.

4. Optimization results

Random hill climbing, Greedy hill climbing and monte-carlo methods were used for optimization. The best method to optimize was monte-carlo giving the results as follow.

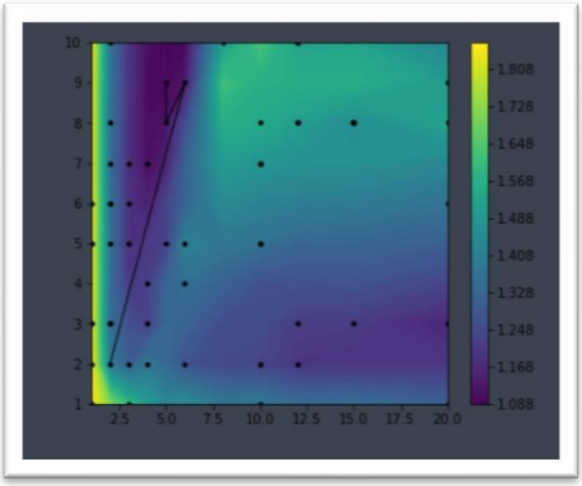

Figure 1Monte carlo simulation

The best and most optimal solution is 6 trains per hour with 10 signalling blocks, but this is not feasible solution as this won't allow smooth transmission of public and will increase the wait time of people. It is not economical to the rail as well. The best possible alternative is to use 20 trains per hour with only 2 blocks as this would allow all the trains to run at their highest speed for maximum time.

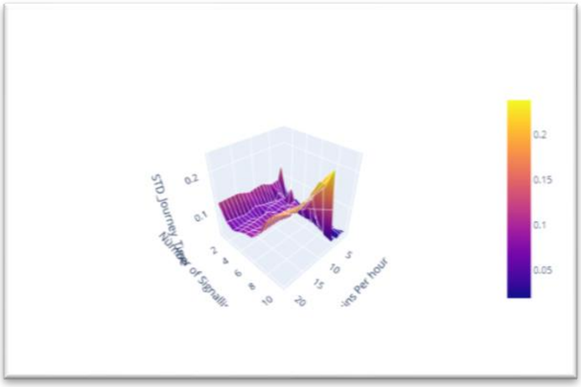

Figure 23D visualization

The 3D optimized model was also studied to reveal the most optimized solution is K= 10 blocks with n=6 trains per hour.

```
env = simpy.Environment()
network=Network(7, 22, 300)
network.trace(line='HS2', start="07:00", stop="22:00")
network.registerIncident(start="09:00", stop="09:35",
                         line='HS2', loc="London Old Oak Common")
env.process(network.process())
env.run()
```

Figure 3 Delay environment simulation

The delay was introduced of half hour and the simulations were repeated to get optimal signaling block and train per hour value. The delay gave 14 blocks as optimal with 4 trains per hour as optimal value.

5. Delay Distribution

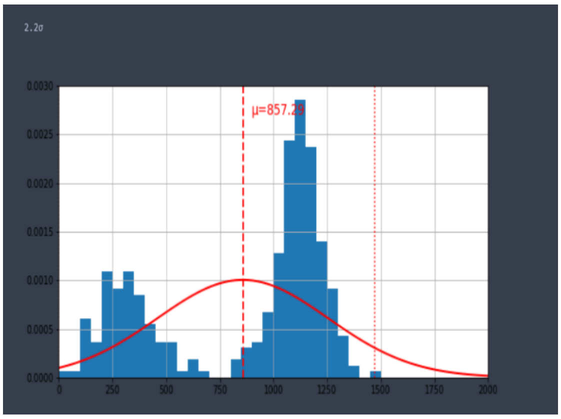

Figure 4 delay distribution

The delay graph has a mean of 857.29 seconds which mean average delay time is 14 minutes and the graph is highly Kurtoses indicating coefficient of kurtosis as negative.

6. Conclusion

The Simulation of train system for London to Birmingham showed that Monte Carlo is the best method to optimize the signaling blocks and train per hour.

- Optimal- 6 trains per hour with 10 blocks
- Most economical- 20 trains per hour with only 2 block allowing maximum speed to be used for larger time.

The delay time distribution was not completely Normal. It showed highly Platykurtic data. The graph also shows average delay of 14 minutes with a standard deviation of 4 minutes. This shows that most of the train showed a delay time of 10 to 18 minutes.

7. Future work

The delay distribution with optimal solution of train and block with improved track conditions should be modelled.

8. References

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