Modelling, Simulation and Optimization

H9MSO

CA1 Report

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***Abstract*— This project has been focused on the simulating and optimizing the HS2 high-speed train route between London and Birmingham. The high-speed line between the London Old Oak and Birmingham Interchange has been taken into consideration. Normal deviation in the drive time in the trains are introduced in order to reflect the real-time operational condition. Initial simulation has been done with the consideration of one hour and observed that 9 trains can travel. And an interruption has been introduced for half-an-hour which resulted that trains has reduced to 6 in the period of time. Optimization part has been done with the help of Monte Carlo technique which resulted that the optimized value for the block count and number of trains is 14 and 9 respectively with the optimum drive time of around 10.6 minutes between the blocks.**

Keywords – HS2 line, Simulation, Delay, Optimization, Monte Carlo.

I. Introduction

The High-Speed lines (HS2) is considered to be the key upgrade in transportation network in United Kingdom. It is also considered to supporting factor for the future growth of the British economy through investment [1]. This development of the high-speed railway lined has between planned into two phases, where the first phase covering the line between London Euston and Birmingham north and interchange which will be connecting the Western Midlands and the second phase extends from north to east of the mainland. This project was involved in developing a simulation and optimization of the blocks and train in the HS2 lines between London Old Oak commons to Birmingham Interchange section which extends for 145 kms which is considered in meters in the research. The research has been conducted with certain conditions, which are mentioned in the subsection below.

A. *Assumptions:*

- First block from the London old oak and Last stop near Birmingham interchange change start has more run time since the time taken by the train for acceleration and deceleration.
- Signal in every block change to red in the presence of train in the block and takes 5 seconds to change to signal from red to green after the train has left the block.
- Number of blocks between the two stations are considered as 10 initially, with equal length between them as mentioned in the description.
- Normal distribution is induced in the drive time of the trains using the probability distribution function in order to replicate the real-time operation of the train.
- Increasing the block count increases the count of trains between the stations and reduced drive time between blocks.
- Incident of 30 minutes delay has been induced in the simulation as delay due to temporary breakdown, for validating the count of train reduced with the interruption in the track.
- The time and distance travelled during optimum deceleration will be double the time the distance travelled to accelerate the train to maximum velocity since the energy involved is half of value needed to accelerate the train to max speed.

II. Implementation

Initializing the project, the values provided in the description of the project were stored in the variable, where the value of acceleration as 0.76 and to reach the maximum velocity of 86.1 m/s (310 km/hr). And the optimum deceleration of the train to stop in the station as 0.38 m/s2 and the sudden deceleration in case of any emergency as 2.5 m/s2 which was utilized in the 30 minute delay in the train caused by temporary break down, which causes the trade-off in the line. The time for accelerating the train to maximum velocity is 113.3 seconds and with the distance of 4878 meters covered during the time of acceleration, since the optimum deceleration of the train is 0.36 m/s2 which is half of the acceleration the following assumption has been made as time and distance covered during optimum deceleration as 226.6 seconds and 9756 meters respectively. Assumptions were made with considering the initial number of blocks as 10 with assumption of atleast one free block between the train in order to keep the safe distance. As per description the distance of 145 kilometers between the two stations has been divided by the number of blocks introduced between them.

A) *Simulation*

The simulation model of the project has been done with the help of SimPy module in python language. And yield statement to provide the resource for the trains to run the track line function.

Objective:

a) To create a simulation of the trains running between the London Old Oak and Birmingham Interchange station, and the count of trains is recorded.
b) Validate the simulation by inducing 30 mins delay at 9.00 a.m. and the record the number of trains simulated.

1. *Preparation of Dataframe for Simulation.*

Initially a dataframe has been created for the simulation with the normal distribution induced in the drive time of the train between the blocks which helps the data to replicate the real-time scenario of the variations in the train travel time due to certain conditions like weather, wind, passenger movement in the stations. The Probability Normal Distribution has been calculated with the values of mean $\mu = 3.378$ with standard deviation of $\sigma = 0.751$ as referred from[2], Fig.1 shows the normal distribution of the drive time attained from the above values, the average drive time obtained is 318.12 seconds with the value of standard deviation of 2.5.

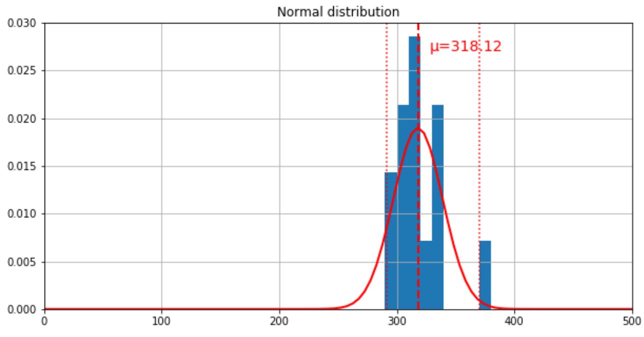

Fig.1 Probability Normal Distribution graph of Drive time.

2. *Development of Simulation model*

The development of the simulation model has been done with keeping the 'NetworkNode' class as base class, which calls the functions such as tracking the position of the train, check the availability of the line and function that induces different delays as incidents for the simulation. Incident handling has been done with the functions to trace the output of the incident, register an incident, check the presence of any incident already in the block and if not inducing the delay in the block.

The 'Depot' class will handle the function to handle the departure of the train from station and checks the availability of the resource before from the introducing the train to the block. The 'Station' class works by calling the information of lines from the Base class, it calls the source and destination of the train, provided the availability of one resource for the train to run. The 'Track' class handles the start and stop time of train, also checking for the delay and calls the network information, line information, and station information. The process function of the Simpy has been overwritten in this class to for the provided yield condition and to check for the resource and to allocate to blocks to the train and makes the resource available once after the train has passed with buffer period of 5 seconds. The function 'allStations' provides the information of source and destination of the particular train travelling between the stations.

The 'Network' class calls the data such as the track details, tracing the position of the train, interruption of delay. This class covers the entire functionality of the network of the line between the two stations. 'Train' class has been initially initiated with no trains and furthers the calls the details of the track, position details of the train and the track. This class works to provide the resource information for the train to travel on the blocks and the allocation of the resource for one particular train at an instance. This function takes care of changing the signal of the block by changing the signal to Red on the presence of the train and changing the signal from Red to Green after the train leaving the block with 5 seconds delay as buffer.

Helper class 'Incident' and functions such as 'timeTo', 'daytime' and 'parseTime' has been utilized in the project. 'timeTo' function which provides the value of the time taken by the train to accelerate and deceleration of the train at different point to instances. 'Incident' class helps to induce the start and stop time of the incident to the Incident handling function. 'parseTime' helps in the conversion of the time values entered in the experiment into suitable metrics. 'daytime' function helps to call the current time of the instance whenever it is called.

3. *Execution of Simulation Model*

Initially the environment for the simulation has been assigned for the period of one hour considering it between 9.00 a.m. to 10.00 a.m., and the simulation has been created with the help of the trace function from the network class, with the distributed variation in the drive time provided in the dataframe. And the result has been observed that maximum 9 trains can accommodate in the environment in the considered time. As shown in the Fig.2.

```
09:57:34 HS2 [Train 7 ] arr Block2
09:57:34 Block2 Signal Turns Red
09:57:34 HS2 [Train 3 ] dep Block7 for Block8
09:57:39 HS2 [Train 7 ] dep Block2 for Block3
09:57:39 Block7 Signal Turns Green
09:57:44 Block2 Signal Turns Green
09:58:48 HS2 [Train 8 ] arr Block1
09:58:48 Block1 Signal Turns Red
09:58:53 HS2 [Train 8 ] dep Block1 for Block2
09:58:56 HS2 [Train 4 ] arr Block6
09:58:56 Block6 Signal Turns Red
09:58:58 Block1 Signal Turns Green
09:59:01 HS2 [Train 4 ] dep Block6 for Block7
09:59:06 Block6 Signal Turns Green
09:59:41 HS2 [Train 5 ] arr Block5
09:59:41 Block5 Signal Turns Red
09:59:46 HS2 [Train 5 ] dep Block5 for Block6
09:59:51 Block5 Signal Turns Green
Max Trains 9
```

Fig.2 Simulation of number the trains without any temporary breakdown involved.

4. *Validation of Simulation*

Post the initial simulation, in order to validate the simulation of train between 9.00 a.m. to 10.00 a.m., a delay for 30 minutes has been introduced in the simulation environment, as that it occurs between 9.00 a.m. to 9.30 a.m. due to the temporary break down due to electrical malfunction, 30 minutes to fix the problem. This simulation has resulted that the 6 trains that can be added to the track with the temporary delay of 30 minutes as shown in Fig.3. And the Fig.4 shows the delay occurred at the Block 1 due to breakdown for 30 mins between 9.00 a.m. to 9.30 a.m.

```
09:57:24 Block5 Signal Turns Green
09:58:46 HS2 [Train 2 ] arr Block4
09:58:46 Block4 Signal Turns Red
09:58:51 HS2 [Train 2 ] dep Block4 for Block5
09:58:56 Block4 Signal Turns Green
Max Trains 6
```

Fig.3 Simulation of number the trains with any temporary breakdown of 30 minutes involved.

```
09:00:25 London Old Oak Signal Turns Red
09:00:30 HS2 [Train 0 ] dep London Old Oak for Block1
09:00:35 London Old Oak Signal Turns Green
09:05:55 HS2 [Train 0 ] arr Block1
09:05:55 Block1 Signal Turns Red
09:05:55 HS2 [Train 0 ] inc Block1 ######Temporary Delay due to Electical Malfunction### Expected delay for: 00:24:04
09:30:00 HS2 [Train 0 ] inc Block1 ####Delay Cleared after the Repairing the Malfunction########
09:30:05 HS2 [Train 0 ] dep Block1 for Block2
09:30:10 Block1 Signal Turns Green
09:30:10 HS2 [Train 1 ] dep London Old Oak (DEPOT) for London Old Oak
09:30:30 HS2 [Train 1 ] arr London Old Oak
09:30:30 London Old Oak Signal Turns Red
09:30:35 HS2 [Train 1 ] dep London Old Oak for Block1
09:30:40 London Old Oak Signal Turns Green
```

Fig.3 Simulation showing the delay in train route that occurred due to temporary breakdown.

B) *Optimization*

Objective:

a) To optimize the number of blocks and number of trains running between the London Old Oak station and Birmingham station.

b) To simulate a schedule using the optimum number of blocks, between the period 7.00 a.m. to 10.00 p.m., provided a delay of 30 minutes introduced in the schedule at 9.00 a.m.

1. *Preparation of Dataframe for Optimization*

For performing the optimization part of this report initially an a dataframe has been created with the increase in number of blocks with the resulting number of the trains that can be added to run the network for one hour and their drivetime with operational delay induced in it by normal distribution which was calculated with the values of mean $\mu = 3.378$ and standard deviation $\sigma = 0.751$.

2. *Optimization using Monte Carlo*

With the help of Linear Regression function from the sklearn.linear_model package in python, the Number of blocks and Maximum number of trains has been provided as the independent variables to the function and respective drive time as dependent variable. The coefficients for the objective equation have been derived which is as provided below

Objective Equation:

48.09 (Number_of_block) -119.4(Max_Trains) + 1137.67= Drive_time

Providing the above equation to the Monte Carlo function with the bound values set for the Maximum trains as 1 to 12 and the bounds for the number of blocks as 12 to 18. The Monte Carlo function has resulted that the optimum value of number of blocks to be 14 and optimum number of trains that can run in one hour as 9 and optimum drive time for the trains 636.24 seconds (i.e. 10.6 minutes) as shown in the Fig. 4.

(2, 14, 9, 636.24)

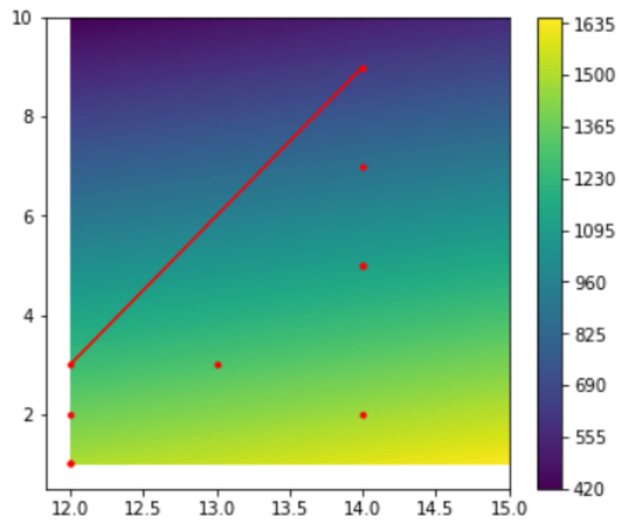

Fig.4 Result of the Monte Carlo Optimization.

3. Simulation of the schedule using the optimized value

From the optimum values of the blocks count and the maximum number of trains, the simulation of the train schedule starting from the 7 a.m. to 10 p.m. has been simulated which has the temporary delay occurring in the Block 1 at 9.00 a.m. to 9.30 a.m. which cause the trade-off on the trains in the before blocks and to wait until it gets cleared, but the trains which has already passed the Block_1 before the interruption delay running across the blocks continuous. After the end of the delay the Train which has been struck at the Block_1 will move and gradually causing the trains which are lined-up behind will start to travel. As per the schedule simulated there will be 210 trains running between the London Old Oak and Birmingham Interchange station between the time 7 a.m. to 10 p.m., as shown in Fig.7

```
09:02:29 HS2 [Train 13 ] arr Block10
09:02:29 Block10 Signal Turns Red
09:02:32 HS2 [Train 22 ] arr Block1
09:02:32 Block1 Signal Turns Red
09:02:32 HS2 [Train 22 ] inc Block1 expected delay 00:27:27
09:02:33 HS2 [Train 20 ] arr Block3
09:02:33 Block3 Signal Turns Red
09:02:34 HS2 [Train 13 ] dep Block10 for Block11
09:02:34 HS2 [Train 17 ] arr Block6
09:02:34 Block6 Signal Turns Red
09:02:39 Block10 Signal Turns Green
09:02:44 HS2 [Train 14 ] dep Block9 for Block10
```

Fig.5 Temporary delay induced in the schedule.

```
09:29:05 HS2 [Train 15 ] arr Block13
09:29:05 Block13 Signal Turns Red
09:29:10 HS2 [Train 15 ] dep Block13 for Block14
09:29:15 Block13 Signal Turns Green
09:30:00 HS2 [Train 22 ] inc Block1 incident cleared
09:30:05 HS2 [Train 22 ] dep Block1 for Block2
09:30:07 HS2 [Train 16 ] arr Block12
09:30:07 Block12 Signal Turns Red
09:30:10 Block1 Signal Turns Green
09:30:12 HS2 [Train 16 ] dep Block12 for Block13
09:30:15 HS2 [Train 23 ] dep  London Old Oak for Block1
```

Fig. 6 Train start to move to next block after the ending the temporary delay.

```
21:59:23 Block9 Signal Turns Red
21:59:43 HS2 [Train 145 ] arr Block8
21:59:43 Block8 Signal Turns Red
21:59:54 HS2 [Train 146 ] arr Block7
21:59:54 Block7 Signal Turns Red
Max Trains that can travel between 7am to 10pm with an incident happended due to tem
porary breakdown 210
```

Fig.7 Maximum number trains added in the schedule.

III. Interpretation and Result

From the experiment conducted on the simulation and optimization of number of trains running in HS2 line between London Old Oak station and Birmingham Interchange station, the following insights has been obtained,

- Without the any delay caused in the line, the HS2 line between the London Old Oak to Birmingham Interchange can accumulate maximum count of 9 trains in the one hour.
- The number of trains reduce by count of 3, when there is a delay of 30 minutes occurred due to temporary malfunction, which causes maximum 6 trains accumulating the line in one hour.
- The optimum value of number of trains that can run in one hour between the considered stations is 9 (n) with the optimum blocks of 14 (k), and the optimum drive time of the trains is obtained as 636.24 seconds.
- Considering the optimum value of the blocks (k) between the two stations and a temporary delay of 30 minutes occurring at 9.00 a.m. the number of trains that can be scheduled between the time 7.00 a.m. and 10.00 p.m. is 210 trains.

IV. Reference

[1] D. for Transport, “Management Case for High Speed 2.”

[2] Y. Yang, P. Huang, Q. Peng, J. Li, and C. Wen, “Statistical delay distribution analysis on high-speed railway trains,” *J. Mod. Transp.*, vol. 27, no. 3, pp. 188–197, Sep. 2019, doi: 10.1007/s40534-019-0188-z.