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Project Submission Sheet – 2019/2020

School of Computing

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High-Speed Train Simulation and Optimization for United Kingdom's HS2 Line

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***Abstract*— Many improvements have taken place in recent years in key railroad operations, including railroad interchange that comprises reformation of railways with high-speed lines. So to make this reorganization that allows the building of high-speed trains on the conventional railway roads. These changes are made by using the modelling, simulation and optimization techniques. In this paper, a progressive approach is implemented on United Kingdoms High Speed Two (HS2) project to find the optimal maximum number of trains that can travel in every hour and also include few delay constraints between the London Old Common and Birmingham Interchange Station. This simulated design can result in the average travel time for a train to complete a journey, the average speed of a train and optimal average trains that can travel in a given hour.**

Keywords*— Modelling, Optimizations, Simulations, conventional railways, High-speed rail

I. Introduction

The inspiration for this project is based on the fact that railways are a key contributing factor to the country's economic growth throughout history [1]. Present times, railway transport is quite a solution for carbon dioxide emission and climate changes. The improved high-speed railways is a solution for many challenges like speed control, delay period, human factor and data communication.

Researchers have developed many optimized models to increase the potential of railway systems and interchange between the conventional railways and high-speed railways. These developed technologies also offer solutions for train delays, mixed traffic and different types of disturbances.

The motivation behind this paper is to create an optimized simulated model for the United Kingdoms HS2 railway network [2]. This project will provide double the economic benefit of which used to build it and also increases the performance of transport through railways.

The proposed simulated model answers the following aspects like engine breakdown, accidents, infrastructure failure, unpredicted weather conditions and accidents. These factors are significantly small disruptions in a system however these factors have a significant impact on the whole working system.

There are many studies conducted such as [3], [4] and [5] which proposes simulated models based on disruptions, passenger lag onboarding, station blocks, signal blocks and train speed. On bases of these factors, we developed a considerable powerful simulation model which answers all the problematic factors.

Enormous compilation of the recommended model solves any kind of scheduling problem under any enormous disruptions.

II. Objective

The main objective of this project is to implement a simulation and optimization model for the UK HS2 railway network. Objectives for simulation and optimization are as follows:

1) *Simulation Objectives*

To create a simulation for London Old Oak Commons to Birmingham Interchange section under the following assumptions:

- Distance between the London Old Common Station and Birmingham Interchange Station is 145 Km.
- A fixed train schedule should be defined which should have a fixed number of trains per hour.
- Fixed number of signalling blocks and train blocks needed to be defined before starting of train.
- Temporary break down due to electrical malfunction for 9 am train from London to Birmingham with 30 minutes of breakdown.
- Introduction of various conditional parameters like weather events, departure delays due to passengers.

2) *Optmisation Objective*

The main objectives of optimization are to maximise the overall average travelling time of train based on the following constraint:

- A train schedule that has arrival and departure and arrival time with the first train leaving at 7 AM and the last train schedules to leave at 10 PM.

III. Implementation

1) *Background*

The proposed project is about simulation and optimization of trains travelling from London to Birmingham on the HS2 line. Initially, the simulation of train class is created that starts from London and ends at Birmingham, included the parameters like 14 signalling blocks and a minimum of nine trains per hour. Next, in the optimization section, the number of trains running per hour is maximized by using creating a class and the optimization technique used here is Monte Carlo optimization.

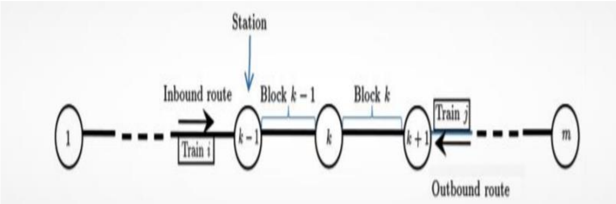

Figure 1 Block diagram

Figure 1 illustrates the infrastructure of a train that tells about how the simulation of the train is working like how many train blocks and signalling are getting added up and the time delay between each train.

2) *Data Processing*

As part of the data processing stage, I created a list of variables like distance, running time, block time and dwell time. All these lists are converted into a data frame then the units of the variables like meters are converted into kilometres and the hours are converted into seconds respectively. Table 1 is the resulted data frame after converting all the variables.

From	**To**	**Distance**	**Run Time**	**Blocks**	**Acc**	**Vel**
London Euston	Old Oak	1000	240	300	0.694	83.33
Old Oak Common	Interchange	14500	1920	204	0.15	151.04
Interchange	Curzon Street	12000	300	270	0.53	80

After the conversion of variables, the acceleration and velocity are derived from the running time and distance variables by using the appropriate formulas on it.

3) *Simulation Methodology*

The simulation of HS2 is performed between two stations on bases of their velocity and speed. There are of a total of fourteen signalling blocks that are considered between two stations. There are many user-defined classes to create the simulation of a train between two stations.

```
Train 1 leaves London Euston at 00:00:00
Train 1 arrives in London Old Oak Common at 00:05:00
Train 1 leaves London Old Oak Common at 00:07:10
Train 1 enters signalling block 1 at 00:07:10
Train 2 leaves London Euston at 00:10:00
Train 2 arrives in London Old Oak Common at 00:15:00
Train 1 reaches end of signalling block 1 at 00:15:21
Train 1 enters signalling block 2 at 00:15:21
Train 2 leaves London Old Oak Common at 00:17:54
Train 2 enters signalling block 1 at 00:17:54
Train 3 leaves London Euston at 00:20:00
Train 1 reaches end of signalling block 2 at 00:23:42
Train 1 enters signalling block 3 at 00:23:42
Train 3 arrives in London Old Oak Common at 00:24:59
Train 2 reaches end of signalling block 1 at 00:27:29
Train 2 enters signalling block 2 at 00:27:29
Train 1 reaches end of signalling block 3 at 00:30:27
Train 1 enters signalling block 4 at 00:30:27
```

Figure 2 Train Simulation with all constraints

The overview of simulation tells about the number of trains running per hour and to creates an overall structure of the problem.

Figure 2 shows a simulation of trains that leaves from 9 am to 6 pm, it has a total of three signalling blocks and all the blocks are of equal length.

	No_Blocks	Train_No	Departure_Time	Arrival_Time	Journey_Time	Day	Trains_PH	Delay	Train_Time_Interval
0	3.0	1.0	00:00:00	00:55:47	0:55:47	1.0	6.0	0:04:51	10.0
1	3.0	2.0	00:10:00	01:13:26	1:03:26	1.0	6.0	0:12:30	10.0
2	3.0	3.0	00:23:20	01:29:17	1:05:57	1.0	6.0	0:15:01	10.0
3	3.0	4.0	00:35:23	01:46:49	1:11:26	1.0	6.0	0:20:30	10.0
4	3.0	5.0	00:48:51	02:00:29	1:11:38	1.0	6.0	0:20:42	10.0
...	...	...	...	...	...	...	...	...	...
294	4.0	79.0	16:43:19	18:00:30	1:17:11	1.0	6.0	0:26:15	10.0
295	4.0	80.0	16:57:34	18:11:52	1:14:18	1.0	6.0	0:23:22	10.0
296	4.0	81.0	17:10:15	18:23:00	1:12:45	1.0	6.0	0:21:49	10.0
297	4.0	82.0	17:22:49	18:36:37	1:13:48	1.0	6.0	0:22:52	10.0
298	4.0	83.0	17:37:01	18:50:01	1:13:00	1.0	6.0	0:22:04	10.0

299 rows × 9 columns

Figure 3 Dataframe with all simulated constraints

Figure 3 illustrates the concatenating of all the simulation of different trains and extracting the information about arrival time, journey time, trains per hour and delay.

Finally, the average of blocks, travel time, trains per hour and delay time have calculated and the results are shown in Figure 3.

	Trains_PH	No_Blocks	Train_Time_Interval	AVG_Delay_Time
0	6.0	2.0	10.0	1148.660377
1	6.0	3.0	10.0	1131.056338
2	6.0	4.0	10.0	1361.457831
3	6.0	5.0	10.0	1647.206522

Figure 4 overall averages

4) *Optimisation Methodology*

In the optimization phase, initially, the linear regression is applied to produce the coefficients like the number of trains, blocks and constants.

OLS Regression Results

Dep. Variable:	AVG_Delay_Time	**R-squared:**	0.972
Model:	OLS	**Adj. R-squared:**	0.915
Method:	Least Squares	**F-statistic:**	17.25
Date:	Thu, 27 Aug 2020	**Prob (F-statistic):**	0.168
Time:	21:53:08	**Log-Likelihood:**	-23.848
No. Observations:	4	**AIC:**	53.70
Df Residuals:	1	**BIC:**	51.85
Df Model:	2		
Covariance Type:	nonrobust		

	coef	**std err**	**t**	**P>|t|**	**[0.025**	**0.975]**
const	407.4540	325.436	1.252	0.429	-3727.599	4542.507
No_Blocks	-160.7072	86.693	-1.854	0.315	-1262.246	940.832
Trains_PH	207.3227	35.392	5.858	0.108	-242.379	657.024

Omnibus:	nan	**Durbin-Watson:**	2.348
Prob(Omnibus):	nan	**Jarque-Bera (JB):**	0.542
Skew:	0.717	**Prob(JB):**	0.763
Kurtosis:	1.905	**Cond. No.**	23.6

Figure 5 Summary of linear regression

Figure 5 is about the summary result of ordinary least square regression, it has a covariance matrix that has a standard error which is correctly mentioned. The obtained coefficients from the linear regression are applied in Monte Carlo Optimisation to find the maximum number of trains running per hour.

After running the Monte Carlo optimization simultaneously for many times it's concluded that with random.seed of 31 and Monte Carlo function with 100 blocks it has resulted that 9 blocks between the stations and optimal maximum number of trains are 11 with a maximum speed of 614 seconds and these results are shown in figure 6.

```
random.seed(31)
monte_carlo(100)
```

```
(2, 11, 9, 614.2646)
```

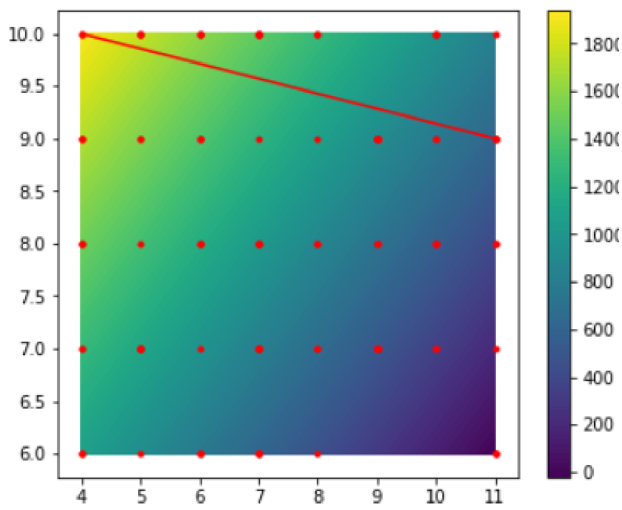

Figure 6 Monto Carlo Optimisation

From the optimized model evaluation, it has shown that the maximum number of trains that can travel per hour is about six trains and with a total of thirteen signalling blocks between the trains.

IV. Conclusion

This projects designed to run a simulation of HS2 railway network i.e. from London Euston to Birmingham Interchange Cruzon. The simulation is able to satisfy the constraints like delay due to incident during the day and the average of time travel, delay time and trains per hours are calculated and concatenated in form of a dataframe. The Monto Carlo optimization has shown maximum of 11 trains can travel per hour.

V. References

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