Modelling, Simulation and Optimisation for the London Old Oak Commons to Birmingham Interchange section of the high-speed line.

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***Abstract*—The paper aims to show a model for the railway traffic that consists of train arrivals and departures between London Old Oak Station and Birmingham Station and also the train movement at different intersections. This is a perfect illustration of a hybrid system for which initially the existing model of London underground is compared and the needs of the model for this problem scenario are identified. The model proposed is utilized to simulate an experimental setup with the traffic based on the Train schedule and trains movement in the stations to analyse whether it can work without any conflicts, impacts of delay on trains. With this, we can determine the schedule of the train, their waiting times and running times. The elements of results have been discussed thoroughly and simulation results are presented with the programs output of train traffic. In the end, the optimization formulation is shown to arrive at an optimum schedule.**

***Index Terms*—Hybrid systems, Railway traffic, Train movement.**

I. Introduction

In the research community, it is common that the study of discrete and continuous systems have been going on from decades. However, the study of the hybrid system that comprises of both discrete and continuous parts is always not straightforward from the perspective of finding the right model for a quick adaptation. Each of the models would have certain strengths and drawback considering different classes of problems.

Railway traffic consists of train arrivals and departures at London Old Oak Station and Birmingham Stations. This is a good example of a hybrid system that has been considered in the work of this paper. The train traffic is considered a discrete part while the passenger flow is considered as continuous but the other school of thought is that it can be considered as ‘discrete-continuous’. The model describes the theory and mathematical parts that were developed to build up the analysis. Different classical typologies of the system are also explained. The simulation is performed using python on Jupyter Notebook for a reference scenario and the simulation results and the interpretations are described. The paper is unique in the sense that we attempt to address both the train traffic and passenger traffic using the Origin-Destination (O-D) matrix that considers all the platforms of the system [**?**].

II. SYSTEM AND PROBLEM DESCRIPTION:

The system that considered in this study is a single railway line with platforms and stations that may be any one of the topology. Below are the definitions that are referred to in the paper:

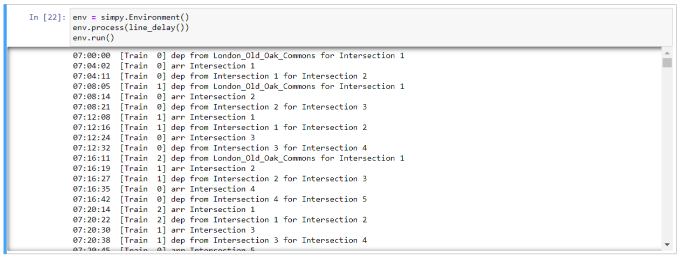
- Starting Station: The London Old Oak Station is starting station and from this place all trains will depart from 7.00 am till 10.00 pm.
- Ending Station: The Birmingham Station is a end point and from this place all trains will arrive from 7.00 am till 10.00 pm.
- Track: In this study only one track is used from London to Birmingham that represents a single path for all train for their movement.
- Intersections: There are 13 intersections considered in this sutdy.

A. Problem Defination:

The simulation model will need to have the following inputs structurally: 1) Schedule of the trains leaving from the London Old Oak Station including the frequency of train and Delays. 2) Distance between the intersections. 3) Dwell time in each station. 4) train arrivals in each station using origin-destination matrices and this is for every station in the system.

III. Simulation:

NAs we know simulation is a framework that allows us to model real-world systems and processes. It is a very popular tool that has been applied in multiple domains simulations are typically characterized by repeated random sampling which means that using the power of random variables to generate multiple outcomes. In this study, a simulation pattern is developed of trains departing from London Old Oak Station and arriving at Birmghimgam Interchange. Here simulations are used solve pretty complex problems simulations perform particularly well in some areas where traditional methods don’t give us a clean solution simulation typically involves the following steps one define the set of outcomes associated with a random variable to assign a probability to each of these



```
In [22]: env = simpy.Environment()
         env.process(line_delay())
         env.run()

07:00:00  [Train  0] dep from London_Old_Oak_Commons for Intersection 1
07:04:02  [Train  0] arr Intersection 1
07:04:11  [Train  0] dep from Intersection 1 for Intersection 2
07:08:05  [Train  1] dep from London_Old_Oak_Commons for Intersection 1
07:08:14  [Train  0] arr Intersection 2
07:08:21  [Train  0] dep from Intersection 2 for Intersection 3
07:12:08  [Train  1] arr Intersection 1
07:12:16  [Train  1] dep from Intersection 1 for Intersection 2
07:12:24  [Train  0] arr Intersection 3
07:12:32  [Train  0] dep from Intersection 3 for Intersection 4
07:16:11  [Train  2] dep from London_Old_Oak_Commons for Intersection 1
07:16:19  [Train  1] arr Intersection 2
07:16:27  [Train  1] dep from Intersection 2 for Intersection 3
07:16:35  [Train  0] arr Intersection 4
07:16:42  [Train  0] dep from Intersection 4 for Intersection 5
07:20:14  [Train  2] arr Intersection 1
07:20:22  [Train  2] dep from Intersection 1 for Intersection 2
07:20:30  [Train  1] arr Intersection 3
07:20:38  [Train  1] dep from Intersection 3 for Intersection 4
```

Fig. 1. An Overview of simulation output with 30 min delay

```
delay_bw_trains = free_signals*np.max(actual_traveling_time)

n[i] = (last_train_time - first_train_time)/delay_bw_trains
n[i] = n[i].astype(int)
print("n =",n[i], "\n")

k = 2
t = 1928.2834234555207
n = 1.0

k = 3
t = 2047.5776270502997
n = 2.0

k = 4
t = 2170.773143863228
n = 3.0

k = 5
t = 2293.5731305789886
n = 3.0

k = 6
t = 2416.311761267856
n = 4.0

k = 7
t = 2537.5186243529997
n = 4.0
```

Fig. 2. An Overview of optimisation output

outcomes the probability distribution three define the relationship between multiple random variables. The simulation part will be explained in the parts as follow:

1) Part 1: Importing necessary python libraries in Jupyter Notebook for various operations.
2) Part 2: Defining different variables name as mentioned in the question and assuming a constant number for k which is 13.
3) Part 3: To create a CSV file, few columns are assumed and stored in Dataframe such as Starting point, Ending point, Pause time, Distance between the intersection and travelling time.
4) Part 4: Here simulation environment is built using classes and function.
5) Part 5: Here simulation environment is run.
6) Part 6: As mentioned in the question we are introducing 30 min delay.

Assumptions and scope considered for the system for modelling and simulation are as follows:

1) 1) The railway lines from London Old Oak Station to Birmingham station are unidirectional and considered for a mass transit railway for local transport.
2) 2) The distance between two stations is fixed which is 14500 m
3) 3) The time required to go from one station to another is the same for all stations.

Simulation output provides all the output matrices needed using which any kind of Graphic output can be presented but we provide the most essential graphical plots that are needed for analysis.

IV. Optimisation:

After modelling the Railway and train traffic, it has been an interest in the research to work on optimization of the Train schedule in the railway network. This is not new in the field of transportation and operational research but the work is normally different considering different applications and systems. This section formulates a mathematical model for the optimization and works upon the algorithm needed to perform the same. An attempt is made to keep this section to be independent for the interested readers so that they could understand the case without reading the earlier sections. Here in this study, optimisation techniques are considered to find out the maximum number of trains travelling through London Old Oak Station till Birmingham in an hour. The Optimisation part will be explained in the parts as follow:

1) Part 1: Importing necessary python libraries in Jupyter Notebook for various operations.
2) Part 2: Defining the range of the number of signals
3) Part 3: Running the simulation for all the above-defined values of the number of signals and calculating the corresponding Actual Traveling time and the number of trains operating per hour.
4) Part 4: Creating a Pandas DataFrame from the values in the output
5) Part 5: Saving the DataFrame as a CSV file

The train waiting time in each platform, travel duration between platforms etc. is considered fixed and will remain unchanged. The train cannot leave the current station as long as there is a train in the next station that is the next immediate destination. This is to ensure that there is a sufficient headway time for safety but it is considered as part of modelling and control and may not be too important for optimization as the passengers would have boarded the train. The timetables exist on the networks that consist of multiple track main lines in each direction with trains running in the same speed and there is no need to consider conflicts of different kind of trains running on line.

V. Results:

From the given simulation and optimisation output, it can be observed that the optimal value of 'n' (maximising 'n') is when k=13 and t=3266.589533.

VI. Conclusion:

This paper is an attempt to give a framework for modelling and simulation of different topologies of metro single unidirectional lines. It also shows different mathematical equations and matrices that are used for the model. The simulation enables the user to provide O-D matrix for each station, different flow rates and enable the plots to visualize different parameters for timetabling. The paper at the end discusses the possibilities of optimisation using the trade-off for the trains running on the line and the passenger waiting time with both cyclic and non-cyclic time tables. The future work is to include the model for the spatial distribution of passengers in stations, include trackside elements for modelling and enhance simulation framework to make it more generic for any system.

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