MSc/PGDip Data Analytics

Modelling, Simulation and Optimisation (H9MSO)

Project

DEADLINE: 23:59 on 26 April 2020
WEIGHT: 60% of overall marks
COURSE: MSc / PGDip in Data Analytics

The Context

A high-speed train as planned for the HS2 line from London to Birmingham has an acceleration of $0.72m/s^2$, about the same as a commuter train. While the trains can brake in an emergency at $2.5m/s^2$, the energy optimal deceleration (using regenerative braking) is $0.36m/s^2$.

The maximum travelling speed of the train is about 300km/h (83.3m/s). Accelerating from 0 to the maximum speed takes therefore 115.7s during which time the train travels about 4,820m. Slow decelerating takes 231.4s and the distance travelled is 9,640m.

A railway line consists of a sequence of signaling blocks. A train is only allowed to enter a block, when there is no other train in the block and the entry signal is green. When a train enters a block the entry signal switches to red. The entrance signal switches back to green 5 seconds after the end of the train has left the block.

Depending on the intended maximum traveling speed there is an optimal distance for setting a pre-signal. At a maximum travelling speed of the train of 300km/h (83.3m/s) the slow deceleration takes 231.4s and the train travels 9,640m during this time. In this case the pre-signal would be 10km before the actual signal at the end of one block and the entry to the next. The length of a block should therefore be at least 10km, but to allow a train to achieve and run as long as possible at full speed, the block length should be at least 1.5x this length. The control problem is to keep the trains moving at maximum possible speed. If there is a slight delay in one train it may cause the train in the following block to decelerate, potentially down to a stop, and then to reaccelerate. This in turn will delay the train thereafter. Just like the “traffic jam” effect you know from the motorway. A train can run constantly at full speed if there is always at least one free block ahead. With a block length of 15km that means that the distance between two trains should be about 30km, at full speed a travelling time of about 6min. This would indicate that one could achieve a maximum schedule of 10 trains per hour. The new government under Boris Johnson is pushing the development of HS2. The economic argument is based on a schedule time of 9 trains per hour.

Part 1: Simulation

Create a simulation for the London-Birmingham section of the high-speed line under assumption of a number k of signalling blocks. A decision on the number of signaling blocks is required, as the track laying is supposed to start soon. Also a decision on the number of trains running per hour has to be made.

Depending on the number of signalling blocks simulate the throughput of trains.
Take into account that between Birmingham Interchange and Birmingham Curzon street as well as between London Old Oak Common and London Euston there will be a practical speed limit and the traveling times are 5 min between London Euston and London Old Oak Common (one signalling block) and 9 min between Birhigham Interchange and Birmingham Curzon Street station (two signalling blocks). Take into account the variability of achievable speeds due to wind and weather conditions on the stretch between London Old Oak Common and Birmingham Interchange. Take into account the variability in stop times, i.e. minor delays due to passenger movements.

London Euston
    5 min
London Old Oak Common
    31 min
Birmingham Interchange
    9 min
Birmingham Curzon Street

The distance between London Old Oak Common Station and Birmingham Interchange Station is 145km. This could be broken down in up-to 14 blocks. If there are less but longer blocks the trains could achieve in theory a higher average speed, however the throughput in trains per hour is smaller.

Part 2: Optimisation

For the project you need to create a simulation of the train network which would give for a given train schedule (numbers of trains per hour $n \in \{1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20\}$) and a given break-down of the line in signalling blocks $k \in \{1, ..., 15\}$ a distribution of average overall travelling time. The simulation results are fed into an optimisation problem to determine (n_{opt}, k_{opt}) to achieve an optimal results.

Using the simulation described above solve the following optimisation problems:

(1) **Minimise the overall average traveling time.**
The overall traveling time consist of the waiting time for the next train and the actual traveling time until arrival of the train. The problem can be simplified by assuming a fixed average waiting time ($0.5*60/n$).

(2) **Maximise the throughput of passengers in peak hours.**
The trains can be configured to run at a length of 200m (short train, 420 passengers)

or 300m (max train, 630 passengers). While longer trains carry potentially more passengers, you need to consider the walking times at the train station. The walking speed of a train passenger carrying luggage is between 1.0 and 1.2m/s, which impacts on the stop times at the station. Also more passengers disembarking and embarking may lengthen the stop times.

For a more realistic simulation assume a Poisson-Distribution for passengers arriving at the train station at an average rate of m passengers per hour and how they can be served by n trains per hour. As the trains are on a tight schedule, we cannot assume that everyone gets on board during the short stopping time. Assume that the trains are only filled to 70% of nominal capacity. A backlog of passengers on the departing station will impact on the average travelling time.

Project Report:

Your report should be in the form of a well-formatted Jupyter Notebook. Use section headings as appropriate. References should comprise of a complete list of academic works and/or online materials used in the project and should be in the IEEE citation style.

Grade Criterion	Solid H1 > 80%	H1 > 70%	H2.1 > 60%	H2.2 > 50%	PASS > 40%	FAIL < 40%
Basic Structure (10%)	All elements of project requirements have been thoroughly addressed.	All elements of the project requirements have been thoroughly addressed.	Some minor requirements missing from project.	Multiple omissions from the project.	Major parts of the project are missing.	The solution bears no resemblance to the project requirements at all.
Simulation (25%)	An excellent, thorough simulation was carried out. There is a very high level of interactivity present in the simulation model. Effort exceeds the requirements of the module.	An excellent, fully complete simulation was carried out. There is a high level of interactivity present in the simulation model.	A very good and largely complete simulation was carried out. There is a good level of interactivity present in the simulation model.	A good and largely complete simulation was carried out. Some interactivity is present in the simulation model.	An adequate simulation was carried out. There is very little interactivity present in the simulation model.	Little or no simulation carried out.
Optimisation (25%)	Elegant formulations of the optimisation problems. Objective function is correct, and maximum or minimum value is correct. Variables and constraints are fully correct and justified. A variety of solution approaches, including linear programming, metaheuristics and/or genetic algorithms, are included. Effort exceeds the requirements of the module.	Objective function is correct, and maximum or minimum value is correct. Variables and constraints are fully correct and justified. A mix of solution approaches, including linear programming, metaheuristics and/or genetic algorithms, are included.	Objective function is correct, and maximum or minimum value is correct. Variables and constraints are correct and justified. Varied solution approaches are considered.	Objective function, variables and constraints have slight errors. Only one solution approach is used	Some logical errors exist in the objective function, variables and constraints. Only one solution approach is used	No objective function present. No variables or constraints.
Code Format/Style (20%)	Code is fully commented. There are no syntax or logic errors, and no excess code used. The implementation significantly exceeds the module requirements	Code is fully commented. There are no syntax or logic errors, and no excess code used.	Code is partially commented. There are few syntax or logic errors, and a minimal amount of excess code used.	Code is partially commented. There are several syntax or logic errors, and use of excess code.	Code is poorly commented. There are many syntax or logic errors, and excess use of unnecessary code.	Code is barely commented. There are many syntax or logic errors, and excess use of much unnecessary code.
Evaluation & Results (10%)	Models are completely and thoroughly evaluated. Results are presented and thoroughly discussed.	Models are fully evaluated. Results are presented and thoroughly discussed. There is significant reflection on the challenges faced in this project.	Models are evaluated. Results are presented and thoroughly discussed. There is very good reflection on the challenges faced in this project.	Models and results are presented and appropriately discussed. There is good reflection on the challenges faced in this project.	Cursory evaluation of models. Cursory discussion of results. There is some reflection on the challenges faced in this project.	Little to no evaluation of model. Little to no discussion of results. There is no reflection on the challenges faced in this project

	There is significant reflection on the challenges faced in this project.					
Quality of Writing (10%)	Very well written, with no language errors. All figures are well conceived and read-able. Report is sufficiently detailed. References are appropriately and correctly used.	Well written, with no (large) language errors. All figures are well conceived and read-able. Report is sufficiently detailed. References are appropriately and correctly used.	Main document has a few language and/or style errors. Figures are well presented. Report is sufficiently detailed. References are complete, and correctly used.	Main document has a few language and/or style errors. Some figures are may be hard to read. Report has adequate detail. References are complete, and correctly used.	Main document is readable with some language and/or style errors. Figures may be hard to read or presented in a suboptimal manner. Report is scant on detail. References are mostly complete and correctly used.	Littered with typos, and/or poor use of English. Poor report with very little content/detail. Figures may be hard to read. References (if any) are probably incomplete.