# MSc/PGDip Data Analytics

# Modelling, Simulation and Optimisation (H9MSO)

# Project

**DEADLINE:** 23rd August 2020
**WEIGHT:** 60% of overall marks

## The Context:

A high-speed train as planned for the HS2 line from London to Birmingham has a maximum acceleration of $0.76m/s^2$, 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 $0.38m/s^2$.
The maximum travelling speed of the train is about 310km/h (86.1m/s). For the purpose of this project we will ignore the impact of air resistance. That means we assume a constant acceleration up to maximum speed. Accelerating from 0 to the maximum speed takes therefore 113.3s during which time the train travels about 4,878m.
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.
We assume for the purpose of this project that the signalling blocks have all equal length. Depending on the speed of a train it requires a number of free blocks ahead of it, to maintain the current speed. This speed is determined so that the train is guaranteed to stop safely before a red signal.
This results in a trade-off. When the speed of the train is slower, it is possible to have more trains on the track, as there are less free blocks required between the trains. The faster a train the more free blocks are required in front of the train to continue maintaining the high speed.
Given a number of blocks along a track there will be an optimal point for the number of trains per hour that could be run on the track at full speed.
The control problem is to keep the trains moving at maximum possible safe speed. If there is a slight delay in one train it may cause the train in the following block to decelerate potentially down to stop and then to reaccelerate, which 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 the required number of free blocks ahead.

## Part 1 Simulation:

Create a simulation for the London Old Oak Commons to Birmingham Interchange section of the high-speed line. The distance between London Old Oak Common Station and Birmingham Interchange Station is 145km. Assume that the track consists of k signalling blocks of equal length and that a fixed train schedule of n trains per hour is to be used.

Verify the simulation model by inducing a temporary break down due to electrical malfunction of the 9am train from London to Birmingham. It takes 30 minutes to fix the problem.

To reflect operational conditions introduce variability of travelling times using a suitable distribution on events. You can choose the distribution and the parameters as you deem appropriate. It may be useful to consider two types of variations: normal deviations (of just a few minutes for example caused by common weather events or delays in departure due to passenger movements), and rare events with bigger impact (like heavy rain or technical problems) that may impact also on later trains. Yuxiang Yang et al [1] report a log-normal distribution with $\mu= 3.378$ and $\sigma=0.751$ for the delay times (in minutes( on a segment of a comparable Chinese high-speed train (including the knock-on effect on the following trains).

## Part 2 Optimisation:

For given parameters k and n create a train schedule that sets out the departure and arrival time for trains with the first train leaving at 7am and the last train leaving at 10pm. Using the simulation created in part 1 report the distribution of actual delay times. The aim is to maximise the number of trains operating per hour under the constraint that the average delay time should not be higher than half the scheduled time between consecutive trains. Report your recommendation for the layout of the track (k) and the schedule (n).

## Project Report:

The layout of your experiments and the results of your analysis should be documented in a short project report of maximum 2000 words in length (excluding reference) in IEEE format using appropriate referencing and academic style. MS Word and LaTeX templates can be downloaded from: https://www.ieee.org/conferences_events/conferences/publishing/templates.html .
Use section headings as appropriate. References should comprise of a complete list of academic works and/or online materials used in the project. References should be included as in-text citations according to the IEEE citation style.
The code should be submitted as Jupyter Notebook file that generates all statistics and visuals as used in the report and a printout of the notebook files with all outputs in .pdf format.
The report, the Jupyter notebook files and any supporting files should be submitted via Moodle.

## Note:

While the average delay is normally to be computed for a day you may stop the simulation early to save compute time. For example if you observe a constant increase in delay time so that the constraint on average delay time is not fulfilled, or if you observe after a sufficient number of trains a stable state. You should reflect on any short-cut taken in your report.

## References:

[1] Yuxiang Yang, Ping Huang, Qiyuan Peng, Jie Li, Chao Wen: Statistical delay distribution analysis on high-speed railway trains. J. Mod. Transport. (2019) 27(3):188–197
https://link.springer.com/content/pdf/10.1007/s40534-019-0188-z.pdf

| Grade<br>Criterion | Solid H1<br>> 80% | H1<br>> 70% | H2.1<br>> 60% | H2.2<br>> 50% | PASS<br>> 40% | FAIL<br>< 40% |
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| **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. Effort exceeds the requirements of the module. | An excellent, fully complete simulation was carried out. | A very good and largely complete simulation was carried out. | A good and largely complete simulation was carried out. | An adequate simulation was carried out. | Little or no simulation carried out. |
| **Optimisation (25%)** | Elegant formulations of the optimisation problems.<br>Objective function is correct, and maximum or minimum value is correct.<br>A variety of solution approaches are included.<br><br>Effort exceeds the requirements of the module. | Objective function is correct, and maximum or minimum value is correct.<br>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.<br>Varied solution approaches are considered. | Objective function, variables and constraints have slight errors.<br>Only one solution approach is used | Some logical errors exist in the objective function, variables and constraints.<br>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.<br><br>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 fully evaluated. Results are thoroughly discussed.<br><br>There is significant reflection on the challenges faced in this project and possible resolution to remaining problems | Models are fully evaluated. Results are presented and thoroughly discussed.<br><br>There is significant reflection on the challenges faced in this project. | Models are evaluated. Results are presented and thoroughly discussed.<br><br>There is very good reflection on the challenges faced in this project. | Models and results are presented and appropriately discussed.<br><br>There is good reflection on the challenges faced in this project. | Cursory evaluation of models. Cursory discussion of results.<br><br>There is some reflection on the challenges faced in this project. | Little to no evaluation of model. Little to no discussion of results.<br><br>There is no 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. The IEEE template is strictly adhered to. Report does not exceed the length limits. References are appropriately and correctly used. | Well written, with no (large) language errors. All figures are well conceived and read-able. The IEEE template is adhered to. Report does not exceed the length limits. References are appropriately and correctly used. | Main document has a few language and/or style errors. Figures are well presented. IEEE template and length limit are adhered to. References are complete, and correctly used. | Main document has a few language and/or style errors. Some figures are may be hard to read. IEEE template and length limit are largely adhered to. 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 IEEE template may have been broken. References are mostly complete and correctly used. | Littered with typos, and/or poor use of English. IEEE template not used. Figures may be hard to read. References (if any) are probably incomplete. |