SEMTM0010 Transport and Mobility Modelling
2025 / 2026 coursework

General points.

- You should read the FAQ concerning this coursework which is available in Blackboard in the announcement dated Friday 31st October entitled "Assessment Information *** IMPORTANT ***." In particular, note the following.

- This coursework is open-book, and you are permitted to consult any material (e.g., lecture slides, exercises) that has been posted on the unit's Blackboard page, or indeed your own notes. You are also strongly encouraged to research on the internet, however, significant sources should be cited in an appropriate manner.

- Note this is an individual assessment, and your answers must be your own, and may not be obtained with any outside help. Collaboration is not permitted. If cheating or collaboration are detected, as with any assessment, then this will be subject to the University's rules on academic integrity:
http://www.bristol.ac.uk/students/study/teaching/integrity/.

- Please take note of the University's rules on the use of AI. The level permitted for this assignment is **category 2: minimal** — which means for example, it is ok to use AI to learn, and it is ok to use spelling and grammar checkers to help identify mistakes, but not to rewrite chunks of text. Furthermore, note the use of AI to generate submitted computer code is not permitted.

- The coursework consists of six compulsory questions, Q1–6, one for each section of the course. Each question is worth 20 marks. Each question is annotated with its mark breakdown. All six questions should be attempted.

- The computing elements should use Python/Matlab to solve problems as the lecturer for each section of the course has directed.

- Your submission should constitute a single pdf and might comprise a blend of (for example), pages of (neat) hand-written calculation or argument, figures — hand-drawn or powerpoint/similar, typed text, commented computer code, and computer output (please label and annotate all graphs). There are many ways of addressing this. For example, the use of Matlab livescript or Jupyter in Python is a really neat way of combining (latex) documentation and code. However, livescript/Jupyter/latex are not compulsory and any method which gives a clear and easy-to-follow narrative is fine. However — we must emphasise: your submission should be bound together as a single pdf.

- Your coursework should be submitted via Blackboard, with a deadline of 13:00 GMT on Tuesday 9 December 2025.

Q1. Demand Modelling.

In this question, we will study origin-destination (O-D) demand models of the proposed city 'The Line' in Saudi Arabia. We suppose that the city is organised around a straight double-track metro line of length $L = 170\,\text{km}$, running from $x = 0$ to $x = L$, with N uniformly spaced metro stations at positions $x_i = (i-1)L/(N-1)$, $i = 1, 2, \ldots, N$. We will suppose that the line has a working population of $P = 5,000,000$ individuals, and that their residences and jobs are uniformly distributed along the line so that each station provides a source of $O_i = P/N$ workers and a sink of $D_i = P/N$ jobs. The distance between two metro stations is clearly $|i-j|L/(N-1)$, however we will assume a commute distance of $d_{ij} = (1+|i-j|)L/(N-1)$, to account for an additional commute distance at each end of the metro ride. This formula with $j = i$, so that $d_{ii} = L/(N-1)$, will also be used to model a short commute distance for journeys entirely within a single metro station locality. Throughout the question, you may assume that L and P are fixed. However, N is a parameter that you should experiment with. For example, $N = 10$ would correspond to a sparse provision of metro stations where an additional 'last-mile' transit solution would be needed, whereas $N = 100$ would ensure that nearly all residences and jobs are within walking distance of the nearest metro station.

(a) (Hand calculation.) Consider the application of the classical gravity model where O-D flows f_{ij} from locality i to locality j are prescribed in the form

$$f_{ij} = c\frac{O_i D_j}{d_{ij}^2}.$$

Show that no choice of c will simultaneously satisfy all of the $2N$ constraints

$$O_i = \sum_j f_{ij} \quad \text{and} \quad D_j = \sum_i f_{ij}.$$

(4 marks)

(b) We will now consider the doubly-constrained gravity model where

$$f_{ij} = c_i^{(\mathrm{O})} c_j^{(\mathrm{D})} \frac{O_i D_j}{d_{ij}^2}.$$

involving $2N$ constants $c_i^{(\mathrm{O})}$ and $c_j^{(\mathrm{D})}$.

(i) (Hand calculation.) By using the formulae for O_i and D_j in part (a), derive a system of $2N$ nonlinear equations to solve for the constants.

(2 marks)

(ii) Hence design, develop, explain, and exhibit code to solve for the constants $c_i^{(\mathrm{O})}$ and $c_j^{(\mathrm{D})}$ and hence find and exhibit the flows f_{ij}. Hint: you may either use a general nonlinear system solver such as `fsolve`, or implement your own numerical method — for example, search up the *iterative balancing method* (also called the *Furness method*).

(8 marks)

(c) Design, develop, explain, and exhibit code that computes the resulting flow on each link of the metro line. Without producing full calculations — explain how flows will work out differently if instead the stations (and localities) are equally spaced along a circular double track.

(6 marks)

Q2. Network modelling.

(a) This question considers the metro line design mooted in Q1(c) where N stations are equally spaced along a circular double track of length L. Again $N = 10$ and $N = 100$ may be considered representative choices for your experiments.

Suppose that the city in question has a budget to build a length βL of additional double track, in the form of short-cuts, that is straight-line chords that cut directly across the circle between stations. Here β is a parameter to be experimented with. Clearly a very large value of β will enable a direct link between every pair of stations — not at all a realistic situation — and a small value of β may enable only one very short link to be built between near-neighbour stations — not at all a useful intervention. The interesting regimes are in between.

Design, develop, and explain code to experiment with different designs for introducing the short cuts as β is increased, with implementation in the `Matlab` graph toolbox.

Hint: a good answer will either propose a couple of different heuristic principles, or will propose a systematic procedure, for introducing the short cuts.

For your designs, develop, explain, and exhibit code that computes the shortest path between pairs of nodes and the average shortest path length over all $N(N-1)/2$ distinct (ordered) pairs of nodes. Note that because all of the track is double, you may work with an undirected graph, or a directed graph with a symmetric edge matrix, as you choose.

Hence evaluate the efficacy of your designs as β is increased.

(13 marks)

(b) This question concerns the proposed South Bristol Liveable Neighbourhoods — a form of LTN (low traffic neighbourhood). See
`https://www.bristol.gov.uk/residents/people-and-communities/liveable-neighbourhoods/south-bristol-liveable-neighbourhood`

See also the popular media, e.g.
`https://www.bristolpost.co.uk/news/bristol-news/parking-bans-one-way-streets-10477427`

Choose one of the proposed sub-zones — for example, *Southville*, *Bedminster East*, *Perretts Park* etc. — and using OSM data, build and exhibit a `Matlab` graph representation of the chosen zone.

Describe briefly the sorts of computations you might perform and principles you might invoke to evaluate the impact of the proposed scheme. (Full workings / computer code not required.)

(7 marks)

Q3. Assignment modelling.

In this question, we will consider the classical two-link parallel network as introduced in the lecture videos. The (total) flows of traffic on each link will be $x_1, x_2 \geq 0$ and the (per user) link cost functions will be $f_1(x_1) := a + x_1$ and $f_2(x_2) := 1 + bx_2$, with $0 \leq a, b \leq 1$. The flows must sum to a total prescribed demand $d \geq 0$, so that $x_1 + x_2 = d$.

In contrast to the usual set-up, we will suppose that the demand is split into two components $d_{\mathrm{A}} := \alpha d$ and $d_{\mathrm{L}} := (1-\alpha)d$, where $0 \leq \alpha \leq 1$ is a parameter that you will experiment with. The component d_{A} corresponds to autonomous vehicles that will be programmed to act altruistically (to try to minimise total system cost for all users) and the component d_{L} corresponds to legacy vehicles that are driven by humans who are assumed to be self-optimising in the usual user equilibrium (UE) way. Each link flow will thus consist of two components so that $x_i = x_i^{(\mathrm{A})} + x_i^{(\mathrm{S})}$ and we will suppose that the per user cost experienced by each vehicle on the link is a function $f_i(x_i)$ of the total (autonomous and legacy) vehicle flow on that link. We will explore solutions of this mixed-flow system. Note that $\alpha = 0$ corresponds to the standard UE problem, whereas $\alpha = 1$ corresponds to the standard system optimal (SO) problem.

Consider the following *Stackelberg game*.

- STEP 0. Compute the usual system optimal SO assignment to determine the total flow on each link and assign flows so that each link has the same proportions of autonomous and legacy traffic. Go to STEP n PART 1.
- STEP n PART 1. All the autonomous vehicles maintain link choices from the previous step. The legacy vehicles are re-assigned between the two links so that they are in equilibrium. Go to STEP n PART 2.
- STEP n PART 2. All the legacy vehicles maintain link choices from the previous step. The autonomous vehicles are re-assigned between the two links so as to minimise the total system cost (i.e., total cost of autonomous and legacy vehicles). Go to STEP n PART 1.

The supplementary materials provided on Blackboard show how this game plays out for the classical choices $a = b = 0$ and $d = 1$, with an equal split $\alpha = 1/2$ of autonomous and legacy traffic.

(a) Design, develop, explain, and exhibit code to simulate the Stackelberg game and explore its converged assignments. Examine how the total system cost of the converged assignment reduces as α is swept from 0 to 1. Your calculations should explore the a, b, d parameter space, and note any significant material differences, trends etc as these parameters are varied. Discuss potential practical implications of your results.

(14 marks)

(b) In the real-world, autonomous vehicles may be able to collaborate to drive particularly close together, but only if no legacy vehicles are present. You should model this by supposing that if a link has *only* autonomous vehicles, the congestibility parameter (i.e., the coefficient of x in the link cost function) is halved. Adapt your part (b) solution to explore this effect and comment on any relevant real-world implications.

(6 marks)

Q4. Microscopic modelling.

There is a demonstration taking place with an unknown number of participants, N.

Based on the following observations:

- The crowd completely fills the whole of Westminster Bridge (250m long; 26m wide), three times over (i.e., only one third of the crowd fits onto the bridge at the same time).
- It takes around one hour for the crowd to pass through a cross-section of the bridge.

Assume that the walking speed of the crowd can be described by $v(\rho) = 1.3(1-\rho/\rho_{\max})^2$, $\rho_{\max} = 6\text{m}^{-2}$.

(a) Estimate the average density of the crowd $\overline{\rho}$.

(3 marks)

(b) Estimate the total crowd size, N.

(1 mark)

Assume that γ=5% of the crowd participants are wheelchair users, who occupy a circular space with a 0.75m radius. Calculate the maximum crowd flow for the following two design choices:

(c)
- Wheelchair users blend with the crowd and use the whole area (assume that wheelchairs will move at the same speed as the pedestrians).
- 2m out of the 26m width of the bridge is desginated to wheelchairs (who move in a single lane). Assume that wheelchairs move at a constant speed of 0.7 m/s.

(4 marks)

(d) What is the critical value of γ where it is a net-positive (for overall flow) to have designated wheelchair space?

(4 marks)

(e) In order to do more detailed analysis of the problem, specify the equations of a modified social force model (any published specification of the social force model is acceptable) with the following changes:

- Simulate γ=5% wheelchair users; blended within the crowd; occupying a circlar space with a 0.75m radius each; and adhere to the following kinematics (can move forward, backward, and rotate, but can not move laterally).
- A fraction α of the participants are particularly loud. When anyone comes within a 5m distance of those individuals, they will either speed up by 20% (if they are ahead) or slow down (if they are behind) the noisy individual, until they are >5m away from them.

(8 marks)

Q5. Data-driven modelling

For all parts of the question, provide your discussion in bullet points.

(a) Consider the plot shown in figure 1 below. It shows the observed vehicle traffic count (solid line, arbitrary units, a.u.) and the traffic count forecast by two different time-series models (red dashed and blue dotted). Both models are fit to the same data and neither model is a black-box machine learning model.

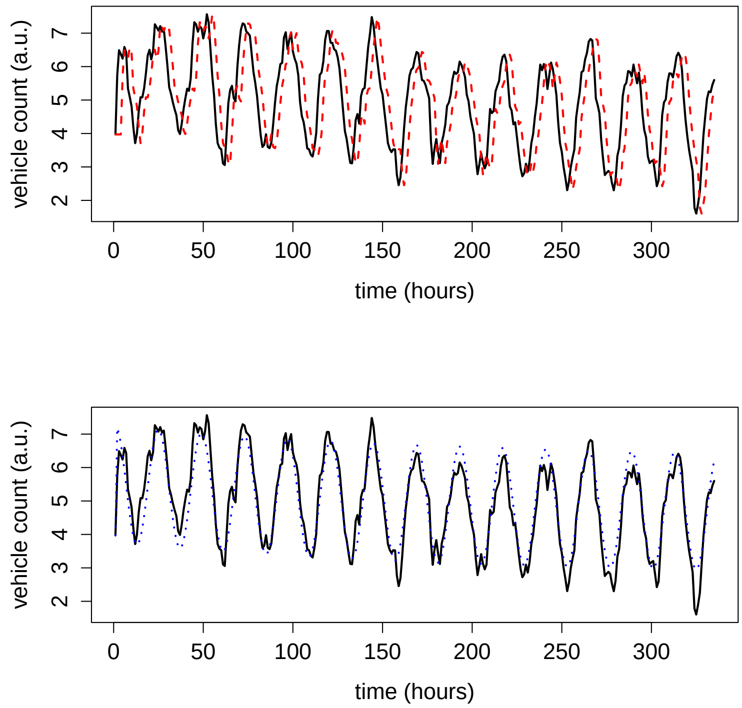

Figure 1: Red and blue model fit to the same data.

(i) Use the plot to list as many properties of the red and blue models as you can identify. Clearly justify which aspects of the plot are indicative for each feature and why and write down indicative equations for each model (there is no expectation for exactly correct model terms and estimated parameters).

(8 marks)

(ii) Discuss the usefulness of fitting these two models to the same data for explaining the dynamics of vehicle counts, clearly justifying the arguments you make.

(4 marks)

(b) This questions extends the worked example on machine-learning a microscopic model covered in the lab sheet for data-driven modelling (section 3 on the lab sheet for data-driven modelling).

(i) Develop and implement in Matlab or Python an improved version of the worked example in the lab sheet that considers the exit location and performs closed loop predictions instead of the open loop predictions shown in the lab sheet. Provide a clear explanation and rationale for the changes you make.

(4 marks)

(ii) Evaluate the performance of your model by additionally using another data set of your choice obtained from `https://ped.fz-juelich.de/db/doku.php`. Justify your choice of data and evaluation approach (note that marking places a higher emphasis on the quality of the evaluation than on the prediction accuracy).

(4 marks)

Q6. Practitioner studies.

For all parts of the question, please provide your answers as bullet points rather than continuous text. Your answer to this question should not be longer than 3 pages A4 (less than approx. 1,500 words).

The *Green Guide* by the *Sports Grounds Safety Authority* is a UK Government-funded guidance book on spectator safety at sports grounds. It provides figures for the egress flow rates of pedestrians moving on level and stepped surfaces.

(a) Find the egress figures mentioned below (they are available online), state them, and provide your source. Critically discuss these egress flow rates.

(5 marks)

(b) Consider you are a consultant who has been given the following brief: *"The city of Clowntown has decided to update their multi-purpose events hall that is used for sports, concerts, and other events. The main change will be a second level of tiered visitor seating above the first level that is also tiered. Currently, the hall has a capacity of 2,000 spectators, the extension will double this capacity with the second level seating arrangement mirroring the first level arrangement. Due to the age of the building, regulatory requirements state that it must be possible to empty the hall in 2 minutes. There is ample walkway provision around the entire hall. Your task is to make suggestions for the number, design, and locations of exits. Please provide justifications for your suggestions. Your customer is concerned with safety, construction costs, and user experience in this order of importance. You can find a simplified site plan below (figure 2), the hall currently has four identical exits."*

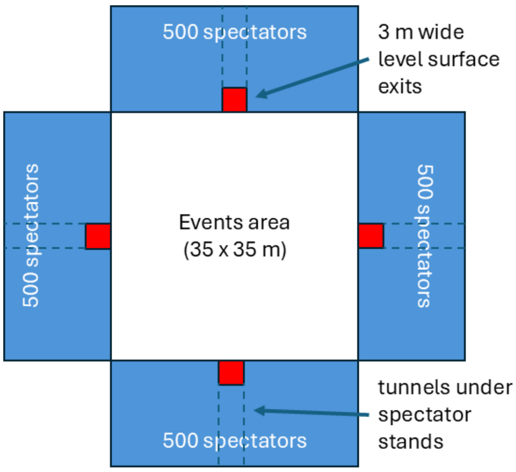

Figure 2: Site plan of Clowntown's multi-purpose hall.

Use the information from the Green Guide, what you have learned on the course, and any additional relevant information from beyond the course to address the brief above, focusing on elements relevant to spectator foot traffic and considering the relevant stakeholders. Explain and justify your approach.

(8 marks)

(c) If you were to be given access to one other model covered in the lecture slides on microscopic modelling to make your design recommendation, which model would it be, and why? Stick to the same brief as in part (b) and state clearly where in the lecture notes the model was covered. We expect a sufficiently detailed explanation as to why you choose this model including an explanation on how it would be used.

(7 marks)

Guideline to allocation of marks for part:

- These are open-ended questions, there is not one correct answer. You are being marked on the level of knowledge, application, and critical appraisal of the methodological background.
- Excellent answers will go beyond what is explicitly taught on the course.