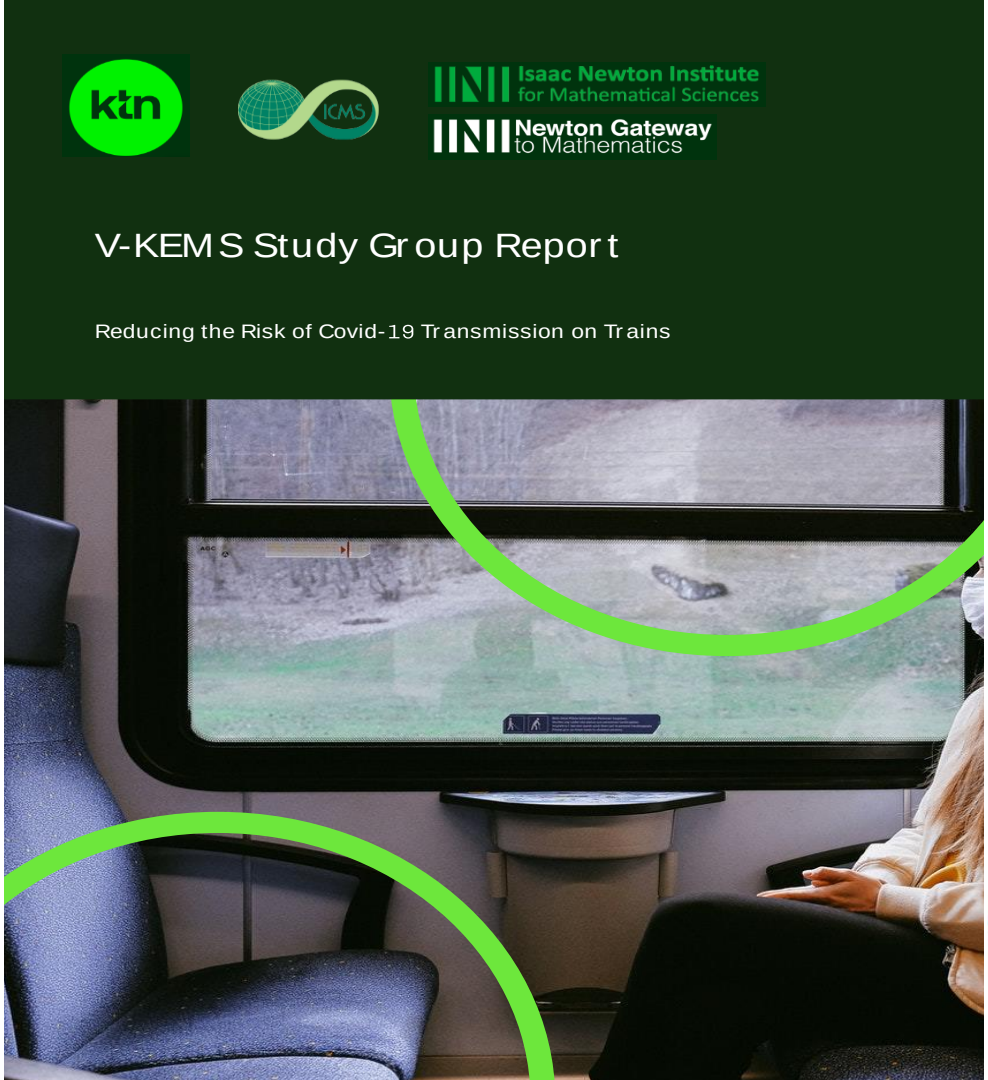


Reducing the Risk of Covid-19 Transmission on Trains

Chris Budd OBE, FIMA

IMI

UNIVERSITY OF BATH

Railway Experts

Jonathan Bridgewood (FirstGroup Rail)

Ben Ford (Network Rail)

Matt Hunt (RSSB)

KTN

Matt Butchers

Daisy Chapman-Chamberlain

Attendees

Simone Appella (University of Bath), Eldad Avital (Queen Mary University of London), Tosin Babasola (University of Bath), Thanos Bantis (Connected Places Catapult), Alexandra Brintrup (University of Cambridge), Chris Budd OBE (University of Bath), Radu Cimpeanu (University of Warwick), Philippe De Wilde (University of Kent), Jess Enright (University of Glasgow), Akshay Gupte (University of Edinburgh), Peter Hicks (OpenTrainTimes Ltd.), Andrew Lacey (Heriot-Watt University), William Lee (University of Huddersfield), Antonio Martinez-Sykora (University of Southampton), Amjad Natour (RDG), Simon Noel (QinetiQ Ltd.), Sophie Peachey (Iotics), Eileen Russell (University of Bath), Dipak Sarker (University of Brighton), Lars Schewe (University of Edinburgh), Yang Zhou (University of Bath)

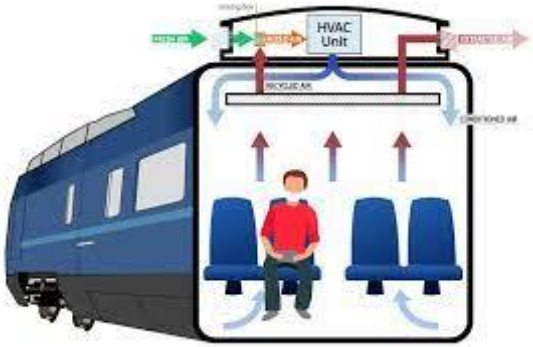
Three scales tackled by three groups

- Scale 1: Modelling of a carriage: controls e.g. airflow, seating design, passenger allocation to seats

- Scale 2: Modelling of a journey: static, dynamic, passenger movement, passengers getting on and off

- Scale 3: Scheduling across the country, passenger allocation to trains; High times of rail usage (e.g. start of university term); Resilience of schedule based on outbreak

Scale1: Carriage Level

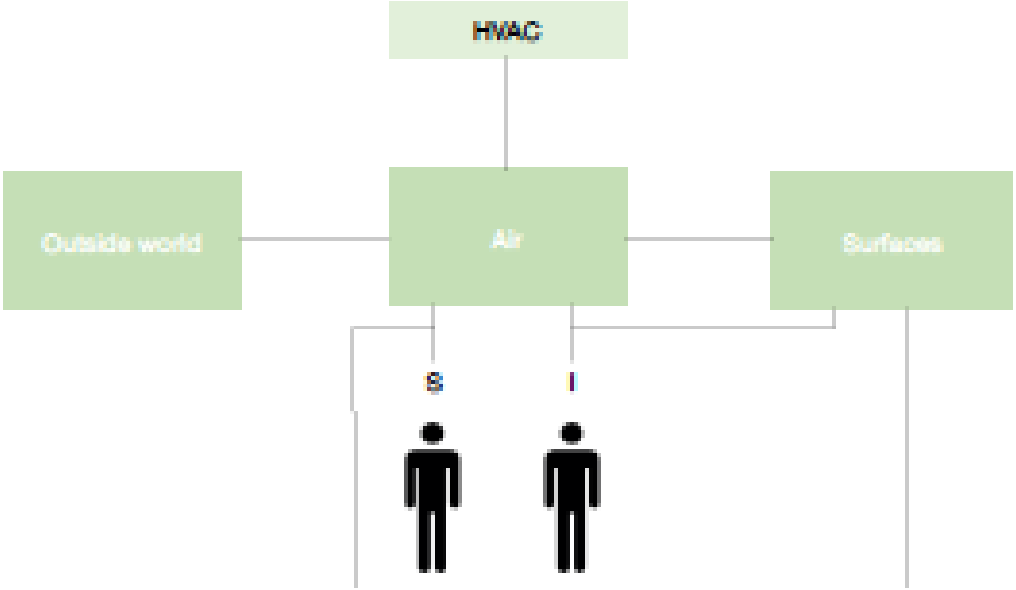


- Model airflow in a carriage
- Model how people interact with the airflow
- Model how people get infected
- Model how to reduce the infection

TRACK project is doing this in detail

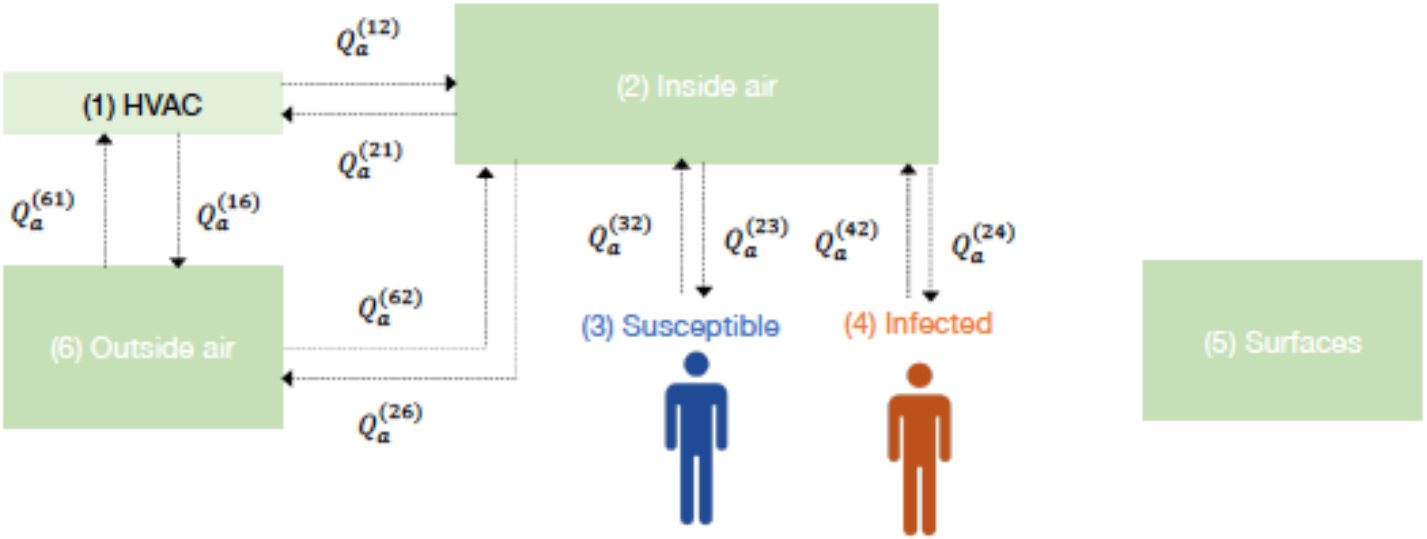
VSG looked at a series of simplified models

Infection routes



High level model of the infection routes in a carriage

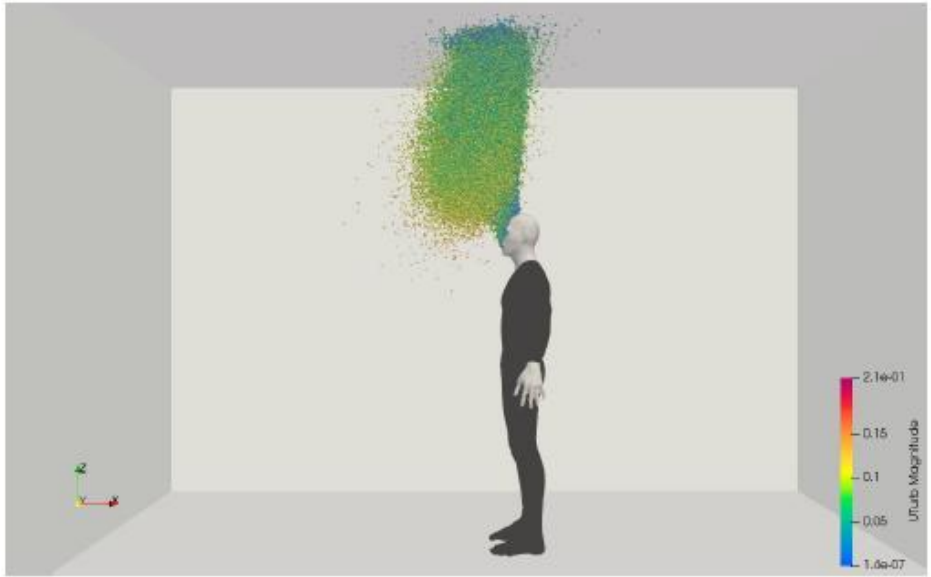
Airflow



Can calculate mean flows by a simple flux balance

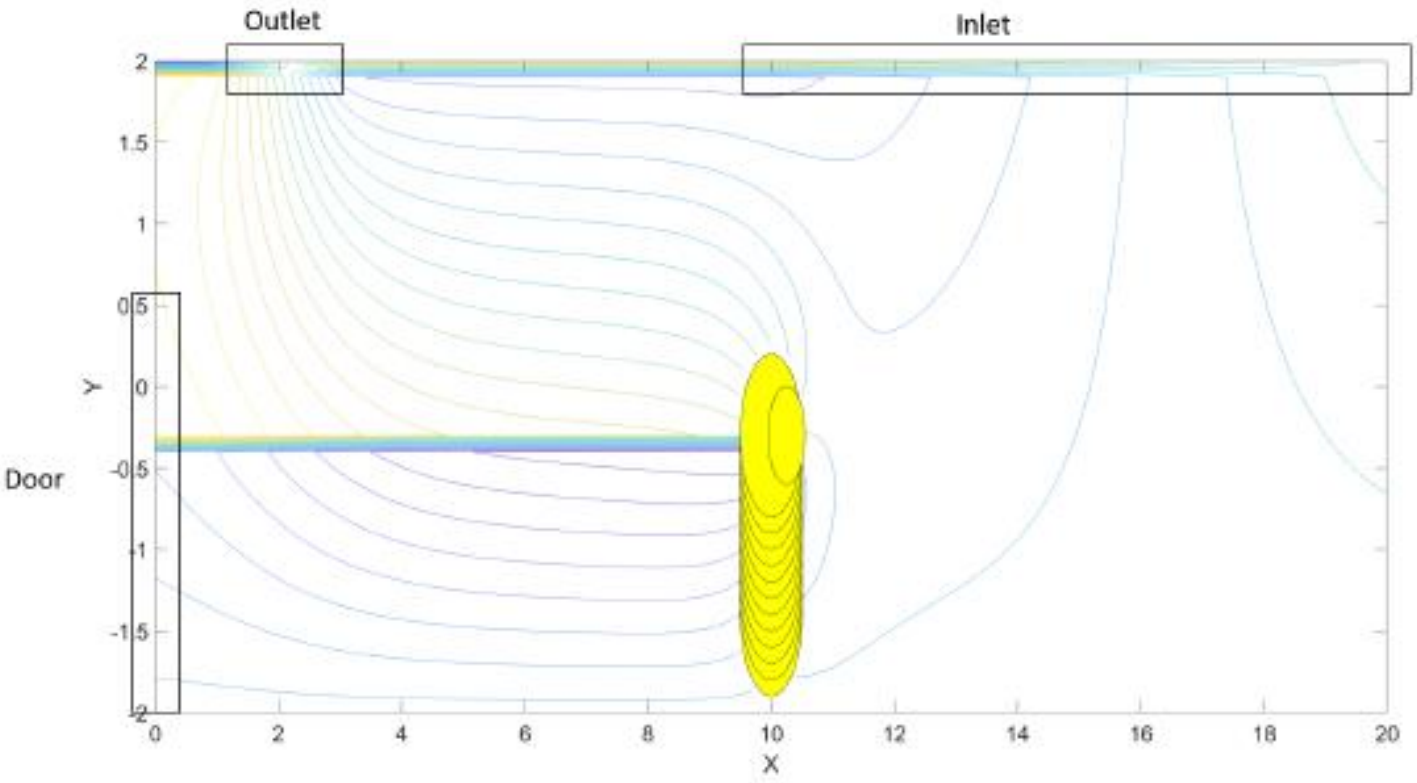
More sophisticated flows using CFD (TRACK)

Droplets move into the air from a person breathing

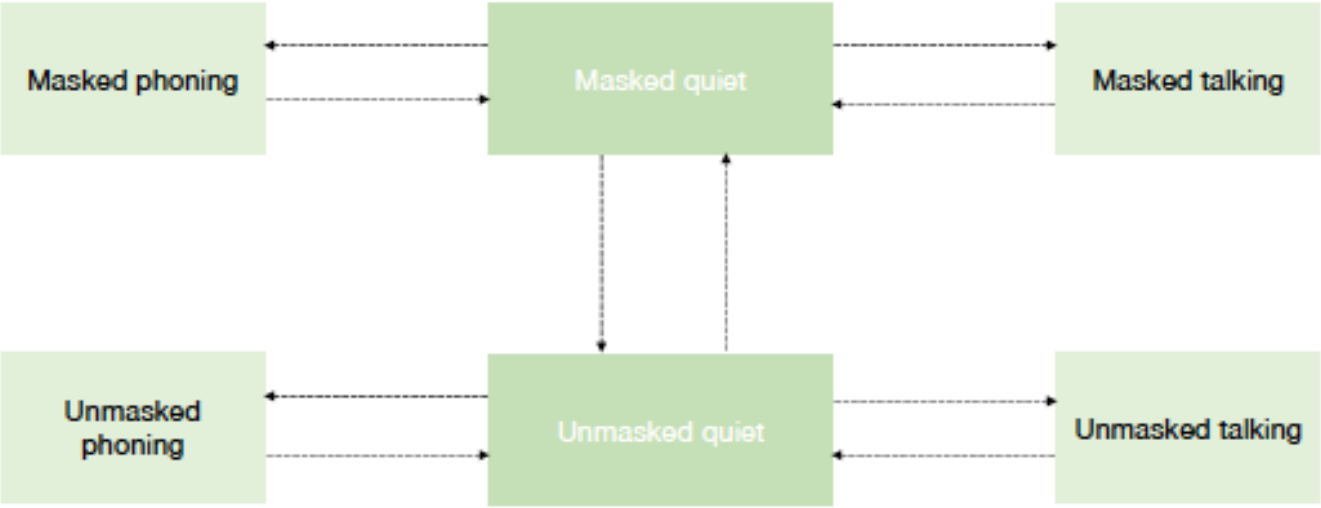


Can estimate particle concentration using the computed flow field

Simulations thanks to William Lee



Different types of person in a carriage



Wells-Riley Model for infection

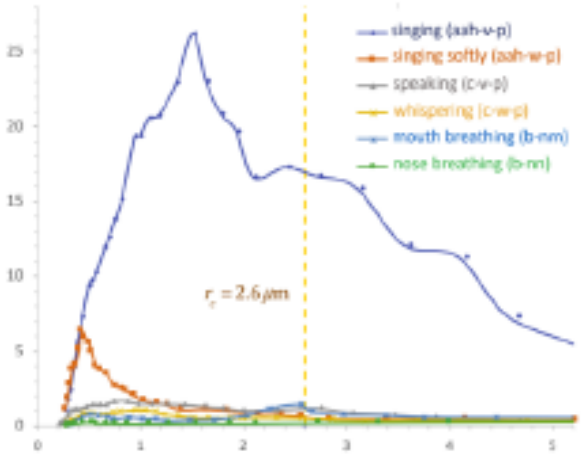
$$P_I = \frac{C}{S} = 1 - \exp\left(-\frac{Ipq\,t}{Q}\right)$$

- P_I is the probability of infection,
- C is the number of infection cases,
- S is the number of susceptible individuals,
- I is the number of infectors,
- p is the pulmonary ventilation rate of a person,
- q is the quanta generation rate,
- t is the exposure time interval,
- Q is the room ventilation rate with clean air.

- Assumes a well mixed flow
- CFD can improve on this but at significant extra cost
- Droplets on surfaces ignored – considered a letter risk than aerosols
- Want to include extra geometry eg. tables and luggage racks

Minimisation of speech and phone use is important

Singing on a train is especially bad!



Scale 2: The Passenger Journey

Typical journey

Travel to station

Travel through station

Enter the train from a platform

Sit on the train

Leave the train onto a platform

Leave the station

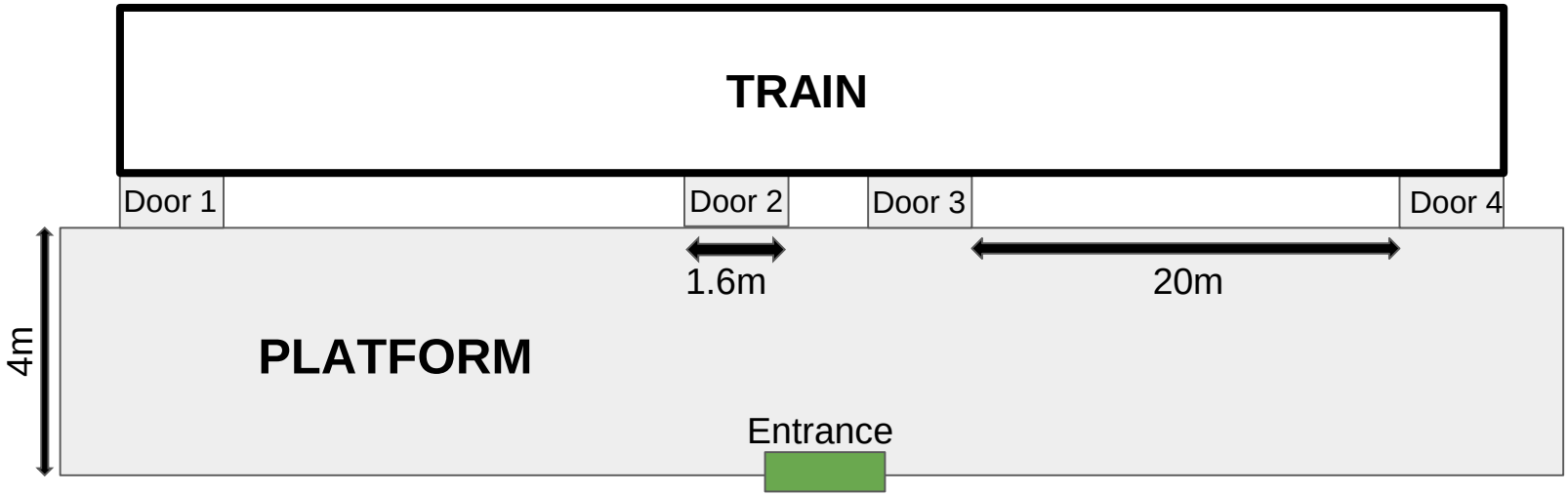
Travel from the station

These two involve a lot of crowding and are potentially the most dangerous as measured by total viral load

Case for longer times at the station

Getting on to the train

Platform Setup - A Toy Model



Passengers assumed to enter the platform at the centre, then distributed according to a Gaussian distribution.

Modelling the Passengers' Motion 1

- Model the passengers' motion as a continuum: convection-diffusion PDE

$$\partial_t u + \nabla \cdot (\vec{v} u) = \nabla \cdot (\sigma \nabla u), \quad u \in C^1(\Omega)$$

where u is the crowd density, $\vec{v}$ is the speed, and σ is the diffusivity parameter.

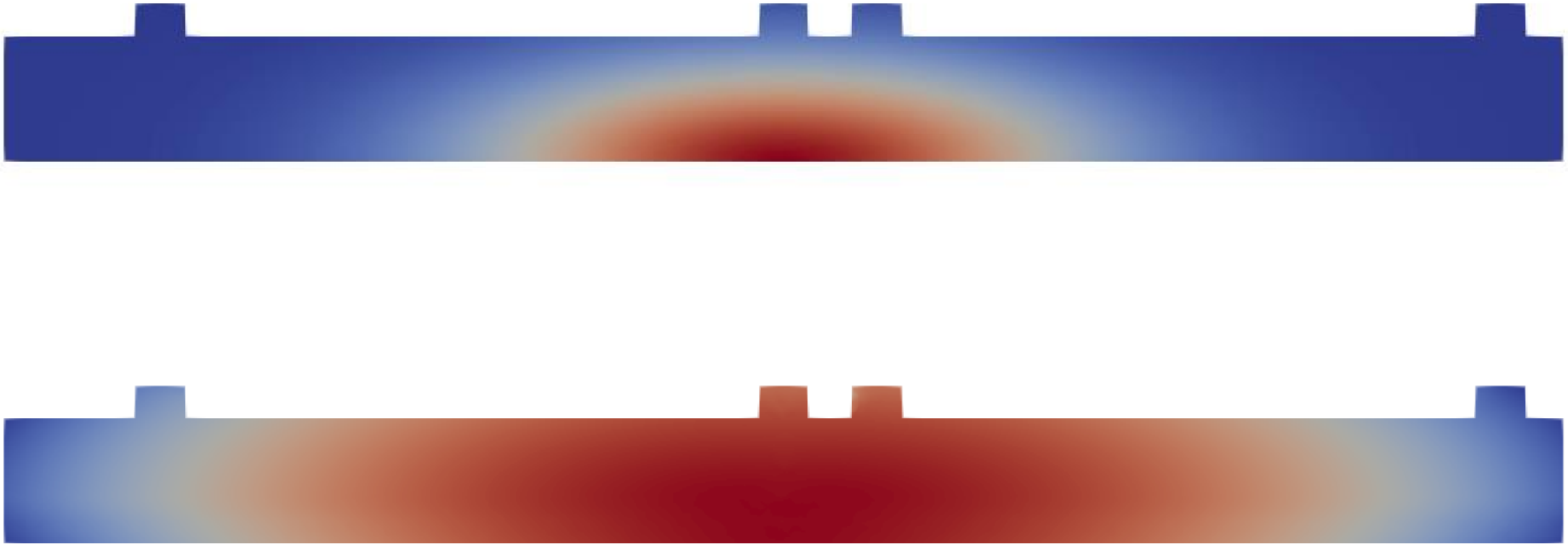
- The passengers scatter from the entrance as an exponential function

$$u_0 = e^{-(\beta_1 (x-0.5)^2 + \beta_2 (y-0.8)^2)},$$

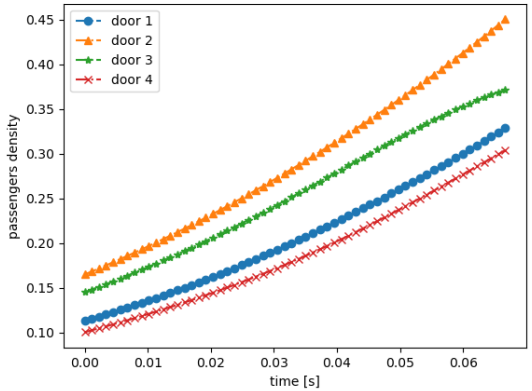
where β_1 and β_2 characterise the level of initial spread.

Results - Simulation of PDE (FEniCS) $\beta_1 = 1e-3$

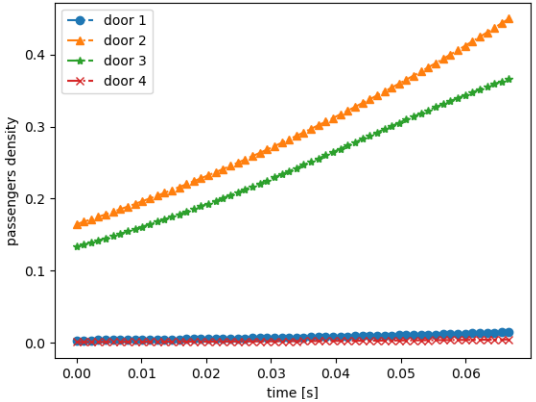
Results - Simulation of PDE $\beta_1 = 1e - 2$



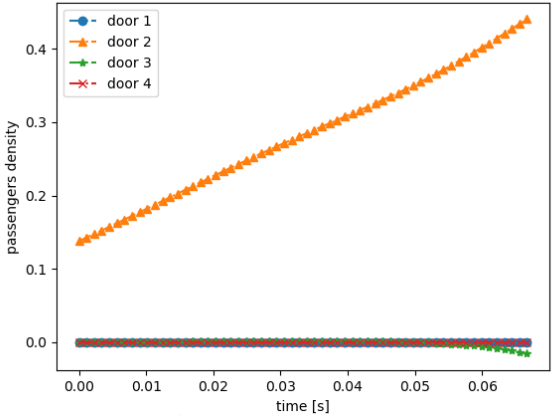
Density of passengers for each carriage door



$$\beta_1 = 1e - 3$$



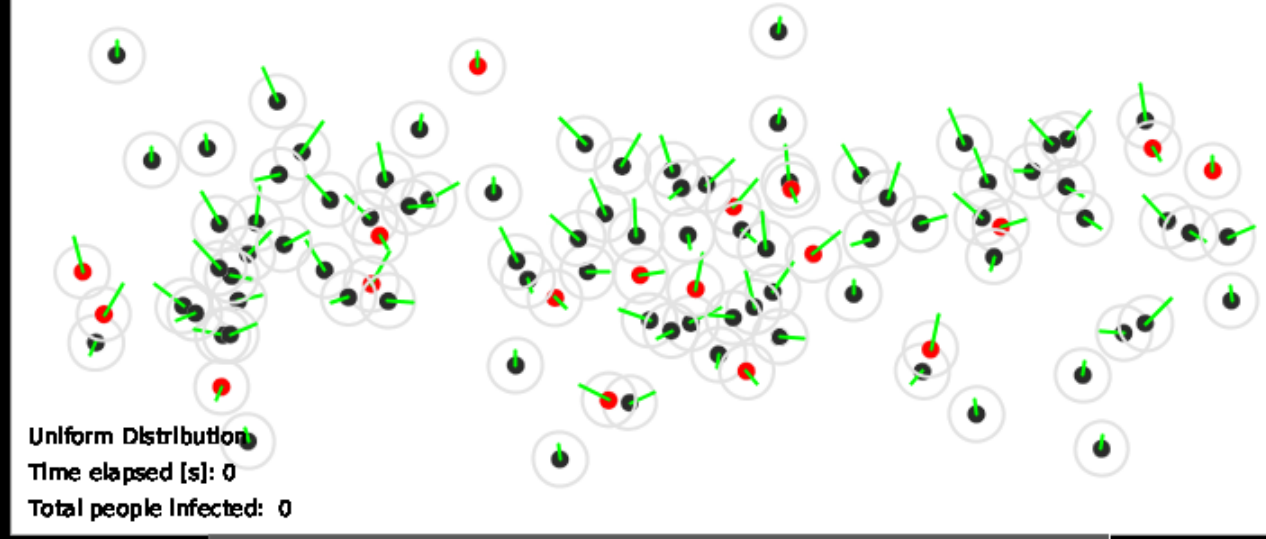
$$\beta_1 = 1e - 2$$



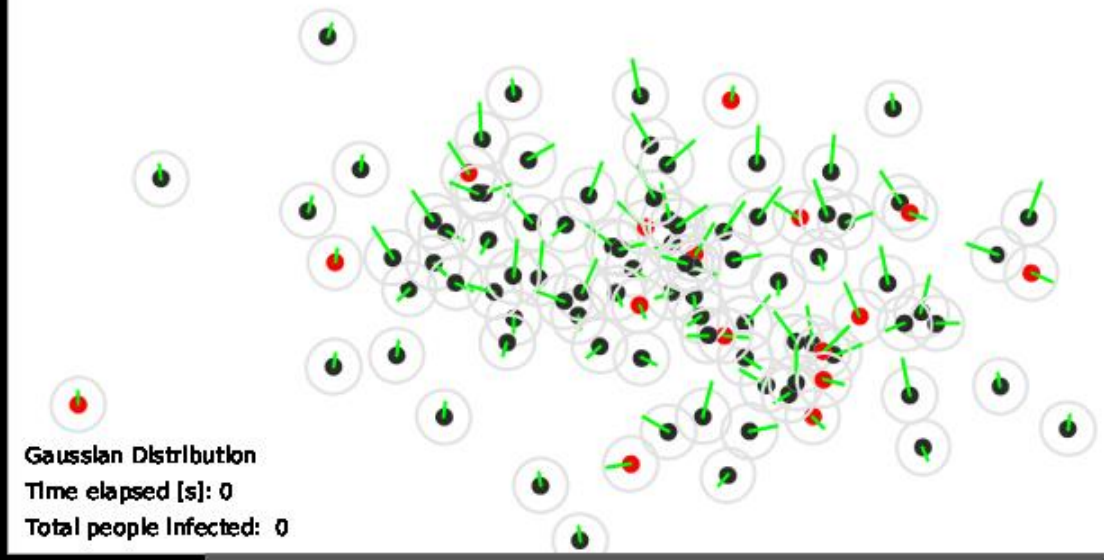
$$\beta_1 = 1$$

ABM Model: Uniform

Simulations thanks to Simone Appela



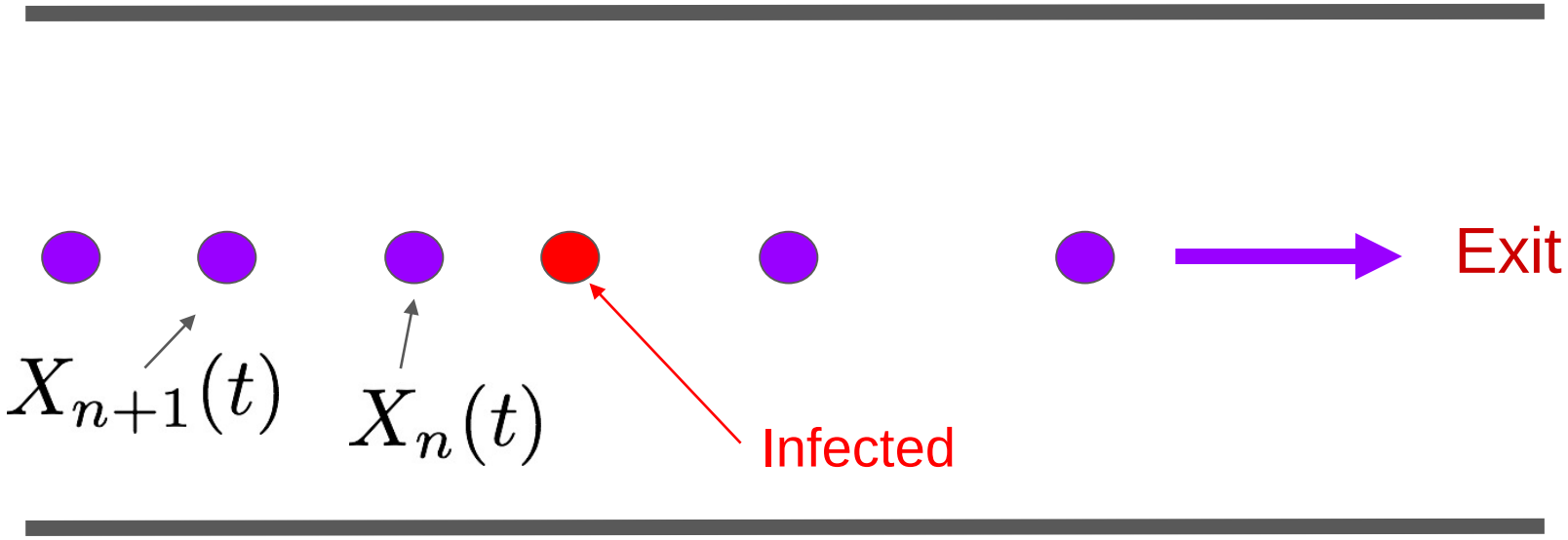
ABM Model: Gaussian



Getting off from a train

Train comes to a halt and passengers leave

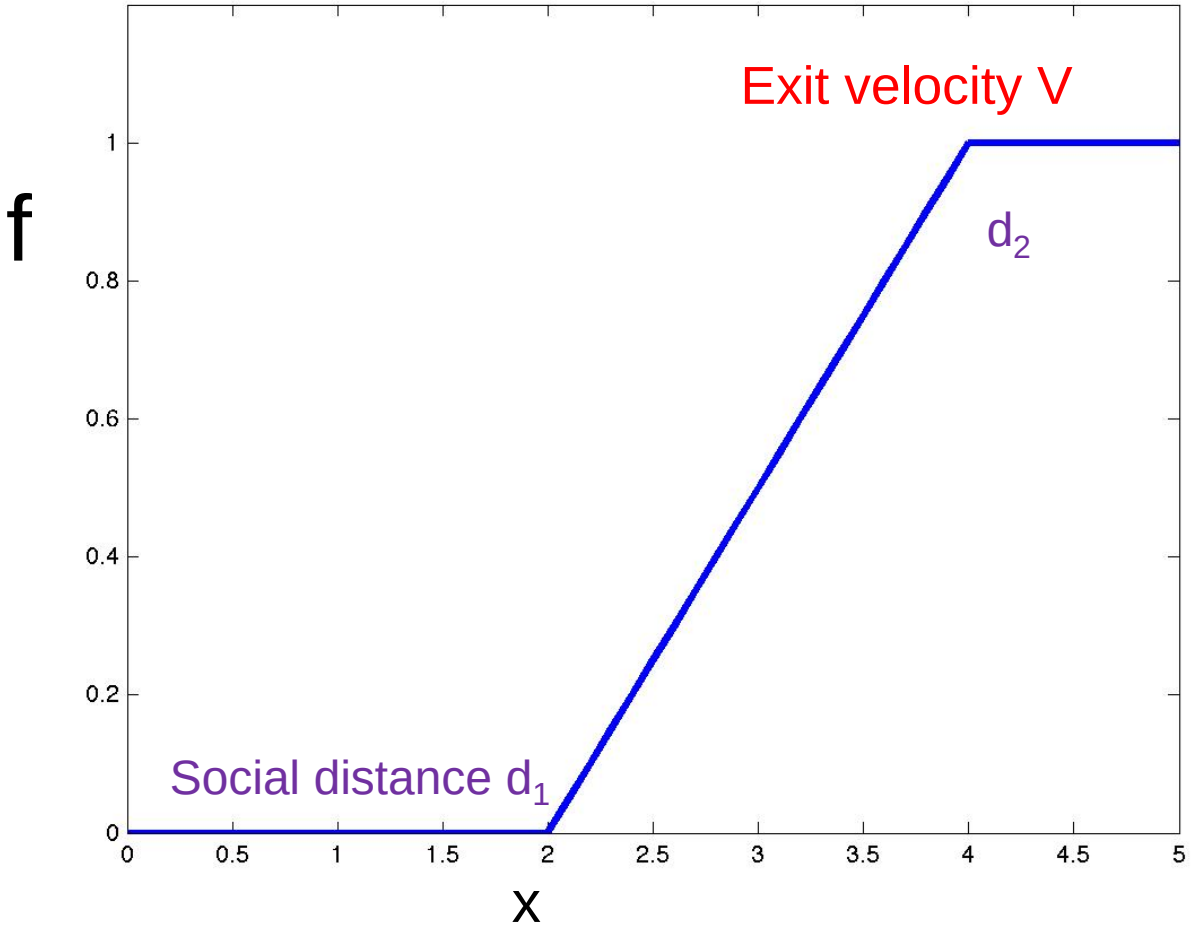
Assume that they leave as an ordered queue



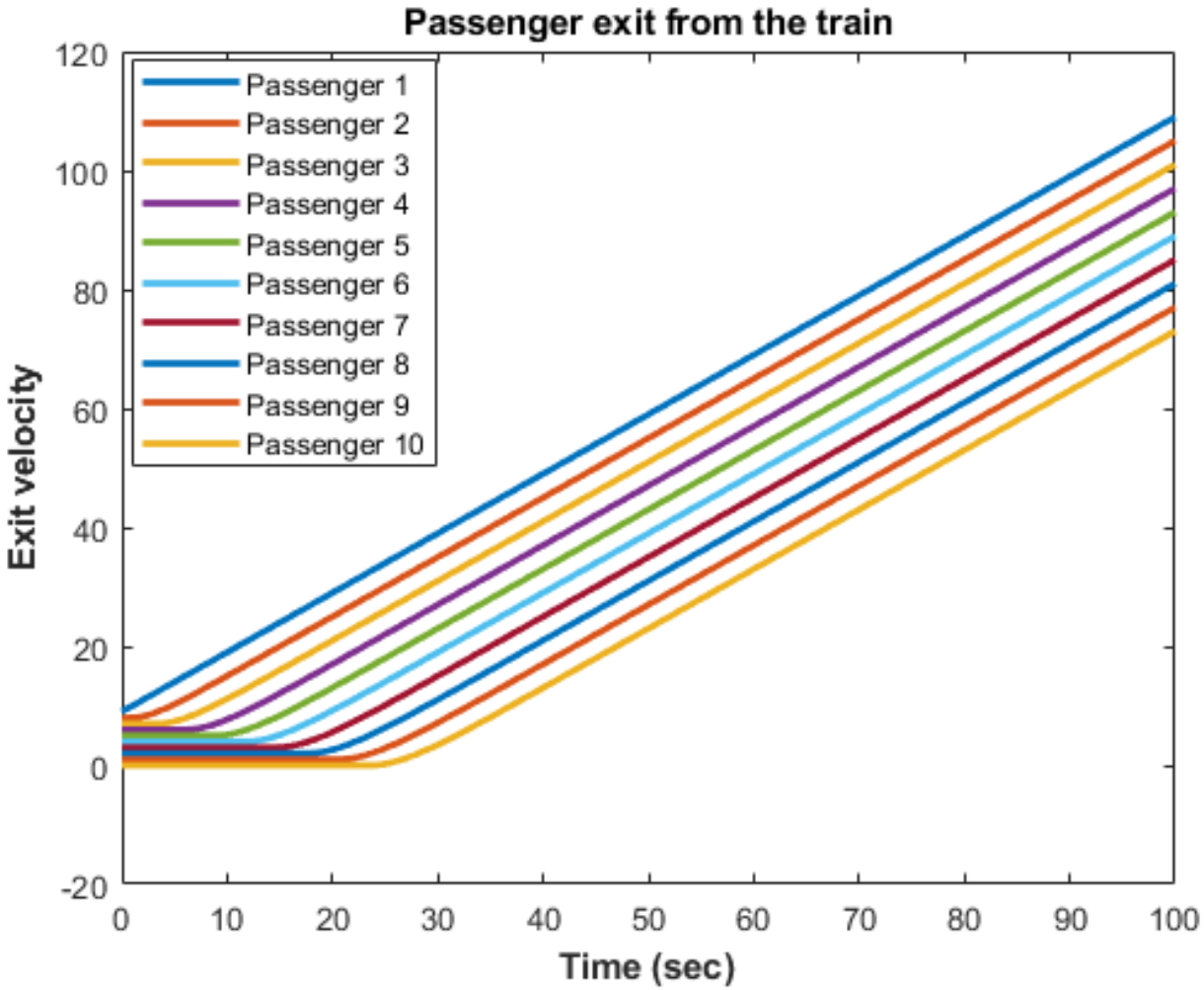
Velocity based model

$$\dot{X}_{n+1} = f_{n+1}(X_n - X_{n+1})$$

$$f(r) = 0 \quad r < d_1, \qquad f(r) = V, \quad r > d_2$$


Exit velocity V
f
d2
Social distance d1
x
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Simulations thanks to Tosin Babasola



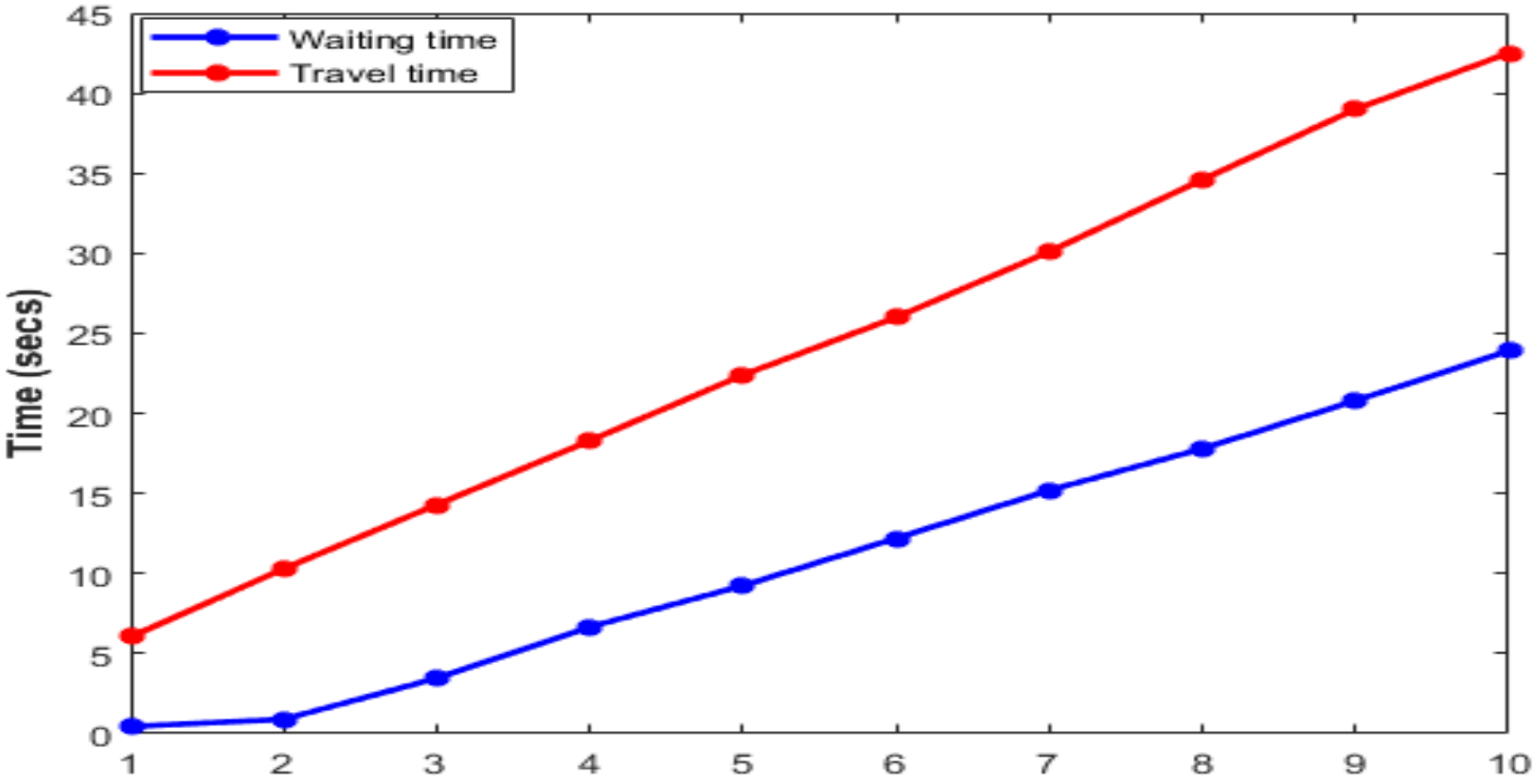
Typically a passenger

Has a waiting time before they can move

Takes a further travel time to leave the train

Both of these lead to potential viral exposure

Passengers waiting and travel time

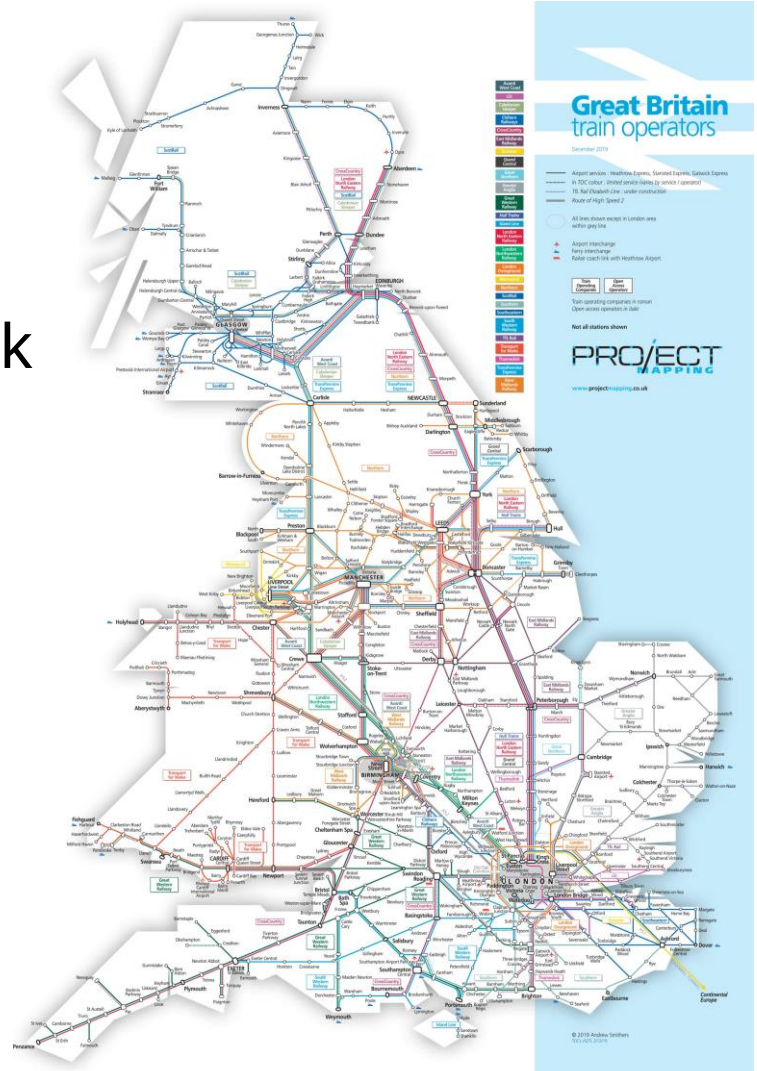


Scale 3: The whole railway network

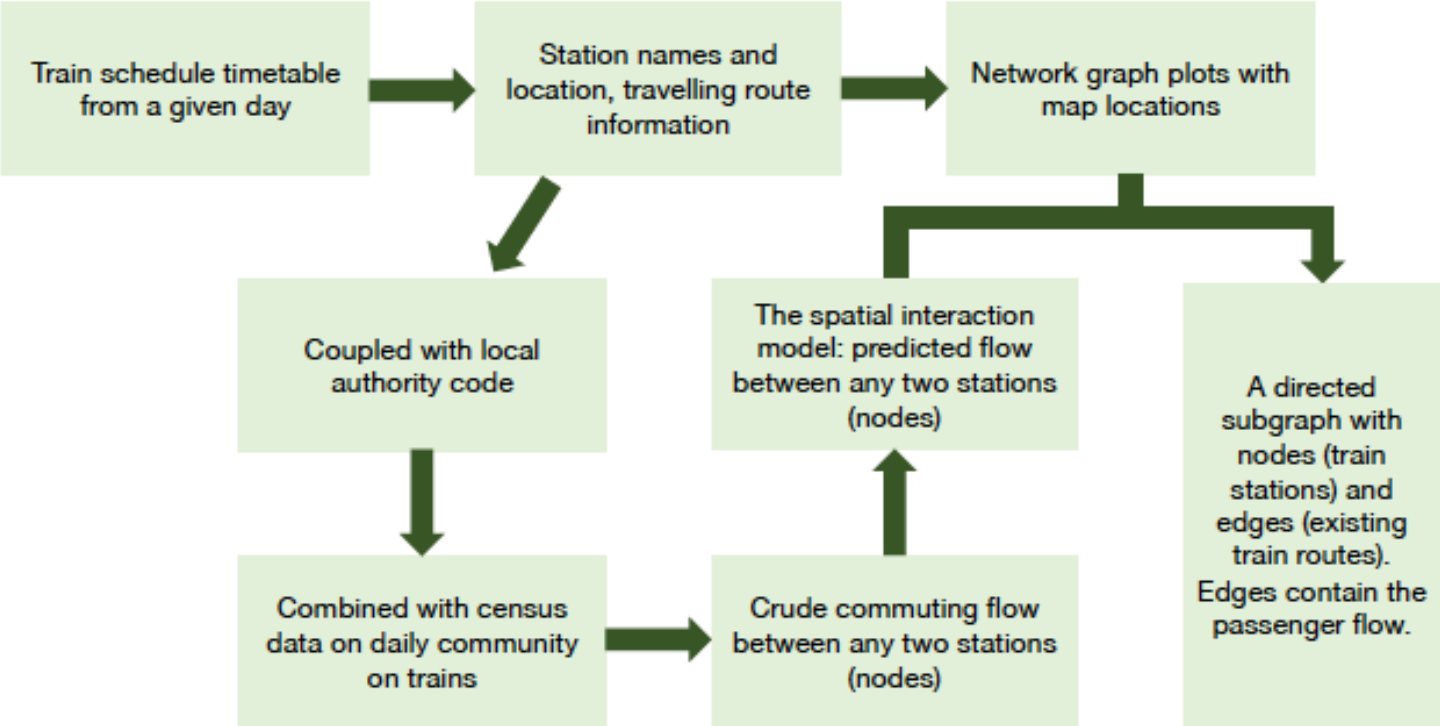
How can the whole network cope safely with National Events

eg. students returning to university

Ensure enough Covid-19 safe carriages



Methodology



Construct a weighted graph to represent the network

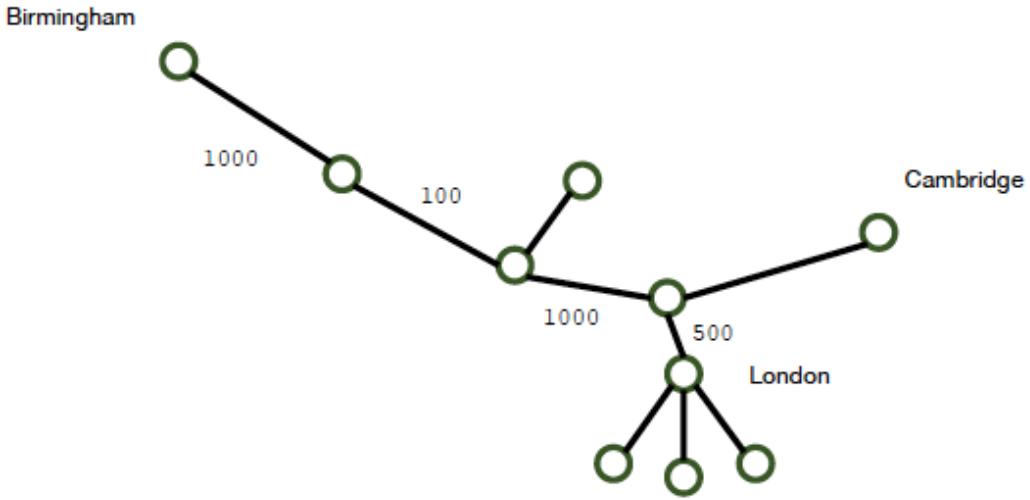


Table 2: Train timetable on 22/12/2020 from London Northwestern Railway and West Midlands Railway. There are 1342 train operation on this section within the day.

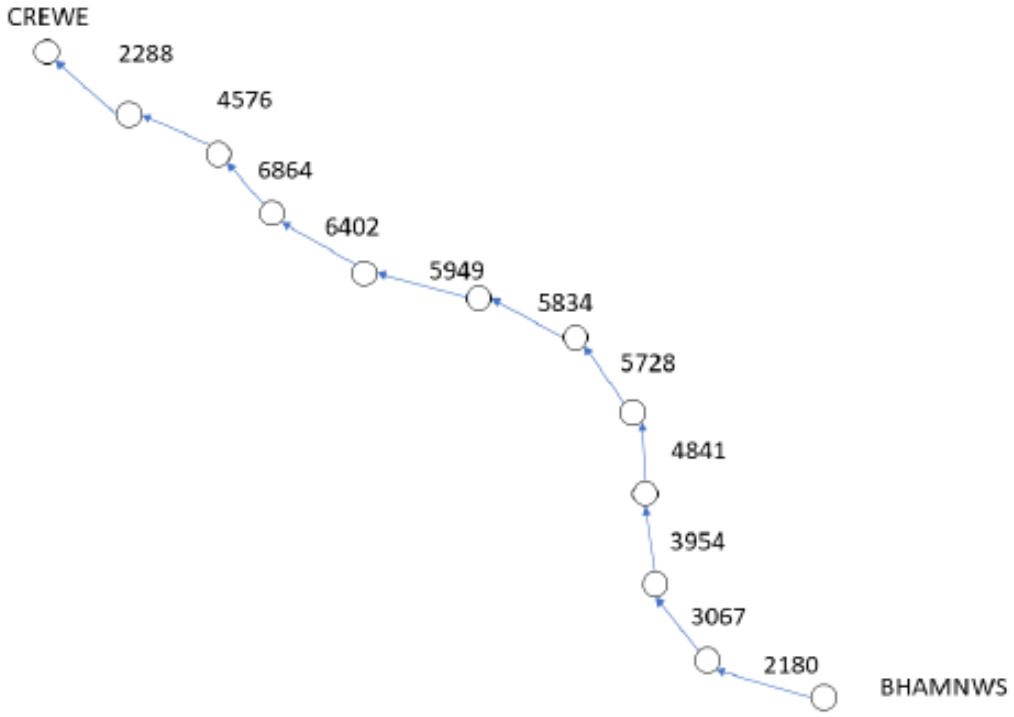
id	production schedule id	sequence	location code	event type	event time	advertised event time
1.74E+08	7507823	1	STRBDGT	A	22/12/2020 19:58	22/12/2020 19:58
1.74E+08	7507294	32	CREWE	A	22/12/2020 23:38	22/12/2020 23:40
1.74E+08	7507294	29	ALSAGER	D	22/12/2020 23:28	22/12/2020 23:28
1.74E+08	7507294	28	ALSAGER	A	22/12/2020 23:28	22/12/2020 23:28
1.74E+08	7507294	27	KIDSGRV	D	22/12/2020 23:24	22/12/2020 23:24
1.74E+08	7507294	26	KIDSGRV	A	22/12/2020 23:23	22/12/2020 23:24
1.74E+08	7507294	25	STOKEOT	D	22/12/2020 23:16	22/12/2020 23:16
1.74E+08	7507294	24	STOKEOT	A	22/12/2020 23:15	22/12/2020 23:15
1.74E+08	7507294	22	STONE	D	22/12/2020 23:08	22/12/2020 23:08
1.74E+08	7507294	21	STONE	A	22/12/2020 23:07	22/12/2020 23:07
1.74E+08	7507294	18	STAFFRD	D	22/12/2020 22:59	22/12/2020 22:59
1.74E+08	7507294	17	STAFFRD	A	22/12/2020 22:58	22/12/2020 22:58
1.74E+08	7507294	15	PNKRDG	D	22/12/2020 22:51	22/12/2020 22:51
1.74E+08	7507294	14	PNKRDG	A	22/12/2020 22:51	22/12/2020 22:51
1.74E+08	7507294	11	WVRMPTN	D	22/12/2020 22:43	22/12/2020 22:43

Estimated flow on Birmingham-Crewe Network

[CREWE ALSAGER KIDSGRV STOKEOT STONE STAFFRD PNKRDG WVRMPTN COSELEY SNOWDUD GALTILL BHAMNWS]

Commuter flow based on census data in 2011:

$$F = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 94 & 94 & 94 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 94 & 94 & 94 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 354 & 354 & 354 & 15 & 15 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 354 & 354 & 354 & 15 & 15 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 555 & 555 & 555 & 45 & 45 & 441 & 441 & 0 & 0 & 0 & 0 & 0 \\ 555 & 555 & 555 & 45 & 45 & 441 & 441 & 0 & 0 & 0 & 0 & 0 \\ 555 & 555 & 555 & 45 & 45 & 441 & 441 & 0 & 0 & 0 & 0 & 0 \\ 555 & 555 & 555 & 45 & 45 & 441 & 441 & 0 & 0 & 0 & 0 & 0 \\ 24 & 24 & 24 & 0 & 0 & 36 & 36 & 175 & 175 & 175 & 175 & 0 \end{bmatrix}$$



Daily flow estimated from the spatial model

f_{ij}^{ts} is the expected flow at time t on arc (i, j) on scenario $s \in S$.

Let H be the number of different types of carriages and let C^h, $h \in \{1, \ldots, H\}$ be the capacity of coach type h. Each train can be represented as a vector $(n_1, \ldots, n_H)$, where n_h is the number of coaches of each type in the train. Note that $C_{ij} = \sum_{h=1}^{H} n_h * C_h$. We seek a solution which satisfies the below;

$$\min \max_{i,j,t,s} \{f_{ij}^{ts} - C_{ij}\}.$$

To investigate

- how many students would want to travel between particular origins and destinations?
- what routes would they use?
- does this exceed capacity under different spreading schemes?

Work to continue this modelling is underway at the University of Bath.

Overall conclusions

Carriage Level

- There is scope for using low dimensional models [Huddersfield/ICMS]
- Fast to run, useful for What-If scenarios

Journey Level

- Loading of a train can be extended to estimate viral load [Bath/ICMS]
- Queuing model can also be extended and compared with RSSB

Network Level

- Data driven approach is essential
- Lots of potential for optimizing network .. If this is possible.