Reducing the Risk of Covid-19 Transmission on Trains

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KTN
Matt Butchers
Daisy Chapman-Chamberlain

Attendees
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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

\[ P_I = \frac{C}{S} = 1 - \exp \left( -\frac{I p q t}{Q} \right) \]

- \( P_I \) 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 \( \sigma \) 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 \( \beta_1 \) and \( \beta_2 \) 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

\[ \beta_1 = 1 \times 10^{-3} \]

\[ \beta_1 = 1 \]

\[ \beta_1 = 1 \times 10^{-2} \]
Simulations thanks to Simone Appela

ABM Model: Uniform

Uniform Distribution
Time elapsed [s]: 0
Total people infected: 0
ABM Model: Gaussian

Gaussian Distribution
Time elapsed [s]: 0
Total people infected: 0
Getting off from a train
Train comes to a halt and **passengers leave**

Assume that they leave as an **ordered queue**

\[
X_{n+1}(t) \quad X_n(t) \quad \text{Infected}
\]
Velocity based model

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

\[ f(r) = 0 \quad r < d_1, \quad f(r) = V, \quad r > d_2 \]
Social distance $d_1$

Exit velocity $V$

$x$
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

1. Train schedule timetable from a given day
2. Station names and location, travelling route information
3. Network graph plots with map locations
   - Coupled with local authority code
   - The spatial interaction model: predicted flow between any two stations (nodes)
   - A directed subgraph with nodes (train stations) and edges (existing train routes). Edges contain the passenger flow.
4. Combined with census data on daily community on trains
5. Crude commuting flow between any two stations (nodes)
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.

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Estimated flow on Birmingham-Crewe Network

Commuter flow based on census data in 2011:

\[
F = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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\end{bmatrix}
\]
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 \( C_{ij} = \sum_{h=1}^{H} n_h \ast C_h \). We seek a solution which satisfies the below:

\[
\min_{i,j,t,s} \max \{ f_{ij}^{ts} - C_{ij} \}.
\]
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.