Modelling passenger movement within trains of Paris suburban network

Rémi Coulaud[1, 2], Mathilde Vimont[2], Joshua Wolff[2]

[1]Laboratoire de Mathématiques d'Orsay
[2]SNCF Mobilités/Transilien

18 June 2021

Passenger distribution's impacts on railway operations

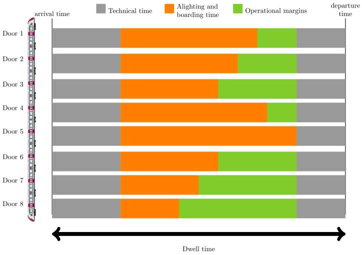


Figure: Critical door and dwell time

Figure: Transilien "Hector" testing and Zhang et al. (2017) Swedish experimentation

How Transilien measures trains load (I)?

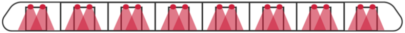


Figure: From APC measure of alighting (a) and boarding (b) passengers by door[1]

Conservation flow property for train k at station S

$$l_{k,S} = \sum_{s=1}^{S} b_{k,s} - a_{k,s}$$

One issue when replicating it at the coach scale: communicating coaches

[1] In our context door = coach

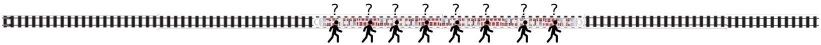
Boarding and alighting flow: a solution?

Boarding and alighting flow: a solution?

Step 1: Brian boards coach 3

Boarding and alighting flow: a solution?

Step 2: where is Brian?



Boarding and alighting flow: a solution?

Step 3: Brian alights from coach 1

Boarding and alighting flow: a solution?

How to obtain load by coach?

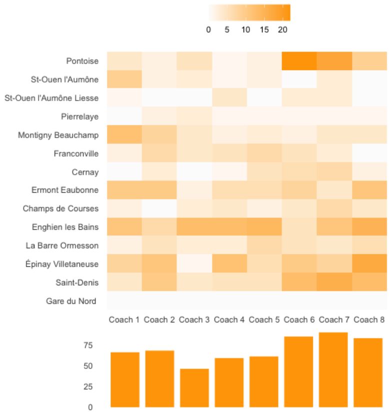
Boarding and alighting flow: a solution?

> How to obtain load by coach?

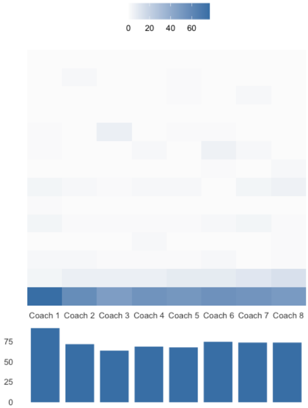
To simplify the problem, we consider:

1. alighting and boarding passengers density, not individual trajectory
2. alighting and boarding passengers at the trip scale, not at the station scale

From station scale to trip scale

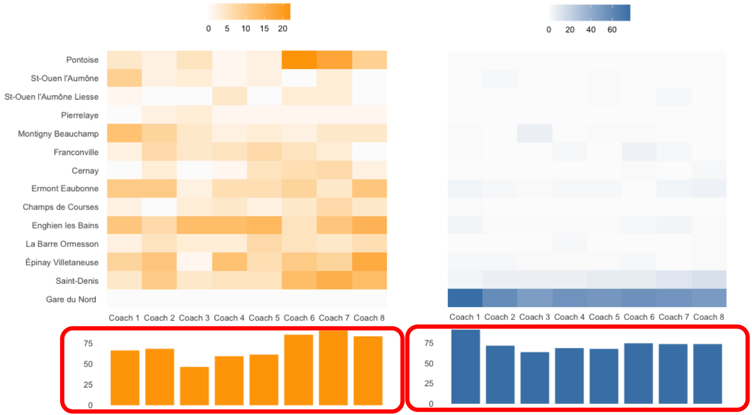


(a) Boarding passengers



(b) Alighting passengers

From station scale to trip scale



(a) Boarding passengers (b) Alighting passengers

State of the art

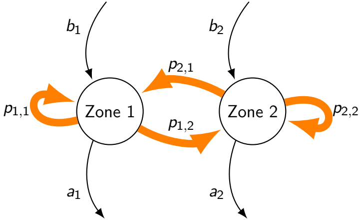
Figure: From macro to micro modelling

	Variables	Space	Data	Model	Scale
Krstanoski (2014)	boarding	platform	video	multinomial distribution	by zone (doors)
Seriani & Fujiyama (2019)	boarding	PTI	laboratory	multinomial distribution	by zone (layers around door)
Wang et al. (2011)	occupancy	building	no data	Markov chain	by zone (room)
Shelat et al. (2020)	occupancy	building	no data	Markov chain	by zone (room)
Zhang et al. (2008)	alighting and boarding	PTI	survey	cellular automate model	microscopic

To sum up

No exact similar problem in transportation literature but we take inspiration from Krstanoski (2014)

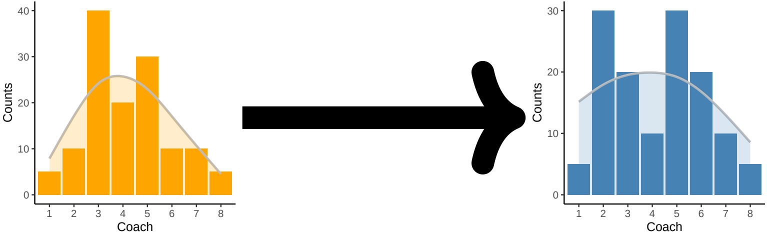
Methods: zone definition and notations



Notation	Description
$p_{i,j}$	proportion of passengers boarding coach i and alighting from coach j
$X_{i,j}$	shifted passengers boarding coach i and alighting from coach j
b_i	passengers boarding coach i
a_i	passengers alighting from coach i

Methods: goal and hypotheses

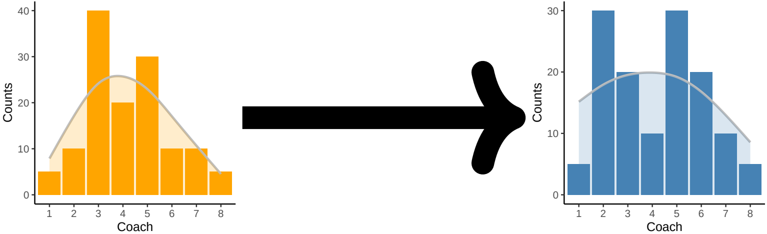
Goal: match boarding to alighting distribution
among coaches through shifted passengers $X_{i,j}$



Hypotheses:

Methods: goal and hypotheses

Goal: match boarding to alighting distribution among coaches through shifted passengers $X_{i,j}$



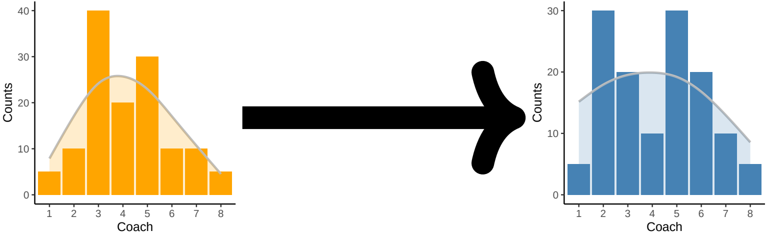
Hypotheses:

1. Passenger movement between coaches is parametric:

$$X_{i,\cdot} \sim \mathcal{M}(b_i, p_{i,1}, \ldots, p_{i,8})$$

Methods: goal and hypotheses

Goal: match boarding to alighting distribution among coaches through shifted passengers $X_{i,j}$



Hypotheses:

1. Passenger movement between coaches is parametric:

$$X_{i,\cdot} \sim \mathcal{M}(b_i, p_{i,1}, \ldots, p_{i,8})$$

2. Shifted passengers between coaches i and j is:

$$X_{i,j} = b_i p_{i,j}$$

Optimisation problem: a **least square** problem under constraints

The ideal problem we want to solve:

$$\min \quad \frac{1}{K}\sum_{k=1}^{K}\sum_{j=1}^{8}\left(a_j^k - \sum_{i=1}^{8} X_{i,j}^k\right)^2 \tag{1}$$

Optimisation problem: a **least square** problem under constraints

The problem we can solve with plug in hypothesis 2:

$$
\begin{aligned}
\min_{p} \quad & \frac{1}{K}\sum_{k=1}^{K}\sum_{j=1}^{8}\left(a_j^k - \sum_{i=1}^{8} b_i^k p_{i,j}\right)^2 \\
\text{s.t} \quad & \forall i,j,\ 0 \le p_{i,j} \le 1 \\
& \forall i, \sum_{j=1}^{8} p_{i,j} = 1
\end{aligned}
\tag{1}
$$

Optimisation problem: a **least square** problem under constraints

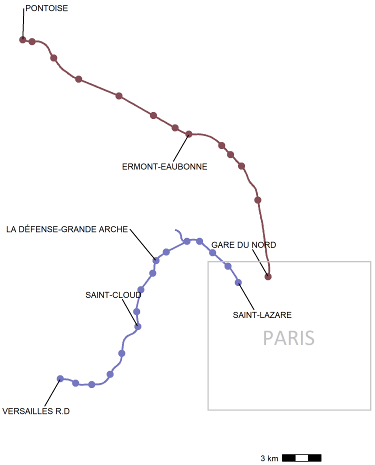
The problem we can solve with plug in hypothesis 2:

$$\min_{p} \quad \frac{1}{K}\sum_{k=1}^{K}\sum_{j=1}^{8}\left(a_j^k - \sum_{i=1}^{8} b_i^k p_{i,j}\right)^2$$
$$\text{s.t} \quad \forall i,j,\ 0 \le p_{i,j} \le 1$$
$$\forall i, \sum_{j=1}^{8} p_{i,j} = 1 \qquad (1)$$

Parameters interpretation as an adjacency matrix:

$$p = \begin{pmatrix} p_{8,1} & \cdots & p_{8,8} \\ \vdots & \iddots & \vdots \\ p_{1,1} & \cdots & p_{1,8} \end{pmatrix}$$

Data from 09/2020 to 04/2021 on lines H and L



	$\|S\|$	N trips	Mean crowding factor[2]
L	16	13,927	18 %
H	14	12,803	22 %

[2] Load divided by the seating capacity

Benchmark models: from no movement to uniform movement, where does the reality stand?

Name	Parameters	Idea
Static	$\begin{pmatrix} 0 & \cdots & 1 \\ \vdots & \iddots & \vdots \\ 1 & \cdots & 0 \end{pmatrix}$	boarding passengers stay where they board
Least square	$\cdots$	optimal proportions
Uniform	$\begin{pmatrix} \frac{1}{8} & \cdots & \frac{1}{8} \\ \vdots & \iddots & \vdots \\ \frac{1}{8} & \cdots & \frac{1}{8} \end{pmatrix}$	boarding passengers move with equal chance to each coach

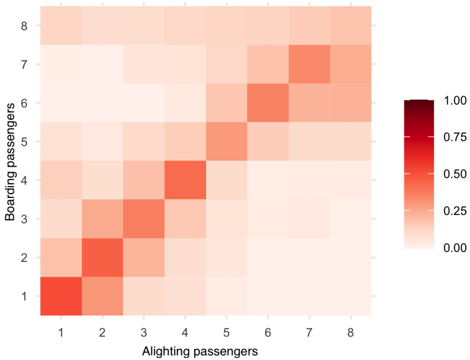
Our reference is a_i compare to $\sum_{j=1}^{8} b_i p_{i,j}$

Performance results

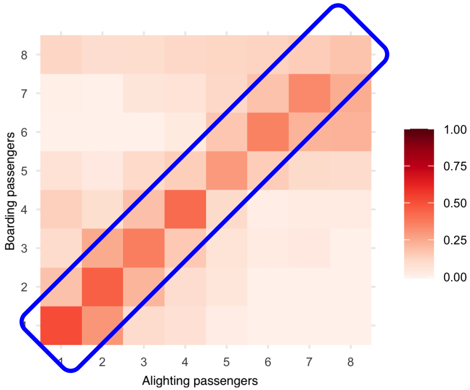
	H			L		
	MAE	RMSE	Extreme loads	MAE	RMSE	Extreme loads
Static	86	41	1,059	69	35	121
Uniform	71	30	0	55	26	0
Least square	48	21	4	33	15	1

- Need to move boarding passengers
- A simple model is not enough

Estimated parameters and passenger movement

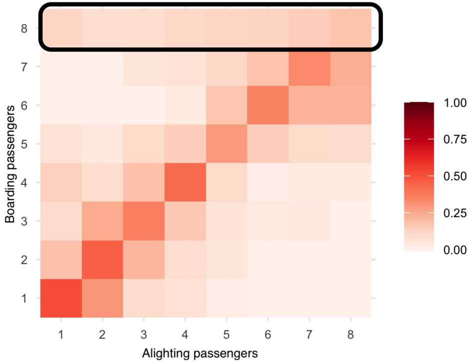


Estimated parameters and passenger movement



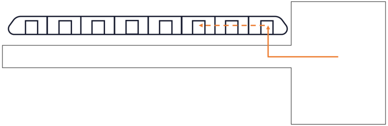
1. few movements when boarding

Estimated parameters and passenger movement



1. few movements when boarding
2. apart from specific coaches

Estimated parameters are driven by some specific stations



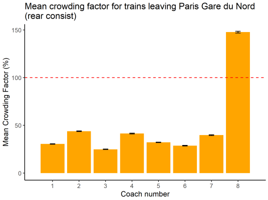


Figure: Gare du Nord

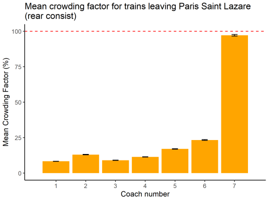


Figure: Paris Saint-Lazare

Crowding factor impacts passenger movement

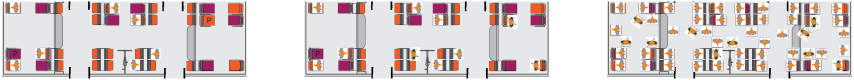


Figure: Crowding factor impacts passenger movement

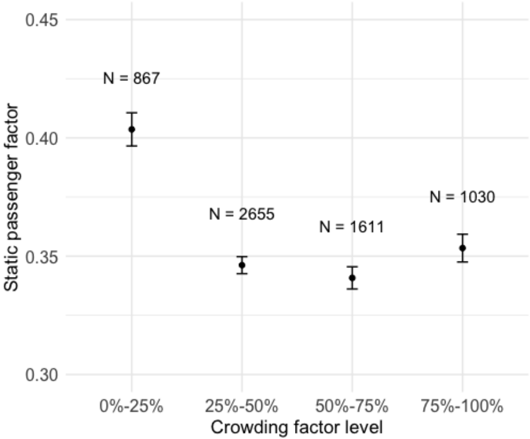
Crowding factor impacts passenger movement

Static passengers factor: $\text{spf} = \frac{\sum_i p_{i,i}}{\sum_{i,j} p_{i,j}} \in (0,1)$

$$p = \begin{pmatrix} p_{8,1} & \cdots & p_{8,8} \\ \vdots & \iddots & \vdots \\ p_{1,1} & \cdots & p_{1,8} \end{pmatrix}$$

- $\text{spf} = 1$: all passengers stay where they board
- $\text{spf} = 0$: all passengers move at least from one coach when they board

Crowding factor impacts passenger movement



Conclusion and perspectives

Conclusion:

- Passenger movement are important for communicating coaches trains
- Movements are consistent with intuition: few movements far away apart from specific situations
- Crowding factor changes passenger movement behaviour within trains

Conclusion and perspectives

Perspectives:

1. How RTCI affect passenger movement within trains
2. Estimated transition matrices for each station departure
3. Cross APC measures with weight measures

Thank you for your attention!
Questions?

Bibliography

Krstanoski, N. (2014), 'Modelling passenger distribution on metro station platform', *International Journal for Traffic & Transport Engineering* .

Seriani, S. & Fujiyama, T. (2019), 'Modelling the distribution of passengers waiting to board the train at metro stations', *Journal of Rail Transport Planning & Management* .

Shelat, S., Daamen, W., Kaag, B., Duives, D. & Hoogendoorn, S. (2020), 'A markov-chain activity-based model for pedestrians in office buildings', *Collective Dynamics* .

Wang, C., Yan, D. & Jiang, Y. (2011), A novel approach for building occupancy simulation, *in* 'Building simulation', Springer.

Zhang, Q., Han, B. & Li, D. (2008), 'Modeling and simulation of passenger alighting and boarding movement in beijing metro stations', *Transportation Research Part C: Emerging Technologies* .

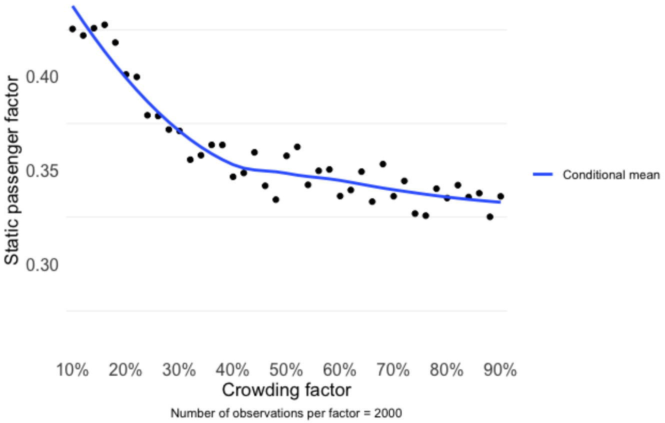
Zhang, Y., Jenelius, E. & Kottenhoff, K. (2017), 'Impact of real-time crowding information: a stockholm metro pilot study', *Public Transport* .

Robust check for scale

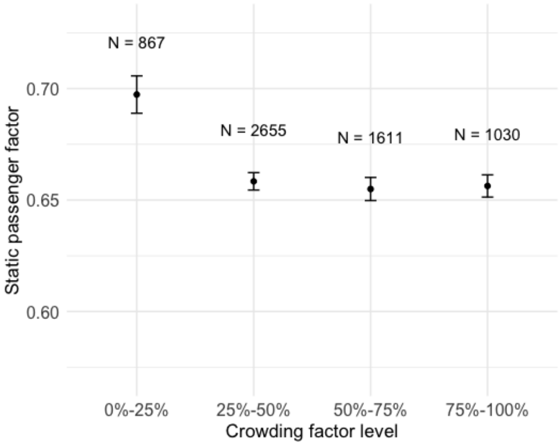
		L way	L line	H way	H line
Boarding	Simple	28 (±0.5)	29.1 (±0.5)	22 (±0.2)	23.5 (±0.3)
	Double	28.2 (±0.5)	29.6 (±0.5)	22.4 (±0.2)	24.3 (±0.3)
	Quadruple	28.4 (±0.5)	30.5 (±0.5)	-	-
Alighting	Simple	29.9 (±0.5)	40 (±0.5)	22.9 (±0.3)	24.4 (±0.3)
	Double	30.2 (±0.5)	39.6 (±0.5)	23.1 (±0.3)	24.9 (±0.3)
	Quadruple	30.4 (±0.5)	41.3 (±0.5)	-	-

Table: MAE error at the coach scale for different dataset split

Robust check for load effect (1/2)



Robust check for load effect (2/2)



Stability of parameters estimation