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An agent-based model for modal shift in public transport

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Abstract

Modal shift in public transport as a consequence of a disruption on a line has in some cases unforeseen consequences such as an increase in congestion in the rest of the network. How information is provided to users and their behavior plays a central role in such configurations. We introduce here a simple and stylised agent-based model aimed at understanding the impact of behavioral parameters on modal shift. The model is applied on a case study based on a stated preference survey for a segment of Paris suburban train network. We systematically explore the parameter space and show non-trivial patterns of congestion for some values of discrete choice parameters linked to perceived wait time and congestion. Work in progress includes the application of optimization algorithms to the model to search for optimal compromises between congestion in different modes.

Keywords: Modal shift; Public transport disruption; Agent-based modeling; Model exploration

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Disruptions in public transport networks are not rare events, often worsened by an increased complexity of these networks and their management (Dekker et al., 2018). Network resilience is then tightly linked to patterns of modal shift Stamos et al. (2015), and a better understanding of these is crucial both from a theoretical and operational viewpoint. In that context, users have to make decisions in a limited time and under partial information. The study of modal shift under disruption is therefore improved when taking into account users behavior and a detailed representation of users cognition (Brisbois, 2010). More particularly, the role of information provided in real time can in some cases become crucial, as rerouting may in fact increase the congestion in other parts of the network and ultimately increase the average travel time (Chatterjee et al., 2002; Chorus et al., 2006).

To study mechanisms linking information given to users with modal shift, and more generally the evolution of multi-modal network flows under disruptions, agent-based modeling has been highlighted as a relevant approach (Leng and Corman, 2020b). For example, Leng and Corman (2020a) show that the issue time of information has a significant impact on the total congestion. Agent-based models are used in similar studies of modal share, such as by Baindur and Viegas (2011) for freight. Raney et al. (2003) describe an application of the Matsim model, which is a data-driven agent-based and activity-based transport model, to a large sample of Switzerland transport network. The Matsim model can be applied at large scales in a reproducible manner, such as in the case of Ile-de-France illustrated by Hörl and Balac (2020).

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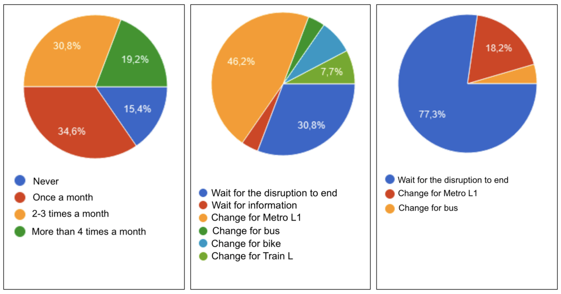

Fig. 1. Results of the stated preference survey. *(Left)* Number of times a month users experience a disruption; *(Middle)* Behavior of users when no information is given; *(Right)* Behavior of users when a 10 minutes traffic stop is announced.

Large transport agent-based models such as Matsim however require an extensive parametrisation on real data, are difficult to systematically validate given their runtime and large parameter space, and despite their high modularity can be tuned only to some extent regarding a precise description of users behavior in public transport and their interactions with a network disruption. This paper therefore proposes to introduce a simple and stylised agent-based model to understand the role of information and user behavior in modal shift under disruptions in public transport. With a reduced computational complexity but also parameter space to explore, under limited requirements for data, such a model can be used to systematically explore if some qualitative stylised facts are robustly found under different scenario, and possibly extended into a decision-making tool. Our contribution is threefold: (i) we contextualize the construction of the model with a reduced stated preferences survey, applied on a case study in the Parisian public transport network on a specific segment often subject to disruption; (ii) we introduce the simple agent-based model as an open-source tool, which can be extended or modified to test concurrent hypotheses on user behavior; (iii) we proceed to a systematic exploration of the model parameter space, unveiling some non-linear patterns and a counter-productive reaction of users to the disruption in terms of congestion for some scenarios.

We first proceeded to a small size stated preferences survey , in order to have a qualitative overview of processes needed in the model and to have a case study for model application. Martin et al. (2016) have indeed shown that there exists a high heterogeneity in user reaction to disruptions. We choose to study the line A of the *RER* suburban train in Paris, which has the highest load in the region and has a non negligible frequency of disruption. We focus on a subpart of the network, in order to sample users which have a higher chance of realizing a given origin-destination pattern, and for which several modal alternatives exist. Therefore, the segment *Etoile-La Defense* was chosen, as it features alternative trips with the *Metro Line 1* and several bus lines.

We surveyed a total of $N = 48$ users, among which a subsample of $N = 27$ were regular users for which the full questionnaire was given. Main results which can inform our model context are shown in Fig. 1. We first confirm that disruptions are indeed frequent on the line, as around 50% of users experience a disruption at least twice a month. We then find that under no information, user behavior is heterogeneous and a large part shifts to alternative itineraries. Finally, when users are informed of a 10 minutes disruption, on the contrary more than 75% decide to wait on place. Therefore, the model must include various modal shifts, but also take into account how perceived wait time will influence user choice.

The agent-based model is based on two types of agents: users and RER trains. The simulated segment of the network is included for the main mode (RER train) and alternative modes (metro, bus, taxi, bike, walking). Main mode is simulated in full granularity, i.e. including train boarding, train capacity and train alighting. Other modes are simulated as queues with a given capacity. One simulation covers peak hours (180 time steps) with stationary Poisson arrival of users for each mode. At each time step: (i) users waiting for a train evaluate a discrete choice utility difference (between waiting and shifting to an other mode) given by $U_i = \beta_c \cdot c + \beta_\tau \tau$ where c is perceived congestion given by the current number of user waiting (normalized by platform capacity) and τ is perceived time proportional to user current travel time (time since departure) and current waiting time between trains, and switch mode accordingly with a probability of $p_i = 1/(1 + \exp \Delta U_i)$ and with fixed probabilities across other modes; (ii) next train possibly enter station and users board at a given speed and given train capacity, while users alights at the end of the segment if a train is in station; (iii) train queue on the segment is simulated with proper speeds; (iv) other modes are simulated

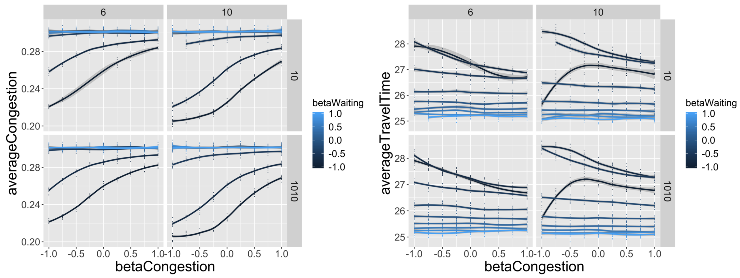

Fig. 2. Model exploration results. *(Left)* Average congestion as a function of β_c, for varying β_τ (colour), train interval (columns) and train capacity (rows); *(Right)* Average travel time for same parameter values.

as queues with a given user capacity. Model results are assessed with indicators giving the average travel time and average congestion over the peak hour and all users.

The model is implemented in NetLogo which is specifically suited for such agent-based simulations. The open-source code of the model and results is available as a git repository at `https://github.com/JusteRaimbault/ReportMasse`. We systematically explored model parameter space by using the OpenMOLE model exploration software (Reuillon et al., 2013), which allows embedding any type of model, provides a seamless access to high performance computing infrastructures, and integrates state-of-the-art model validation and exploration methods. We run 10 stochastic repetitions of the model, for parameters β_c, β_τ, train capacity, train arrival interval within a grid, corresponding to $\simeq 24,000$ runs of the model. We show in Fig. 2 the variation of average travel time and congestion as a function of β_c. We find an interesting non-linear behavior of travel time for low values of β_τ (dark blue, right column), where travel time is maximal around a neutral position of users to congestion: in that context of a low tolerance to waiting, either a low or high tolerance to congestion are better than being indifferent. Regarding congestion, it increases with both discrete choice parameters but differently in the various disruption scenarios.

These preliminary results show how this model can be applied to explore complex congestion patterns in the stylised network following interactions between different components of user behavior. Work in progress includes the application of a genetic algorithm for optimization to the model with the aim to explore compromises between congestion in the train and congestion in alternative modes.

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