

# Research Summary<sup>1</sup>

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**Problem Statement** Nowadays multimodal (public) transportation systems are operated at their capacity limits, and even small perturbations can negatively effect whole economies. Tight budgets, missing investments, and infrastructure constraints do not promise remedy. On the other hand, more and more data on the systems' operational states is available for little cost. The efficient use of that data, e.g. in form of minutes-by-minutes forecasts, requires transportation authorities and operators to understand the network character of those systems including their complicated dynamics: What are the bottlenecks in a particular mode of operation? How do perturbations spread across the different modes and lines?

**Scope** Apart from some exceptions, the different modes and lines of a multimodal transportation network (TN) do not share infrastructure elements, and it is the passenger who connects them through transfers.



Figure 1: Passengers spread perturbations across the different modes and lines of a transportation network

Thus, my research focuses on the passenger transfers with the goal to smooth them in degraded modes of operation; e.g. by delaying vehicle departures, inserting supplementary vehicles into operation, introducing short-turns etc. [1]

**Context** My research, in form of a Ph.D. thesis (from September 2013 until approximately the end of 2016) under the supervision of Ph.D. Stefan Haar, contributes to the academic/industrial project “Modelling, Interoperability, and Communication” (MIC), which is under the technological leadership of the technical research institute IRT SystemX and thus funded by the French program “Investissements d’Avenir”. MIC brings together several academic and industrial partners; among others Alstom Transport, Ifsttar, INRIA, Renault, and SNCF. Apart from the supervision of multimodal transportation networks, it also targets car sharing, and robust timetable planning; with a common simulation platform for the validation of every contribution. More information about MIC can be found at the following link:

<http://www.irt-systemx.fr/project/mic>

**Alternative Approaches** A look into the literature reveals that several mathematical models for the analysis of TNs do exist that have been used for - sometimes more and sometimes less successfully - single modes or lines. To name a few, they comprise purely statistical models, network flow models [2], models derived from the Max-Plus Algebra [3], and multi-agent systems (MASs). Now statistical models do obviously require historical data, and chances are high that this data is not available; especially for degraded modes of operation involving very unpredictable asynchronous events such as passenger incidents. Turning towards network flow models, note that they are based on the assumption that all passengers travel according to cost-efficient paths, which requires the modeller to set up cost functions; also a very difficult

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task for unforeseen degraded modes of operation. Moreover, network flow models do not explicitly account for the vehicle movements and their interactions with the passengers. Then, models derived from the Max-Plus Algebra currently focus on the synchronization of vehicle arrivals and departures at local points in the networks. Passenger movements and the uncertainty that comes along with them are not included, and there seems to be no easy way to add them. Finally, MASs can capture the structure and the dynamics of a TN at hand at an almost arbitrarily level of detail; however with a computational burden that limits the analysis of their huge state spaces to the simulation of single solution trajectories, e.g. by employing the Monte Carlo method.

**Own Approach** The brick of my research is a stochastic hybrid automaton (SHA) model with continuous and discrete Petri nets as the basic modelling blocks. A mode of this automaton model refers to a discrete state in the vehicle operation of the TN at hand: Which vehicle is stopped at which station? Which vehicle is on its way to which station? The driving times between the stations are a priori defined constants. However, this assumption does not render the vehicle movements deterministic. In fact, every mode defines a set of continuous passenger transfer flows between the vehicles and the stations. These transfer flows induce probabilistic passenger load-driven mode transitions (a vehicle can depart because no more passenger wants to board it, etc.).

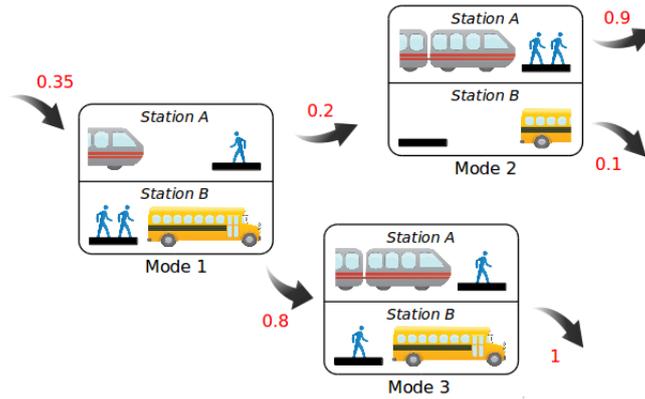


Figure 2: Schematic representation of an SHA model's mode transitions

The SHA model has its roots in a fine-grained deterministic and purely discrete MAS: Every vehicle agent is parked or executes a mission, in which its mission specifies a fixed-route deadheading or transportation service. The passenger agents are grouped into a finite set of trip profiles, and every trip profile unfolds a tree in TN's modelled infrastructure that can account for competing vehicle missions.

The passengers make the MAS a highly-populated system that prohibits the analysis of its discrete state space. Thus, the next logical step was to fluidfy all passenger transfers while keeping all vehicle movements discrete [4]; giving rise to a deterministic hybrid automaton (DHA) model with multiphase flows that captures the passengers' different trip profiles.

Now compared to the DHA model, the SHA model has as input estimations of the passenger loads [5, 6]. Moreover, the deterministic passenger arrival processes were replaced by their stochastic counterparts: a set of decoupled (for every station one) Itô-stochastic balance equations for the different passenger loads governs the continuous passenger flow dynamics in every mode, in which the diffusion terms capture the uncertainty that comes along with the passenger arrival processes.

**Ongoing Work** Currently, the SHA model is in implementation, and first simulation runs of some use cases are planned for the first trimester of 2016.

## References

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