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Forecasting Passenger Loads in Transportation Networks

Stefan Haar and Simon Theissing

MExICo team, INRIA and LSV, CNRS & ENS de Cachan
Cachan, France

Abstract

This work is part of an ongoing effort to understand the dynamics of passenger loads in modern, multimodal transportation networks (TNs) and to mitigate the impact of perturbations. The challenge is that the percentage of passengers at any given point of the TN that have a certain destination, i.e. their distribution over different trip profiles, is unknown. We introduce a stochastic hybrid automaton model for multimodal TNs that allows to compute how such probabilistic load vectors are propagated through the TN, and develop a computation strategy for forecasting the network's load a certain time into the future.

Keywords: Stochastic hybrid automata, Transportation networks, Fokker-Planck Equation

1 Introduction

We continue here the work begun in [6] for capturing both the discrete vehicle movements and continuous passenger transfers in a multimodal public transportation network (TN). In [6], a deterministic hybrid automaton (DHA) model was used, so as to overcome via fluidification the state space explosion that makes fully discrete models intractable. For the specification, we used both discrete and continuous Petri nets (PNs) as basic modelling blocks [4], where the marking of the continuous places and the flows between them were vectorial instead of scalar. In fact, we integrated the numbers of passengers belonging to different trip profiles, i.e. having different destinations, as components of vector markings and -flows, with routing matrices relating them.

Now - and this is the starting point of the present work - a *real* TN is everything but deterministic. On the one hand, there are highly unpredictable asynchronous events for which statistical data is hard to obtain. It is thus difficult to include them in the daily network operation [11], e.g. by means of minute-by-minute or hourly forecasts. Typical examples are passenger incidents. Now, note that - apart from few exceptions - such incidents originate locally, in one mode or line, and

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then propagate to other modes or lines by passenger transfers. These transfers are predictable, not necesseraly deterministic, if one knows the destination or trip profile of the passengers; but in general, this can only be known through probabilistic estimates. Finally, there are the “continuous” passenger arrival processes for which statistical data is easier to obtain: How many passenger will arrive at a station at what time? According to which route, including which vehicle missions, will they travel?

Here, we will extend the DHA model from [6] in that we will replace all deterministic passenger arrival processes by their stochastic counterparts, and, in doing so, introduce a stochastic hybrid automaton (SHA) model with jumps between its discrete modes, at a priori equidistantly-spaced discrete points in time, defined a priori. The literature reveals many predecessors of our SHA model, notably in the past two decades, with every approach introducing the uncertainty at a different point in the model dynamics. For instance, the authors of [12] extended the dynamics underlying a PN-DHA model in that the jumps between the discrete modes are either exponentially distributed or immediate; with a weighting function as a means to resolve conflicts among simultaneously enabled immediate transitions [1]. However, in this modelling approach the discrete jumps are decoupled from the continuous states, and the latter evolve according (acc.) to deterministic differential balance equations; the authors of [7] bridge the gap between the continuous states and the mode jumps by means of a guard function. Finally, the deterministic balance equations were replaced by normally distributed balance equations in [13]. Outside the framework of PNs, the authors of [8] introduced an SHA model that exhibits state-driven (forced) jumps between the discrete modes subjected to sets of stochastic differential equations (SDEs), one such set per mode. This approach was extended in [3] in that the mode transitions are no longer limited to forced jumps, but can be initiated by spontaneous jumps with state-dependent transition rates as well. The author of [2], then showed how the SHA model from [3] can be formulated in an equivalent system of integro-differential equations together with boundary conditions. Also notice that the authors of [10] presented a grid-based asymptotic approximation method for a backward reachability problem subjected to the dynamics of an SHA model that encounters spontaneous jumps between its discrete modes; with a system of SDEs assigned to every mode. That system is approximated by a Markov chain following a space and subsequent time discretization; whereas in our approach the discretization of the time precedes the discretization of the space, and the latter comes along with a numerical integration of the continuous states in a discrete mode.

In the rest of this paper, we will discuss the specification of TN’s infrastructure in our vectorial SHA model, and the vehicle operation as well as the routing of all passenger flows thereon (Sec. 2 on p. 51) . We will then elaborate the SHA model’s time-continuous dynamics, before pinpointing all mode transition times to an equidistantly-spaced mesh, which can be regarded as a first major step to render forecasts of the model’s hybrid state feasible (Sec. 3 on p. 56). Next, we will integrate the SHA model’s discrete-time approximation into a computation strategy which