hEART 2017
6th symposium arranged by European Association for Research in Transportation
Haifa, Israel, 12-14 September 2017

Extended abstract

Hybrid traffic simulation of an innovative catenary-free electric bus service

Riccardo Scarinci [1] riccardo.scarinci@epfl.ch
Michel Bierlaire [1] michel.bierlaire@epfl.ch
Alessandro Zanarini [2] alessandro.zanarini@ch.abb.com

15 March 2017

---

[1] École Polytechnique Fédérale de Lausanne (EPFL), School of Architecture, Civil and Environmental Engineering (ENAC), Transport and Mobility Laboratory (TRANSP-OR), Switzerland, `transp-or.epfl.ch`

[2] ABB Corporate Research Center, Baden, Switzerland

Introduction

The TOSA bus system is a revolutionary catenary-free electric bus concept that includes small short-range on-board batteries and a series of fully automated fast charging stations installed at specific bus stops. The automatic fast-charging stations partially replenish the bus batteries in a few seconds whenever a bus arrives at the bus stops. This system has been implemented in a pilot test in the city of Geneva, Switzerland, in 2013. A decision support tool, called myTOSA, has been developed to facilitate the planning of a public transport bus network of TOSA busses. This tool is composed of several modules for computing the optimal configuration of a TOSA solution, including an energy consumption module that models the consumption of the on-board battery (Chen *et al.*, 2014).

This paper presents a complementary module of this decision support tool, a traffic simulation that models the movement of TOSA busses in a specified bus network. The traffic simulation allows the evaluation of key performance indicators (KPI), like the battery state of charge, in multiple scenarios, including extreme cases.

The methodological challenges of this work are several. Examples are the identification of the elements and dynamics to simulate, the definition of the simulation scale, i.e. macro-, meso-, micro- or nano-scopic, and the integration with the other modules of myTOSA. A further challenge is the definition of a simulation that is robust to missing data. The traffic simulation should be usable at an early stage of the planning, where information such as intersection locations, traffic light phases and traffic conditions are unknown.

To address these challenges, we develop a hybrid simulation that includes macroscopic elements like traffic flow, microscopic elements like individual passengers, and elements represented by random variables like unknown intersection locations. In addition, an interface with the nanoscopic energy consumption module is implemented. The traffic simulation returns the probability distributions of the KPIs useful to practitioners to evaluate extreme cases.

We first introduce the structure of the simulation framework, and then we describe how we integrate a nanoscopic energy consumption model into our hybrid traffic simulation.

1 Simulation framework

The simulation framework defines the structure of a discrete event traffic simulation of TOSA busses (Bierlaire, 2015). We identify the main elements that should be represented, such as origin-destination matrixes, nodes and arcs, passengers and drivers (see Figure 1).

To compensate the lack of information, several elements are described by their statistical properties. To clarify this concept, we describe how we represent intersections. In our hybrid model, the number and location of intersections in the road network is unknown a priori. Therefore, we represent traffic lights, bus priority stops and roundabouts as random variables. We define the probability

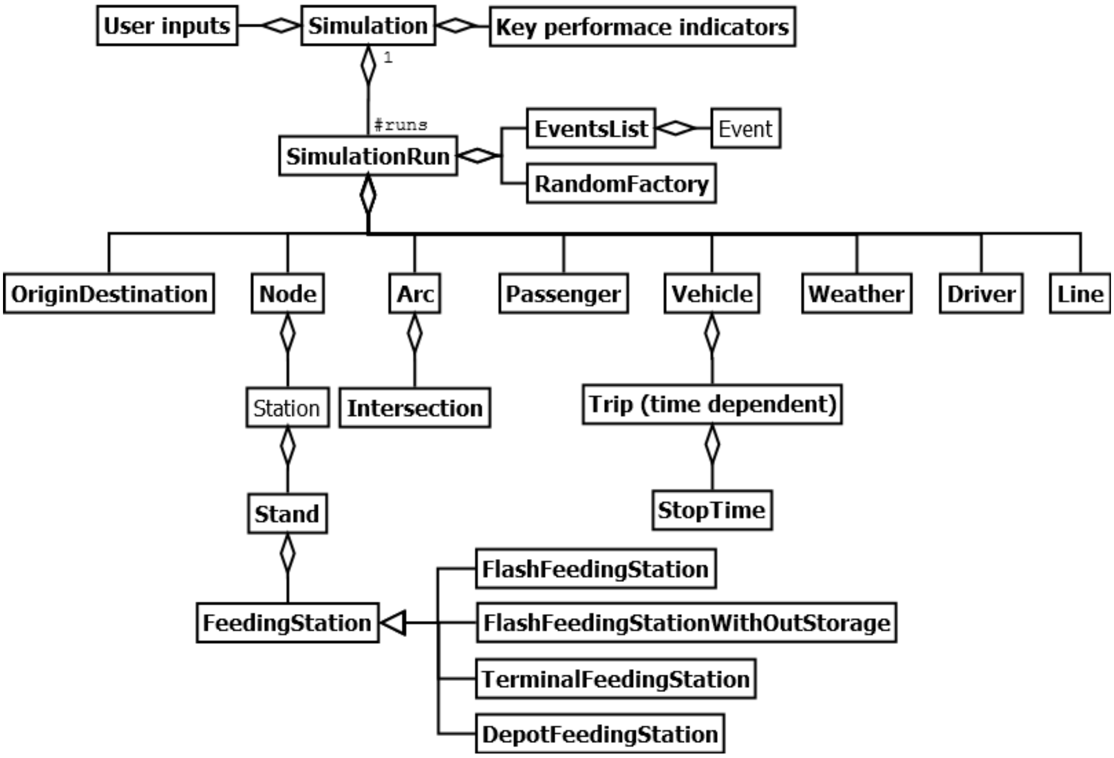

Figure 1: Main elements of the traffic simulation.

distribution of the number of intersections and their locations using information from geographic information system databases. Based on this, we evaluate the impact that they have on the bus dynamics by sampling probable speed profiles, and then evaluating the resulting KPIs. Note that the location of intersections is the main factor influencing the speed profile of a bus, and, as a consequence, the energy consumption (Fernandez, 2010).

The same approach is used for other elements. For example, the total weight of the passengers on board is another crucial factor influencing the energy consumption. Therefore, we use homogeneous and non-homogeneous stochastic Poisson processes to mimic passenger arrivals and embarking. Each passenger is generated with a weight drawn from a distribution representing the general population weight. Empirical distributions from the literature are used for discrete and continuous random variables representing the elements of the system.

The state variables, describing the status of the system, are updated at the occurrence of specific events, and time is discrete. The traffic simulator uses the state-of-the-art methodologies in modeling, simulation and traffic theory to represent the unique case of the TOSA system.

Energy consumption

Whiting the myTOSA decision support tool, the energy consumption model is a detailed representation of the physical components of the bus that influence the

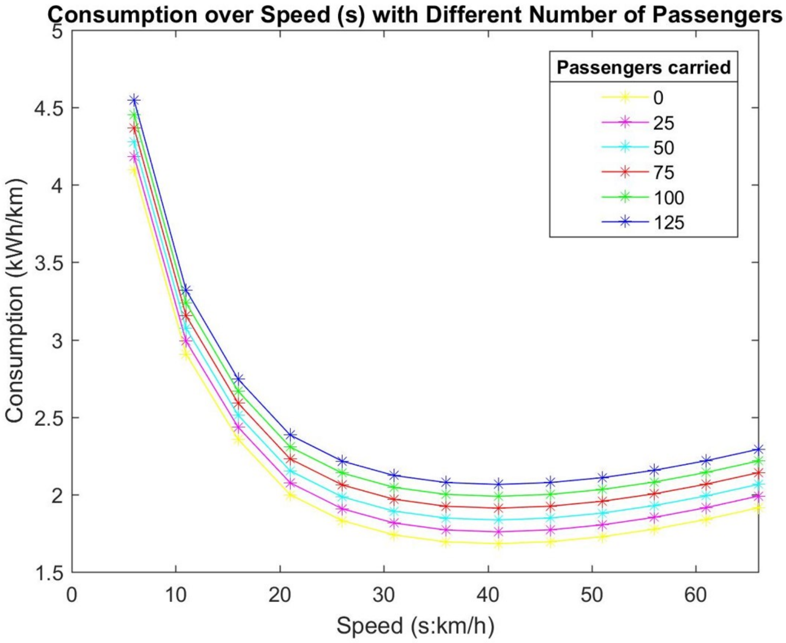

Figure 2: Example of energy consumption induced by the variations of two parameters: speed and number of passengers.

energy consumption. Examples of these components are the traction system, the cell chemistry and type, the type of auxiliary for cooling and heating. This model can be classified as nanoscopic. It is used to give a precise indication of the energy consumption of the bus in a specific setting.

This nanoscopic energy consumption model cannot be used directly in the traffic simulation due to the computationally expensive performance. Moreover, the investigation space of the scenarios is extremely vast, given the stochastic nature of several elements in the traffic simulation, e.g. intersections. To decrease the computational time, instead of calling the battery model directly at every time step for every bus, an analytical representation of the battery model is used. We define an analytical formulation of the energy consumption as a function of the most relevant parameters. The parameters are identified using the battery model as an empirical experiment to generate energy consumption values for different parameter values. For each parameter, we identify the lower and upper bound, and the step between the bounds. Then, we fix a subset of parameters, and we vary the others to estimate the energy consumption. Figure 2 shows an example of the energy consumption varying the bus speed and the number of passengers.

We estimate a polynomial model approximating the output of the energy consumption model using the generated data. We test different specifications, from degree 1 to 5, and observe the coefficient of determination as well as the root-mean-square-error ($RMSE$) using a cross-validation set. The results are listed in Table 1.

The estimated function is used by the traffic simulation to simulate the bus consumption over a large number of scenarios. The scenarios with the most critical

Table 1: Comparison of polynomial regressions of different order

	First	Second	Third	Fourth	Fifth
Coefficient of determination	0.8127	0.9315	0.9582	0.9693	0.9739
RMSE	1.9579	1.1811	0.9249	0.7924	0.7306

KPI values are re-evaluated with a direct call of the nanoscopic energy consumption to obtain more accurate results.

Conclusions

We develop a hybrid traffic simulation model of a catenary-free electric bus. Elements are represented at different modeling scales and, when there is a lack of information, they are represented as random variables. This approach is robust to missing data and allows evaluating the key performance indicators in an early stage of the planning phase. Thanks to the integration of a macroscopic representation of the nanoscopic energy consumption model, we can to evaluate a multitude of scenarios in a short computation time. This allows the identification of extreme cases that require a more accurate evaluation.

References

Bierlaire, M., 2015. Simulation and optimization: a short review. *Transportation Research Part C: Emerging Technologies* 55, 4–13.

Chen, J., Bierlaire, M., Robenek, T., 2014. *myTOSA: simulation tool for the dimensioning, commercial promotion and case study set-up for ABB's revolutionary catenary-free 100% electric urban public mass-transportation system.* Technical Report TRANSP-OR 140430. EPFL.

Fernandez, R., 2010. Modelling public transport stops by microscopic simulation. *Transportation Research Part C: Emerging Technologies* 18, 856–868.