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A Dynamic Multiagent Simulation of Mobility in a Train Station

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Abstract

Modeling and simulating activities in and around train stations is a challenging task. Indeed, it implies the consideration of a dynamic and heterogeneous set of actors, obeying to different rules and control systems. In this paper, we propose a multi-agent model for such simulations. The proposal comprises three parts. The first part is a multi-agent simulation model of travelers together with their interaction with the station platform. Passengers adapt their behavior to the other travelers while pursuing their travel objective, and in interaction with the available information sources, either local at the station, or personalized (through their smart phones for instance). The modeling of this traveler's information system is the second part of the model, where transportation operators are able to define strategies regarding the type of information to be provided, their frequency, and the medium used to broadcast it. Finally, the third part of the model is the management platform of the train station, which monitors both trains and pedestrians behaviors in the station. The platform is responsible for the optimization of the traffic fluidity and passengers' safety and proposes actions related to crowd deviation and access control. The architecture advocates for a closed-loop modeling between the simulation, the train station management and the traveler information, allowing for the testing of whole control systems instead of specific strategies.

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Keywords: Multiagent simulation; Train station; Traveler information; Regulation platform

1. **Introduction**

Mobility policies makers need decision support systems to decide which transportation policies they should implement. The progressive increase in the complexity of railway stations' infrastructure renders the task difficult. Train stations are becoming more and more connected. Large amounts of data are being collected on a daily basis in train stations. Mobile applications (Chandakas et al.(2015), Lopez et al. (2017)), smart card data (Leurent et al. (2017), Van den Heuvel et al. (2014)), video surveillance (Ganansia et al. 2014), Wi-Fi and bluetooth sensors (Van den Heuvel et al. (2014)) are some of the tools that are being used to collect information on pedestrian and train traffic. Exploiting this data offers a new opportunity to analyze and predict the behavior of modern transport networks. This leads to enhancing traffic operations and fluidifying crowd flows in train stations. One of the ways to use the generated data is to use simulation as a tool that allows testing strategies and multiple scenarios without impacting the real traffic as described in (Abadi et al. (2015), Hu et al. (2012)). In addition, simulation can be used for a more efficient management of crowd flows in stations.

Several models that simulate pedestrian flows on a macroscopic (aggregate values) (Huang et al. (2009), Hoogendoorn et al. (2015), Jiang et al. (2009)) and microscopic scale (individual interactions and characteristics) exist (Wijermans (2011), Bandini et al. (2011), Antonini et al. (2004), Hoogendoorn et al. (2004), Helbing et al. (1995)). However, only a few were developed specifically for train stations. In (Fruin (1971)), a macroscopic model was developed in order to evaluate the usage and level-of-service of pedestrian facilities in railway stations. Using data from various sources, a dynamic demand estimator was calibrated and used to feed the pedestrian model with the necessary input to estimate traffic conditions in terms of flow, travel times, speed and density. Though macroscopic models allow predicting traffic conditions in walkways and concourse areas, they are not capable of capturing microscopic interactions between pedestrians on stairs, escalators or train doors. These interactions can sometimes have a significant effect on congestion and thus on train waiting times on platforms. For these reasons, microscopic simulation and mainly agent-based simulations, which adopts an individual-centered approach, are one of the most relevant paradigms to design and implement pedestrian models for applications where individual movement is important to capture (Bessghaier et.al. (2012)). An agent-based travel simulation platform simulates the behavior of travelers interacting in a complex, dynamic and open environment, on which they have a partial perception as stated in (Badeig et al. (2012)). Agent-based simulations are generally designed and implemented to analyze or predict the status of a network or a transportation system, and serve as a decision support tool for operators or transportation agencies. This type of simulations is particularly relevant when modeling and simulating activities in and around train stations, which is a challenging task. Indeed, train stations are an essential part of the transportation chain. They are the meeting point of large numbers of travelers and are more and more designed as multimodal nodes. With limited space extension possibilities of these stations, as it is mostly the case in European cities, managing the crowd flows inside the stations becomes vital for the passengers security, the operations continuity and for overall quality of service.

However, simulations are usually defined independently from the management systems and the traveler information systems. Indeed, deciders feed the simulation with management policies and traveler information strategies and collect the results, which they interpret and draw conclusions. These conclusions imply a new configuration of management policies and information strategies, which will feed new simulation runs (cf. Fig. 1).

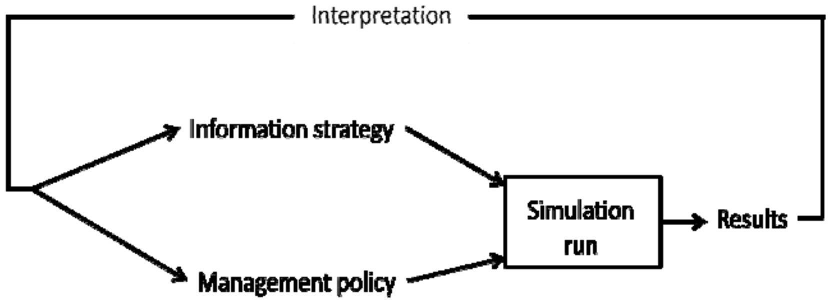

Fig. 1. Traditional simulation-based decision support process

However, this sequential process does not allow for the consideration of the simulation dynamics and for the reactive definition of policies and strategies by the deciders. Indeed, regulation instructions and information strategies impact the simulation behavior and change the environment on which the strategies and policies are based. We need a new architecture that allows management systems and traveler information systems to sense simulations and to define new instructions during simulation execution.

In this paper, we propose a different process for simulation-based decision support systems, in which information systems and management systems sense the simulation status and propose reactive information strategies and management policies (cf. Fig. 2). We believe that this allows for a more precise representation of the reality, in which train station operators provide solutions in reaction to the perceived reality, which in turn changes passengers' reactions and call for new solutions. This interactive loop between management and information systems in the one side and simulation on the other side allows for a better assessment of information and management systems, instead of an assessment of particular policies or strategies.

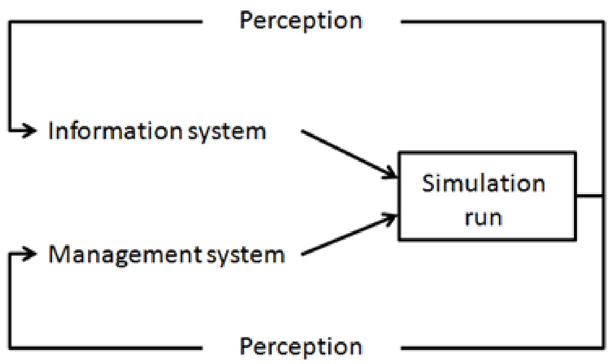

Fig. 2. Proposed reactive simulation-based decision support process

To do so, we propose an architecture that advocates for the simultaneous consideration of the travel simulation, the transportation management system and the traveler information system. The objective of the result system is the maximization of travelers' safety, the maximization of traffic fluidity and the optimization of travelers' preferences (maximal comfort, minimal walking distance, etc.). To do so, several measures can be proposed and implemented: the change of platform-train assignment, the access closure or opening, the evacuation of platforms, trains or stations, and travelers' information.

This paper is structured as follows. Section 2 deals with train station management and observe that it is mostly treated as crowd management. Section 3 describes multi-agent crowd simulations and critics its focus on pedestrian and vehicles movements, without considering the management and traveler information systems. Section 4 describes our proposed architecture and section 5 concludes the paper.

2. **Train station management and information system**

2.1. Management

Dynamic train station management, with the main objective of having a nearly free-flow system, is crucial today. A high congestion could lead to dangerous situations, which can appear on platforms with high density. It also affects the quality of the service for the users. It may finally disrupt operations continuity because of the increase of the dwell time. An efficient station management increases safety, operational continuity and quality of service.

The environment of a train management system is composed of a demand level, a station topology, the different facilities and equipments, such as the train station docks, the stairs, the escalators, the elevators, the corridors, the shops and the information devices.

To reach its objectives, the train dynamic management system needs to identify critical situations regarding incidents and operations, which is mainly based on crowd management. In the literature, there are no specific guidelines dedicated to crowd management in train stations, according to Rail Safety and Standards Board (2003).

Dynamic crowd management has three main parts. The dynamic space management is the first part, with a specific focus on critical parts of the infrastructure, such as bottlenecks, narrow corridors, etc. The control of flows, by directing them and controlling their density is the second part. This could be achieved by dynamically opening or closing specific access or zones in the train station or by deploying staff agents used to dynamically provide path finding information or redirecting travelers. Finally, emergency response is a very important part, where fast reactions have to be defined corresponding to clearly identified situations.

In all these parts, the processes and roles of all the actors have to be specified. To this end, decision support systems have to be designed and implemented. We believe that simulation-based support systems are the most promising for the reasons that we have given in the introduction.

In order to evaluate the management of the station, we have to look at some indicators describing the current state of the situation. Our first goal is to minimize the safety-risk zones. All areas present a risk when crowd density is too high but certain zones like bottlenecks and platforms are more accident prone, these are the areas we need to observe the most. The second goal is to ensure the continuity of the supply which means to avoid too long dwell times that can disturb trains schedule. Finally the quality of the service provided and the comfort of the passengers has to be looked at. To evaluate the station management, at least three kinds of indicators must be displayed:

- Indicators of congestion/density of pedestrian per area, especially on the safety-risk zones.
- Average waiting time and travel time inside the station for the travelers.
- The difference between theoretical timetable and the real train schedule

2.2. Information

Information management decides which information should be sent to which communication medium (mobile applications, screens, etc.) and when to provide the information. Functionally speaking, Information and management are tangled. Indeed, when a management measure is taken, travelers need to be informed. When information is given, the next management measures have to take this information into account. Information and management have to be in complete synchronization. However, they also have to be independent, since traveler information is not restricted to local information devices such as signs, screens, or voice announcements; they also concern personalized information on personal phones. Traveler information has also to have its own coherence between all devices and all broadcasted information, and have to have a complete system dedicated to this task. Information and management systems are independent, but are continuously synchronized and continuously exchange information about their current states.

3. Multi-agent pedestrian simulation

Pedestrian mobility can be modeled in multiple ways. Macroscopic models describe travelers' flows between geographic areas with outflow rules and are usually based on theories and methods from particle physics or from fluid mechanics in order to describe the global dynamic of a high density crowd as stated in (Kanmeugne (2014), Kok et al. (2016)). In contrast, microscopic and multi-agent models deal with the crowd as discrete entities which allow to understand the interactions between the travelers and to see more details in the travelers' behavior during their mobility. Some of the most common are the force-based (Helbing et al. (1995), Chraibi et al. (2012)), cellular automata (Nishinari et al. (2006), Sarmadi (2010)), behavioral (Hoogendoorn et al. (2004), Wijermans (2010)) and discrete choice (Antonini et al. (2004)) models. Agent-based modeling is particularly relevant for the simulation of travelers' mobility since the objective is to take into account human behaviors that interact in a complex, dynamic and open environment as defined in (Davidsson (2005)). In this paper, we focus on a multi-agent based simulation.

Small-scale pedestrian simulation models (at the scale of a road or a neighborhood) are generally described as agent-based models for simulating the actions and interactions of autonomous individuals with the objective of assessing their effects on the system as a whole. Agent-based modeling mimics the simultaneous operations of multiple actors in an attempt to recreate and predict the actions of complex phenomena.

As we can see in the Fig. 3, a pedestrian simulation in a train station needs these inputs:

- Origins and destinations of the pedestrians which are used to generate travelers and to make them move on the network. We can add some intermediate goals such as waiting for another agent or buying a ticket.

- The network describing the station in order to build the infrastructure and the available activities inside the station (buying a ticket, eating a meal, etc.)

Each agent in a model has typically a range of physical attributes, for example his age and his desired walking distance. In addition, each agent maintains a range of behavioral characteristics that may change as he moves through the model space, for instance its aversion to local obstacles.

The main approach to choose a local path for a pedestrian is based on the Von Neumann-Morgenstern utility theorem. Pedestrians evaluate multiple paths and choose the one minimizing their metabolic energy spent to reach their goal as described in (Kanmeugne (2014)). Pedestrians behavior models can be more detailed depending on the goal of the simulation. For instance, we can simulate an emergency situation to assist managers of emergency response in developing appropriate strategies and training, and in designing solutions. In this case we can add interactions in a cooperative vs competitive behavior as in (Zheng et al. (2011)).

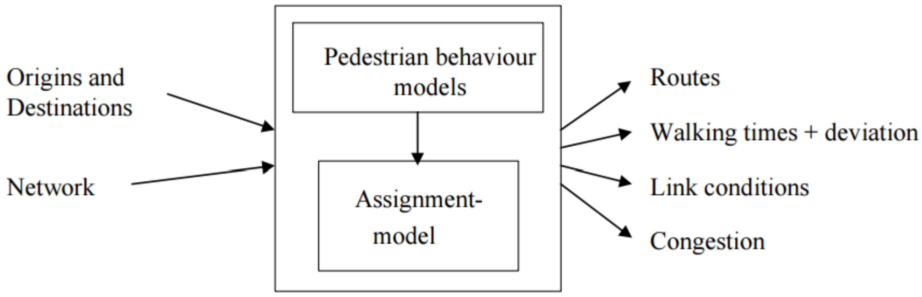

Fig. 3 Simulation environment

The goal of the simulation is to estimate which path pedestrians will take, how much time they spend between their origin and their destination and the congestion on the different links. When all these outputs are available, the simulator can be used to play multiple scenarios like where to place a set of turnstiles without creating congestion and to maximize the comfort of the passengers without slowing them or where to place a new restaurant/shopping to attract as many people as possible.

In short, the developed model is used to evaluate (see (Daamen et al. (2001)))

- the layout of existing transfer stations,
- the effects of extensions and/or adaptations of existing transfer stations,
- the layout alternatives for newly developed stations,
- the alternatives of and changes in different platform allocations,
- the alternatives of and changes in different timetables.

As we can see it in this description, the information environment and the management system are outside the scope of traditional travel simulations, including multi-agent simulations. In the following, we define an architecture that defines a system where simulation, management and information form a complete system.

4. Architecture

Travel simulations are used to predict the traffic and to test the impact of different parameters like an infrastructure change, a timetable change or different ways to broadcast information for the travelers. Because of this, they can help the management system to handle flows of pedestrians and flows of vehicles by allowing them to see the effect of a change and to adopt the best policy. Let's take a look at how the simulation, the traveler information system and the management platform are defined in current simulations.

Currently, management systems are out of the simulation environment. To measure the impact of a given policy, we encode it in the simulation parameters and analyze the output. Currently, travelers information system (what information to give, how, when) are defined following the same procedure, when they are taken into account in the first place (Zargayouna (2015)). What is tested in current simulations is a specific management policy or a specific information strategy. However, in real operational systems, management systems and traveler information systems do not define rigid strategies or policies that they do not change during execution. In the contrary, they are intelligent systems, sensing the reality and reacting to it with new instructions. This has to be reflected in the simulations. What should be tested and evaluated is the whole management system, or the whole traveler information system. To this end, the tuple <simulation, management system, traveler information system> has to be treated as the same interactive system.

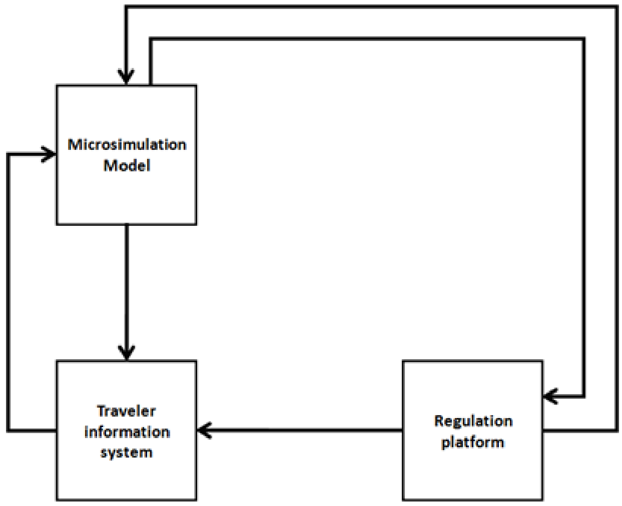

Fig. 4. The closed-loop architecture

We propose a closed and interactive loop that contains the simulation, the management system and the traveler information (cf. Fig. 4). The management system is an intelligent system which adapts its measures depending on the state of the simulator and the information system adapt its information depending of the state of the simulator. The current systems, where the manager chooses a policy, uses it as an input then examines the results, is too static and does not allow to model interactions between travelers, information system and management system. This is why we propose an architecture where these modules are still defined independently, since they require different expertise domains, they are however complementary and interoperable. We define four modules designed as services, and interacting via standard interaction protocols (typically designed as web services).

Following this architecture, the management system and the traveler information system have to sense the simulation and propose the relevant instructions. We define a multi-agent simulation where a scheduler is responsible of incrementing discrete simulation ticks, when all agents have executed their defined tasks for one simulation step. All actions performed during a simulation tick are considered simultaneous. The sensing of the simulation state and the introduction of the instructions by the external systems (the management system and the traveler information system) take place at each tick increment. The workflow of Fig. 5 details one simulation execution with the new architecture. The simulation starts with the loading of the parameters (simulation duration, number of agents of each type, the default speeds of each agent type, etc.). Then, the main context program creates the logical graphs allowing for travelers movements and launches the scheduler. The scheduler is responsible of the synchronization of execution of the agents per tick of simulated time. When launched, each agent executes a step method. When all agents have executed their step method, the management system and the traveler information system sense the simulation status, and define the new management policy and information strategy, and then the tick is incremented. Finally, when the simulation duration is reached, the results are reported and the simulation ends.

The sensed state of the simulation concerns an evaluation of the current situation in the simulation, with indicators about safety, the congestion and quality of service in the different areas of the station. These indicators may concern the density of pedestrians on the train platform, the number of travelers inside a vehicle compared to its capacity, the time it takes for an agent to travel from his origin to his destination, etc.

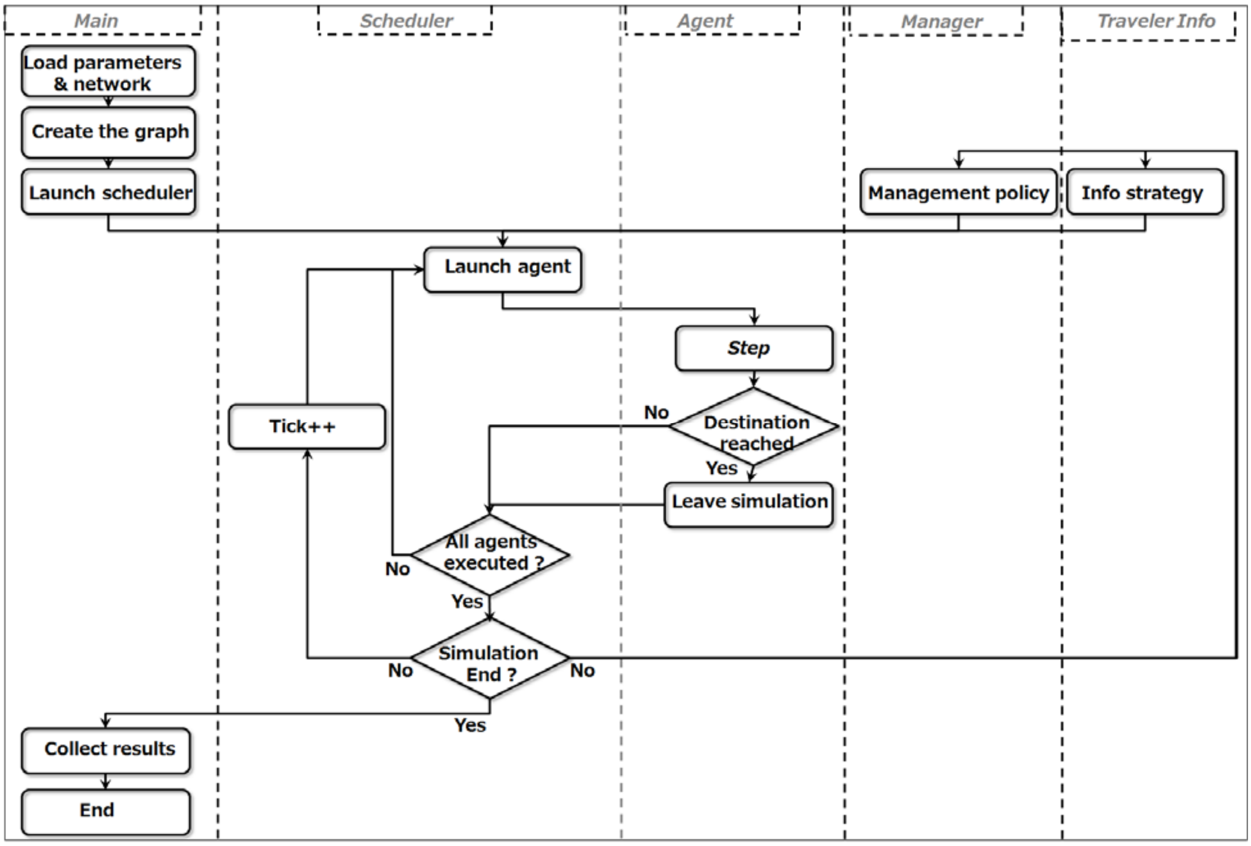

Fig. 5. Impact on the simulation process

The instructions of the management platform and the traveler information system are meant to improve these indicators. The traveler information system manages information given to pedestrians on their mobile phones and on the station screens and voice announcements to allow them to take the right path, to avoid congestions, without information overload. These indicators can be used to detect safety-risk zones where a particular attention must be paid during the peak periods for instance.

6. **Conclusion**

In this paper, we have proposed an architecture that advocates for the simultaneous consideration of the travel simulation, the transportation management system and the traveler information system. This architecture allows for the information systems and management systems to sense the simulation status and propose reactive information strategies and management policies. This new process allows for a more precise representation of the reality, in which train station operators provide solutions in reaction to the perceived reality, which in turn changes passengers' reactions and call for new solutions. This interactive loop between management and information systems in the one side and simulation on the other side allows for a better assessment of information and management systems, instead of an assessment of particular policies or strategies.

In our ongoing work, we are implementing this architecture on top of our previous tools. In the one side, we propose a Web service interface for the multi-agent simulator SM4T (see (Zargayouna et al. (2014))), allowing the management systems and information systems to sense the simulation in real-time. We are also working on a Web service interface for the regulation platform Claire-Siti (see (Scemama et al. (2004))). Finally, we are working on a traveler information system, extension of ATIS (see (Zargayouna et al. (2005))). These systems, working together provide a new way of defining reactive management systems and information systems and new ways of validating them. The validation of information and management measures is also an ongoing work, since we do not validate individual measures anymore, but complete systems. This validation should also take into account several compliance levels of the travelers to the provided information or instructions.

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