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Multi-agent architecture with space-time components for the simulation of urban transportation systems

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Abstract

Transportation systems are increasingly complex and must evolve to incorporate components of sustainable development. It has become appropriate to develop high-level simulation tools for policy makers so that they can analyze the potential consequences of their choices.
In this paper, we propose a decision-maker simulator intended to define and tune urban transportation policy (travel, parking and transportation strategies). In terms of system architecture, we adopted a “system of systems” approach, mainly structured in layers, in order to model the main elements of the system. We represent explicitly, for example, a layer of roads, lights, parking, means of transport, etc. Our system uses an agent-based simulation incorporating spatial and temporal information. It must support the regulatory scenarios to simulate the effect of regulatory strategies on transportation systems. The paradigm of multi-agent systems is well suited for simulating the behavior of the components of an urban transportation system. Existing applications address problems of individual behavior management, management of traffic flows, management of temporal and geographical aspects, multi-modality transport, etc. However, they don’t address organizational aspects of transportation systems that incorporate the adaptability of users’ behavior. In addition, we implemented the mechanism of "traces"; the trace files contain the result of simulation. Travel surveys, census and traffic measurements were used. Analysis of available data and traces were used to evaluate the suitability of our simulations according to different regulatory strategies. Finally, we implemented a prototype for the movement of people in the city of La Rochelle from statistical data of INSEE (the French National Institute of Statistics and Economic Studies) and the BD TOPO 2 of the IGN (the French National Geographical Institute) using the GAMA platform.

Keywords: intelligent transportation systems; multi-agent; regulation; adaptive; software architecture.

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1. Introduction

Urban transportation systems are defined by means of urban transport plans and territorial coherence schemes. Organizational and regulatory policies concerning urban transportation systems are governed by general principles corresponding to strategic direction and policies and integrate infrastructure constraints. Transport systems are becoming more complex and must incorporate not only technological components, but also sociological and political ones. In particular, they should be easy to adapt in order to incorporate the goals set by policy makers, such as the integration of sustainable development settings. It then becomes imperative to develop tools for urban transportation policy makers. So, they can analyze the potential consequences of their policies on flows, the environment, the economy and overall performance.
Currently, there are simulators that deal with concrete problems in the urban transportation system such as the simulation of movement of individuals (Lang & al., 2007), driver's behavior (Champion & al., 2004), the transportation flow (Behrisch & al., 2011), etc. However, there are very few simulators that address the problems of the organization of transportation systems and in particular the problem of analyzing the impacts of regulatory strategies for the transportation system.
The main objective is to provide a simulation tool to help urban transportation policy makers to analyze and evaluate the impacts of regulatory strategies. The simulator consists of modules that contain information describing the infrastructure of transportation systems, means of transport, signaling, individuals' behavior etc. Fig 1 illustrates the interaction between the urban transportation policy maker and simulator components. The simulator must then take into account the following features:

- Support scenarios of regulation: this feature allows the decision maker to define scenarios of regulation strategies (set indicators for the strategies of regulation).
- Simulate movement of individuals in the context of multi-modality of transport: this feature simulates multimodal travel corresponding to a plan of activities (work, school, leisure, shopping, services, etc) of individuals on the infrastructure of the transportation system. The simulation must be multi-scale time and space.

The problems of our research contribute to:

- the development of transportation systems: a theoretical framework for modeling, software architecture supporting configuration and adaptive regulation and integration of temporal and spatial aspects.
- the development of a decision support simulator: modeling of transportation infrastructure, simulation of user's behavior and analyzing the impacts of regulatory strategies.

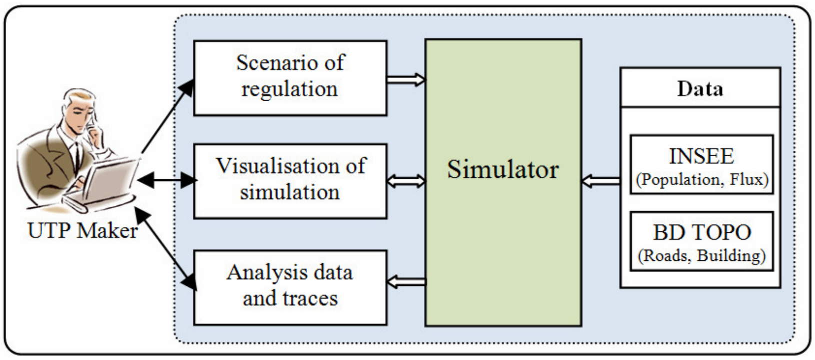

Fig. 1. Interaction between the urban transportation policy (UTP) maker and system

In terms of performance, simulators organizing transportation systems based on the paradigm of Multi-Agent Systems (MASs) are well suited to complex dynamic systems and can describe the behavior of real systems for which equation models are not always satisfactory, particularly when an algorithmic approach is preferred to a probabilistic approach.

The paper is organized as follows: section 2 presents related work simulation applications in the field of transport and platform-based multi-agent systems. Section 3 presents the approach we have used to build our simulator and the architecture of our simulator. In section 4, in order to illustrate our contribution, we propose a prototype for the movement of people in the city of La Rochelle by using the GAMA platform.

2. Related work

Starting with a quick overview of the principal simulators of urban transportation systems, we propose a synthesis of their different characteristics to determine those of our simulator. Furthermore, in order to choose the platform which adapts to the development of our simulator, we will analyze the current multi-agent platforms.

2.1. Transportation systems

2.1.1. Criteria for designing our simulator

Currently there are more and more simulators which deal with concrete problems in urban transportation systems. In order to position our simulator in relation to existing transportation simulators, in this section we present the criteria that our simulator must satisfy. We focus on the following criteria:

- Support for scenarios: this criterion is very important to all simulators, it allows us to manipulate and evaluate the impacts of these scenarios.
- Specification model, simulation granularity, modeling and simulation technology: these three criteria show trends and techniques for designing our simulator.
- Integration and processing geographic information: we focused on this criterion because our simulator deals with geographic information such as roads, residential and work places, etc.
- Parking: parking plays a very important role in the individual movement and for the regulation of transportation systems.
- Multimodal transport: the movements are in fact multi-modal, so simulators must support this criterion so that the simulation result is more realistic.
- Attraction points: residential places, work places, schools, commercial centre, etc. They influence individual movements and also regulation of transportation systems.

In the next section, we present existing applications in the transportation field in relation to these criteria.

2.1.2. Application in the transportation field

There are several modeling and simulation applications used to solve problems of simulation in transportation systems. Those that we felt were most relevant to our study are: ARCHISIM, TRANSIMS, MIRO and MobiSim. This section details these applications with respect to our objectives, features and desired criteria for our simulator.

ARCHISIM (Champion & al., 2004): the objective of this project is the modeling and simulation of a driver's behavior. It uses agent-based technology to simulate individual behavior. However, this system doesn't address problems of transportation system regulation; individuals are drivers, so we can't illustrate the influence of all individual types in a transportation system.

MobiSim (Antoni, 2011): the objective of this project is to develop a simulation platform for the prospective study of residential and daily mobility in the French and European cities by 2025, and their relationship to development, sprawl and urban development. However, MobiSim doesn't address the problems of regulating the transport system or multimodal transport.

TRANSIMS(Nagel, 2001; Koohbanani, 2004): the main objectives of TRANSIMS are to simulate multimodal movements and to evaluate impacts of policy changes in traffic or demographic characteristics. Nevertheless, TRANSIMS doesn't interest the aspects of parking and attractions point. Fig 2a illustrates multimodal means of movement in a transportation system.

MIRO (Lang & al., 2007; Antoni, 2011) : is a research project in the field of geomatics which tries to reproduce the urban dynamics of the city of Dijon. The main objectives of the MIRO project are to assist planners in the definition of new urban policies and to propose a prototype of multi-agent simulation that is able to test planning scenarios and to specify individuals' behaviors. Fig 2b illustrates the system structure of MIRO. However, it addresses only the movement of individuals, there isn't any management of the means of transport used by the individual and in addition, it isn't centered on organizational and regulatory problems of the transportation system. This project proposed a method of creating a synthetic population, the simulation of individuals' movement which we have adopted to design our simulator.

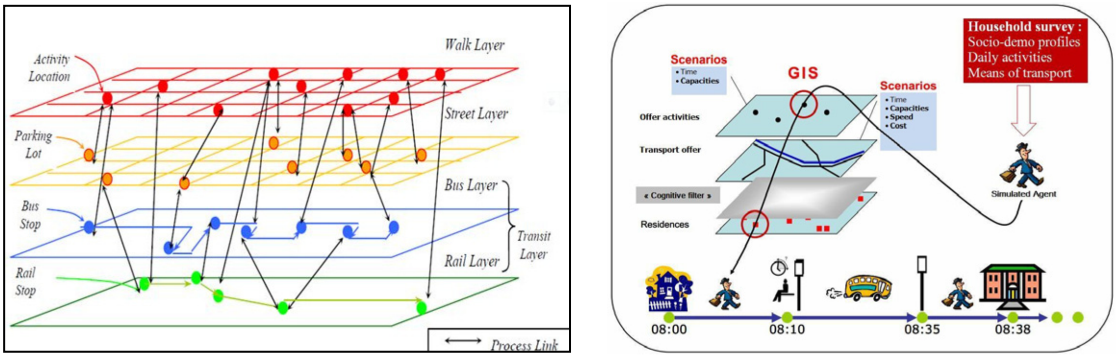

Fig. 2. (a) Multimodal movement in TRANSIMS project; b) Movement of individual in MIRO project (translated from MIRO (Lang & al., 2007))

2.1.3. Synthesis and discussions

In order to position the characteristics of our simulator, we compared existing applications of simulation in transportation systems according to the criteria presented in section 2.1.1.

Table 1. Comparison MAS platforms

Needs / Existing	Support scenarios	Specification model	Granularity of simulation	Modeling simulation technology	GIS	Multimodal transport	Parking	Attraction points
ARCHISIM	Yes		Microscopic	MAS	No	No	No	No
MIRO	Yes	UML	Microscopic	MAS	Yes	No	No	Yes
MobiSim	Yes	Spatial ontology	Microscopic	CA, MAS	Yes	No	No	No
TRANSIMS	Yes		Microscopic	CA,MAS	Yes	Yes	No	No
Our simulator	Yes	UML	Microscopic	MAS	Yes	Yes	Yes	Yes

(CA: Cellula Automata)

Existing applications address problems of individual behavior management, management of traffic flows, management of temporal and geographical aspects, multi-modality transport, etc. However, they don't address organizational aspects of transportation systems that incorporate adaptability of users' behavior. In Table 1, we show that the approach of the MIRO project was closest to our goals. It integrates and processes geographical and temporal information using a multi-agent system simulation. MIRO details the modeling and simulation steps of individual movements. It addresses the appearance of attraction points, the infrastructure of a transportation system. However, it doesn't address the influence of parking or the means of transport that people use, or transportation price.

Multi-agent systems paradigm is well suited for simulating the behavior of components of an urban transportation system. Simulation applications using MAS technology are increasingly used. In the next section, we synthesize existing multi-agent based platforms to select the best suited platform for our simulator.

2.2. Multi-agents platform

Currently, there are several multi-agent based platforms, e.g NetLogo, MadKit, Jade, Repast, GAMA, etc. The design approach of our system is based on using an existing platform that includes features concerning spatial and temporal aspects.

2.2.1. Agent-based simulation platforms

NetLogo (Wilensky, 2009) is a simulation platform which can easily be learned given the numerous implanted behavioral models, its ease of use and the comprehensive documentation available. However, it uses its own programming language to create new models; its meta-model is not expandable and is suitable for small systems. The JADE platform (Bellifemine & al., 2001) focuses on studying the patterns of communication between agents but it doesn't support geographic data integration. MadKit (Gutknecht & Ferber, 2001) open source multi-agent platform written in Java and built upon the AGR (Agent/Group/Role) organizational model: MadKit agents play roles in groups and thus create artificial societies. Nevertheless, MadKit poorly supports the processing of geographic data. Repast (North & al., 2006) is an agent based simulation platform written in Java and open source which supports many well developed spatial data libraries. However, advanced GIS operations have to be programmed, this is far from reach of many modelers.

GAMA (Amouroux & al., 2009; Taillandier & al., 2012) is a simulation platform which aims at providing field experts, modelers, and computer scientists with a complete modeling and simulation development environment for building spatially explicit agent-based simulations. We can use the GAMA platform to develop our simulator because it has advantages compared with other platforms. For example, it is developed with the Java programming language and is open source. Geographic information is well integrated. It has implanted example models and has a language for defining models. However, GAMA has weaknesses in relation to our objectives, e.g the simulation is not yet adaptive and we cannot change the parameters during the simulation.

2.2.2. Synthesis and discussions

For our approach, in terms of specifications, the ideal platform would be to have an agent based platform that meets the following criteria: research and application domains, open source license, runtime environment, support for users and ability to integrate and process spatial information. In our application, we address the problem of geographic information processing such as network transportation infrastructure, points of attractiveness (home, workplace, shopping centre, etc.), so we focused on platforms that incorporated modules integrating and processing geographic information.

Table 2 presents an overview of simulation platforms against the criteria presented and enabled us to choose a suitable platform for the design of our simulator.

Table 2. Multi-agent platforms

Platform	Domain	License	Operating system	User support	GIS capabilities
JADE	Distributed applications composed of autonomous entities	LGPL	All Java Platform	Documentation tutorials, API, FAQ.	No
MadKit	General purpose multi-agent platform with agent based simulation layer	GPL, LGPL	JVM (Java 2)	Documentation, online forum, examples, FAQ.	Yes
Repast	Social sciences	BSD	Java version 1.4	Documentation, tutorials, examples, FAQ.	Yes
NetLogo	Social and natural sciences	GPL	All Java Platform	Documentation, tutorials, third party extensions, FAQ.	Yes
GAMA	Social and natural sciences	LGPL	All Java Platform	Documentation, tutorials, examples	Yes

According to our specifications, and after emphasizing the weak points of the different platforms, we selected GAMA which seemed the most appropriate. In the next section, we present the approach and architecture of our simulator.

3. Our informatics application

3.1. Our approach

The system of systems approach is increasingly used in complex systems.
A system of systems (SoS) is an assemblage of systems that can potentially be acquired and/or used independently for which the designer, purchaser and/or user seeks to maximize performance of the global value chain, and for a set of possible assemblies (Luzeaux & Ruault, 2008).
Characteristics for a SoS are the operational independence of elements, the managerial independence of elements, evolutionary development, the emergence of behavior and geographic distribution (Maier, 1998). The SoS is studied mainly in the defense sector, the airline industry, transportation systems, space exploration. Other applications where it can be applied include health and the design of the Internet.
To model the components of the multimodal urban traffic system we use a layered approach (Fig 3a) to categorize the main elements of the system to model them:

- Means of transport: cars, buses, bicycles, etc.
- Attraction point: shops, schools, universities, etc.
- Sign: traffic lights and road sign.
- Road: the road network infrastructure.
- Study area: the map of the study area.

In our proposal, each layer plays a role as a system, for example, parking management system, management system of means of transport, sign management system of signs, etc.
Our system must support several scenarios of regulation and the interaction between the system and each layer depends on the scenario. For example, the regulation scenario "Reduction of downtown parking influences the flow of traffic in the city center? ". This scenario makes interactions with layers: means of transport (this scenario acts on means of transport for example, changing the means of transport of individuals e.g. individuals can use

public transport instead of their cars), parking (choose parking in which the number of places is limited), attraction point (reducing the number of individuals who visit).

3.2. Architecture and operation mechanism

The input data of the simulator are geographic data for the study area, infrastructure of the transportation network (land, roads) provided by the BD TOPO 2 from IGN, etc. and the results of surveys and the general census of the population provided by INSEE that contain the information to set individual’s behaviors. The advantages of this INSEE source consist in the fact that this is a database with large sample, which ensures accurate data and provides a spatial presentation of the population, and data movements of individuals.
Fig 3b presents our system architecture. This system consists of two parts: the first part for the interaction with the urban transportation policy maker where he can enter control scenarios and watch the visualization of simulation results and finally, it can analyze the impacts of regulation strategies. The second part is the system kernel, it contains a module simulator whose input is the configuration of the simulator, the behavior of individuals; a *Traces* module stores the simulation results. The *Analysis* module compares the data traces and the actual data from census and surveys to analyze the impacts of regulation.

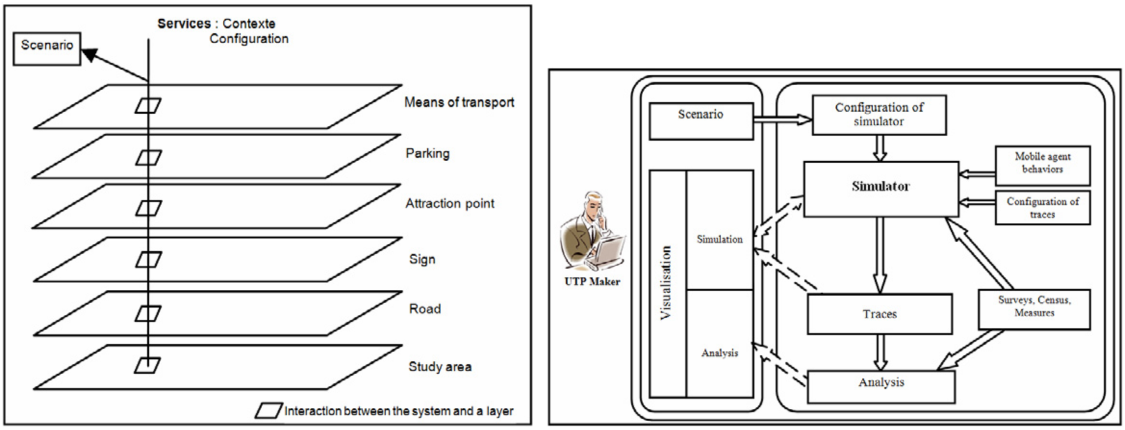

Fig. 3. a) Layer approach b) System architecture

4. System prototype

4.1. Case study

In order to evaluate the suitability of our proposition, we chose the simulation of individual movements in the city of La Rochelle. We used data from INSEE 2006 and BD TOPO 2 (delivered on 22/10/2011) of IGN. The OrbisGis software was used to process the geographical data of BD TOPO 2 for system infrastructure (roads, paths), attraction points (home, work, school, etc.).
Our simulator has layers:

- Study area is the map of the city of La Rochelle.
- Road: road network, these data were retrieved from the BD TOPO 2 of the IGN.
- Attraction point: home building, work or school places.
- Means of transport: we haven’t yet addressed the means of transport, people make a round trip from home to work or school at an average speed.

In this first version, we have not yet integrated parking and signs.

4.2. Individual profile

For simulating individual movements, each individual was represented by an agent. An individual agent is characterized by fields that contain information concerning the description of an individual category (age, sex, work, etc.), calendar of individual activities, etc.

There are three types of individual agent:

- Internal agent who lives and works in the same study area (S.A).
- Internal agent who lives in the S.A but works outside the S.A.
- External agent who works in the S.A but lives outside the S.A.

The study area is characterized by criteria, for example, entry points and output points, park and ride, parking, attraction points, etc.

Fig 4a below illustrates the movement diagram of an individual agent in the spatial dimension; on the other hand, Fig 4b shows the movement of an individual agent in the temporal dimension.

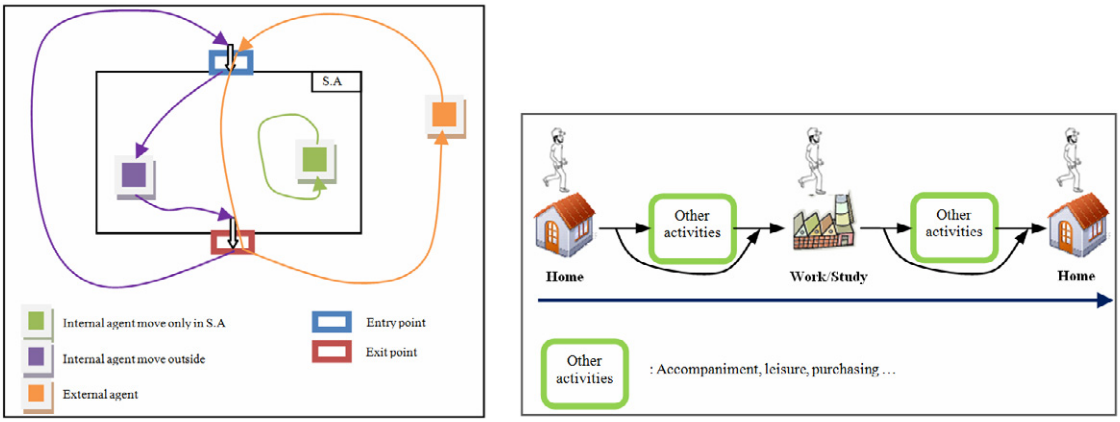

Fig. 4. (a) Movement of an individual in the spatial dimension; (b) Movement of an individual in the temporal dimension.

The individual agent profile is defined by:

- Category of person
- Type of individual agent
- Residential area
- Activity plan: this is a list of activities (activity1, activity2,.., activity n). The activities are work, study, home, accompaniment, leisure, etc. Each activity takes place at a location, for a duration, etc.

4.3. Simulate individual movements

We installed a simulation of individual movements using the GAMA simulation platform version 1.4. System infrastructures (roads, paths, buildings) were stored in shapefiles (Esri ref). Each section of road or path was represented by an agent, each building was also represented by an agent and all these manipulations were performed automatically from a shapefile. The number of individuals in this simulation was 10000 (the actual population of La Rochelle is around 76000). Each individual was represented by an agent, it had a place of residence and a place of work or study, its activity plan consisted only of the round trip from home to work or study. The individual movements were determined by the shortest path algorithms.

Fig 5 presents the interface of individual movement simulation by the GAMA platform. The red areas are work or study places, whereas blue areas are home. Individuals are represented by yellow cycles and roads are green.

We could export data concerning individual movements in files (.csv); these files are considered "traces" files to analyze the simulation results.

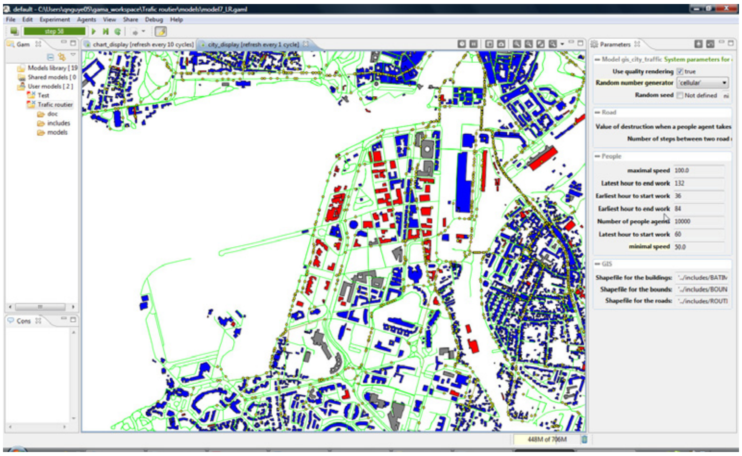

Fig. 5. Interface of individual movement simulation in the city of La Rochelle

4.4. Discussion

In the case of the city of La Rochelle, the prototype of our simulator proved that using the GAMA platform is well suited for our purposes. Based on the statistical data acquired, our software environment enabled us to set information for the simulation like the number of individuals, individual's behaviors (time for work or study), roads and buildings. Our simulator simulated individual movements on the road infrastructure provided by real data of the BD TOPO from IGN.

For multi-scale simulation in spatial dimension, the presentation of individual profiles proposed in section 4.2 enabled us to simulate a transportation system at different levels such as the departmental level, the agglomeration communal level and the communal level. The activity plan of each individual in this simulator is still very simple, with a round trip from home to work or study, but it already provides the elements of decision.

5. Conclusion

We addressed research objectives for the regulation of urban transport systems. For transportation systems, we proposed a multi-layer approach for modeling system components, we also presented a system architecture which enabled us to configure and control the simulator. This simulator integrated geographic information. Besides a decision support simulator, the modeling of a transportation infrastructure was addressed; roads, paths and buildings were represented by agents using shapefile data provided by the BD TOPO of the IGN. We implemented the mechanism of "traces" for the analysis of impacts of regulatory scenarios.

We implemented a prototype for individual movements in the city of La Rochelle using the GAMA simulation platform. The results obtained proved the feasibility of our choices for the design of our simulator and for the integration of geographic information (roads, buildings) in the simulation. Nevertheless, there are still several limitations e.g. this simulator has yet to address the problem of multimodal travel and parking. We are developing new features to improve the quality of the simulation.

For future work, we will focus on the integration of the means of transport into our simulator and the improvement of the activity plan for each individual (the demonstration only addressed the activity of a round trip from home to work/study). Currently, individual movements are made by the shortest path algorithms but we will consider adding criteria such as traffic jams on the road, traveling costs, etc. to make them more realistic.

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