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Towards a Model for Urban Mobility Social Simulation

A perspective from J-MADeM Decision Making

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Abstract Metropolitan mobility models, mainly based on the massive use of the car instead of the public transportation, will soon become unsustainable unless there is a change of citizens' minds and transport policies. The main challenge related to urban mobility is that of getting free-flowing greener cities, which are provided with a smarter and accessible urban transport system. In this paper, we present an agent-based social simulation approach to tackle this kind of socio-ecological systems. The Jason Multi-modal Agent Decision Making (J-MADeM) library enable us to model and implement the social decisions made by each habitant about how to get to work every day, e.g., by train, by car, sharing a car, etc. In this way, we focus on the decision making aspects of this problem at a micro level, instead of focussing on spatial or other macro issues. The first results show the different outcomes produced by societies of individualist and egalitarian agents, in terms of the average travel time, the use of the urban transportation and the amount of CO_2 emitted to the environment.

Keywords Multi-Agent Systems · Urban Mobility · J-MADeM

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1 Introduction and Related work

The mobility models followed within metropolitan areas, mainly based on the massive use of the car instead of the public transportation, will soon become unsustainable unless there is a change of citizens' minds and transport policies. This fact has been highlighted, for instance, by the European Commission through the Green Paper on Urban Mobility [6]. Cities all over the world face similar problems, e.g., congestion, road safety, security, pollution, climate change due to CO_2 emissions, etc. Since these problems are increasing constantly, humankind pays a high price both in economic and environmental terms, as well as for the health and quality of life of citizens. This money would be better spent for developing more efficient transport systems.

The main challenge for urban mobility is that of getting free-flowing greener cities, which are provided with a smarter and accessible urban transport system. Agent-based social simulation (ABSS) has been proposed as a suitable manner to tackle this kind of Social-Ecological systems and Environmental Management [14], as well as in Economics [21], Anthropology [15], and Ecology [12]. ABSS provides a framework for implementing techniques that fulfill the requirements of environmental modelling. First, ABSS allows to couple the model of the environment to the social entities that it includes. For example, it makes possible to model aspects such as the roles of social interaction and the disaggregated adaptative human decision-making; and second, it enables the study of the relationships between the micro-macro levels of decision making, and the emergence of collective behavior as the response to changes in the environment or in the environmental management policies.

In this paper we present an ABSS approach to model the mobility within a metropolitan area by focusing on the social aspects of agent's decision making. The rest of the paper is organized as follows: The next section reviews related works on mobility simulation and agent-based social simulation. Section 3 briefly describes the J-MADeM library, which allows programming MADeM decisions at the agent level. In section 4 we introduce the urban mobility simulation framework as well as the definition of a simple "travel to work" scenario. Section 5 shows the different outcomes produced by a society of individualist and a society of egalitarian agents in terms of the average travel time, the use of the urban transportation and the amount of CO_2 emitted to the environment. Finally, in section 6 we state the conclusions and discuss about future work.

2 Related work

A number of platforms have faced the problem of simulating mobility within metropolitan areas (e.g. UrbanSim [23]). These systems have mostly followed an approach focused on spatial issues to simulate large-scale urban areas by using gridcell, zonal, or parcel geographies. Some of them have been used to investigate route choice scenarios, for instance in [2] the Braess paradox (a well-known phenomenon: adding a new road to a traffic network may not reduce the total travel time) is studied to discus the effects of giving route recommendation to drivers in order to divert them to a situation in which the effects of the paradox are reduced.

Route choice as well as traffic lights coordination and control have also been studied in [20, 16] but following a microscopic approach. Within this context, SUMO (Simulation of Urban Mobility) [3] is an open-source microscopic traffic flow simulation package that can simulate large cities on a single vehicle and single traveller basis. Since 2001, SUMO has been enhanced to simulate intermodal traffic, and it can be used to simulate the communication between the different entities. Therefore, it allows to simulate new modes in a transport system, and to execute the trips being generated by a demand modelling (which is not part of SUMO, here it relies on external input) and see their effects in terms of time, traffic, energy, pollutants, etc. In turn, MATSim [1] provides a toolbox to implement large-scale agent-based transport simulations. Currently, MATSim offers a toolbox for demand-modeling, agent-based mobility-simulation (traffic flow simulation), re-planning, a controler to iteratively run simulations as well as methods to analyze the output generated by the modules. In [22] authors present different traffic congestion scenarios where reinforcement learning techniques are used to optimize the main parameters of the model. Agents, provided with their own original timeliness functions, need to learn how to coordinate their actions with those of other agents. For instance, they show how drivers aiming to optimize their own personal timeliness objective lead to poor performance with respect to a city manager's objective function.

The work presented in this paper focuses on the social aspects of agent's decision making. Social and organizational models are being studied under the scope of multi-agent systems (MAS) in order to regulate the autonomy of self-interested agents. Nowadays, the functioning of a MAS is determined not only by the degree of deliberativeness but also by the degree of sociability. In this sense, sociability points to the ability to communicate, cooperate, collaborate, form alliances, coalitions and teams. The assignment of individuals to an organization generally occurs in Human Societies [17], where the organization can be considered as a set of behavioural constraints that agents adopt, e.g., by the role they play [8].

Social reasoning has been extensively studied in MAS in order to incorporate social actions to cognitive agents [7]. As a result of these works, agent interaction models have evolved to social networks that try to imitate the social structures found in real life [13]. Social dependence networks allow agents to cooperate or to perform social exchanges attending to their dependence relations [19]. Trust networks can define different delegation strategies by means of representating the attitude towards the others through the use of some kind of trust model, e.g., reputation [9]. Agents in preference networks express their preferences normally using utility functions so that personal attitudes can be represented by the differential utilitarian importance they place on the others' utilities. Following this preferential approach, the MADeM (Multi-modal Agent Decision Making) model [10] is a market-based mechanism for social decision making, capable of simulating different kinds of social welfares (e.g. elitist, utilitarian), as well as social attitudes of their members (e.g. egoism, altruism). In this work, the J-MADeM library has been used to model and implement the social decisions made by each habitant about how to get to work every day, e.g., by train, by car, sharing a car, etc. The main goal of the proposed system is to be used for research and as a decision support platform for metropolitan planning.

3 The J-MADeM library

J-MADeM [11] is a full-fledge AgentSpeak(L) [18] library that implements the Multimodal Agent Decision Making (MADeM) [10] model in *Jason* [4], the well known extended java based interpreter for this agent oriented programming language. The MADeM model provides agents with a general mechanism to make socially acceptable decisions. In this kind of decisions, the members of an organization are required to express their preferences with regard to the different solutions for a specific decision problem. The whole model is based on the MARA (Multi-Agent Resource Allocation) theory [5], therefore, it represents each one of these solutions as a set of resource allocations. MADeM can consider both tasks and objects as plausible resources to be allocated, which it generalizes under the term *task-slots*. MADeM uses first-sealed one-round auctions as the allocation procedure and a multi-criteria winner determination problem to merge the different preferences being collected according to the kind of agent or society simulated.

The J-MADeM library provides an agent architecture that *Jason* agents can use to carry out their own MADeM decisions; an ontology to express MADeM data as beliefs and rules; and a plan library to execute MADeM processes. The agent architecture `jmadem.MADeMAgArch`, implements in Java a set of actions (See table 1) performing the basic operations of the model. As usual in *Jason*, actions are prefixed by the name of the library, e.g. to set the welfare of the society as a nash equilibrium, the action `jmadem.set_welfare(nash)` is executed in a plan. Other MADeM parameters are defined in the same way.

Although this Java based actions are often more efficient than the AgentSpeak(L) plans and rules, they hide information to the agents. For instance, consider that the action *construct_allocations*/4 basically computes the cartesian product of the slots domains, so that some kind of filtering at the Java level is required to obtain "legal" allocations; but the agents do not know what a "legal" allocation is, to the detriment of the agent metaphor, e.g., they can not reason about legal allocations, nor communicate about them.

In order to provide a full-fledge AgentSpeak(L) layer in the library, J-MADeM agents use an ontology (See table 2) to define the data of a decision process declaratively, as beliefs and rules. In this way, data is accessible to Test Goals and Speech Acts with *Ask*-like performatives.

Utilities and filters can also be defined as beliefs or rules. For instance, considering allocations of the form showed below in equation 1, the rule:

```
jmadem_utility(dummyUF,_,Alloc,0) :- .my_name(Myself) &
owns(Myself,Vehicle) & .member(travel_by(_,Vehicle), Alloc) & not
.member(travel_by(Myself,Vehicle),Alloc).
```

expresses that an agent is not interested in sharing his vehicle if he is not travelling by too, following the utility function `dummyUF`. And:

```
jmadem_filter(dummyFilter,Alloc) :- .my_name(Myself) &
owns(Myself,Vehicle) & .member(travel_by(_,Vehicle), Alloc) & not
.member(travel_by(Myself,Vehicle),Alloc).
```

Table 1 Actions defined in the J-MADeM library.

Action	Description
`add_utility_function("P.U")`	P is a Java package name and U the utility function name.
`add_utility_function(U,N)`	U is a utility name and N is fully qualified name of the function Java class.
`construct_allocations(T,S,E,Al)`	$T = t(S_1,\ldots,S_n)$ is a function denoting a task t of n slots, $S \subseteq \{S_1,\ldots,S_n\}$ is a set of task slots to be allocated, $E = [[e_1,\ldots,e_j],\ldots]$ elements in the domain of each slot, Al is the computed list of allocations
`launch_decision(A,AL,U,DId)`	A is a set of agents, AL is a set of allocations, U is a list of utilify functions, and DId is the output parameter.
`launch_decision1(A,AL,U,DId)`	As above, but it returns only 1 solution.
`remove_utility_function(U,N)`	U and N are as above.
`reset_personal_weights(PW)`	$PW = [jmadem\_personal\_weight(A,\_),\ldots]$.
`reset_utility_weights(UW)`	$UW = [jmadem\_utility\_weight(U,\_),\ldots]$.
`set_list_of_personal_weights(PW)`	$PW = [jmadem\_personal\_weight(A,W),\ldots]$, where A is an agent and $W \in \Re$ his personal weight.
`set_list_of_utility_weights(UW)`	$UW = [jmadem\_utility\_weight(U,W),\ldots]]$, where U is an utility name and $W \in \Re$ its weight.
`set_personal_weight(A,W)`	A is an agent and $W \in \Re$ is his weight.
`set_remove_MADeM_data(V)`	If V is *true* MADeM data is deleted at the Java level, once the decision is done.
`set_timeout(T)`	T is a numerical value in milliseconds (1000 by default).
`set_utility_weight(U,W)`	U is a utility name and $W \in \Re$ is its weight.
`set_welfare(W)`	$W \in \{utilitarian, egalitarian, elitist, nash\}$ is the welfare.

Table 2 The ontology used by J-MADeM agents.

Belief formula	Description
`jmadem_list_of_personal_weights(PW)`	PW is a list of personal weight, as defined below.
`jmadem_list_of_utility_weights(UW)`	UW is a list of utility weights, as defined below.
`jmadem_filter(F,Al)`	F is the name of the filter Al is an allocation to be filtered.
`jmadem_personal_weight(A,W)`	A is an agent and $W \in \Re$ his weight.
`jmadem_timeout(T)`	T is the timeout in millisecond (1000 by default).
`jmadem_utility(U,N)`	U is the utility function name and N is the name of the java class.
`jmadem_utility(U,A,Al,V)`	U is the utility function name, A is the auctioneer agent, Al is an allocation, and V is the utility value assigned to Al according to U.
`jmadem_utility_weight(U,W)`	U is an utility name and $W \in \Re$ is its weight.
`jmadem_welfare(W)`	$W \in \{utilitarian, egalitarian, elitist, nash\}$.

defines a filter to delete such instances from the set of allocations computed by the agent. In addition, J-MADeM provides a library of plans `jmadem.asl` to call MADeM processes as Achieve Goals. The trigger events recognized by these plans are listed in table 3.

Utilities and filters can also be defined as plans. For instance, the utility function in the previous example would be defined as a plan as follows:

```
+!jmadem_utility(dummyUF,_,Alloc,0) : .my_name(Myself)&
```

Table 3 Trigger Events used by J-MADeM agents.

Trigger Event	Description
`+!jmadem_get_utility_function_names(U)`	*U* is a list of utility names.
`+!jmadem_construct_allocations(T,E,Al)`	*T* is a set of task slots, *E* is a logic formula to compute the elements of the allocation, and *Al* is the resulting set of allocations.
`+!jmadem_filter_allocations(F,Al,FAls)`	*F* is a filter, *Al* is a set of allocations, *FAls* is a set of filtered allocations.
`+!jmadem_launch_decision(A,Al,U,DId)`	*A* is a set of agents, *Al* is a set of allocations, *U* is a list of utility function names, *DId* is a decision identifier.
`+!jmadem_launch_decision1(A,Al,U,DId)`	As above, but for 1 solution.

```
owns(Myself,Vehicle) & .member(travel_by(_,Vehicle), Alloc) & not
.member(travel_by(Myself,Vehicle),Alloc).
```

Then, Speech Acts with *AskHow*-like performatives can be used to exchange utilities and filters defined as plans. Interestingly, there is a plan for constructing allocations after the beliefs of an agent, finding all the allocations that satisfies a logical query *E* defined by the programmer. Thus "legal" allocations are computed directly. Alternatively, allocations can be further filtered by means of the achieve goal `!jmadem_filter_allocations`.

4 Urban mobility simulation framework

In this section we introduce an urban mobility simulation framework developed over Jason that allows to model the mobility within a metropolitan area. We use Jason instead of another agent-based simulation platform (such as Repast) mainly because of two reasons. Firstly, our approach focuses more on the agent's decision-making than on the spatio-temporal simulation of the problem and Jason is specifically devoted to run BDI agents. Thus, we believe that a BDI modeling of the agents is more convenient to describe the simulation and its results. Secondly, we propose using a market-based mechanism for social decision making that has already been implemented as an open souce library over Jason, named J-MADeM, and choosing another simulation platform would have entailed the implementation of the MADeM mechanism from scratch.

The urban mobility simulation framework is available at the examples section of the MADeM project website (http://www.uv.es/grimo/jmadem/index.html). It can be downloaded and run locally from the Jason editor or using the ant launcher or Java Web Start. The multi-agent system is highly configurable through XML configuration files, thus, it can be applied to different scenarios in order to replicate the experiments shown in this section. For instance, the user can specify how many towns surround the city as well as the roads that interconnect them through the file "./traffic/configuration.xml". For each of these entities, concrete parameters can be set such as: the number of habitants, the income per capita distribution, the transports available (e.g. car, train, bus), the length and flow of the roads, etc. The environment is based on a very simple traffic simulator that returns the real times and consumptions of each vehicle. On the other hand, each citizen is represented by an agent that uses the J-MADeM library to make decisions that balance individual and social preferences. The number and the characteristics of each individual as well as of the whole environment can be set within the multi-agent system launcher file named "./CO2-jmadem.mas2j".

As a proof of concept, in this paper we present the "travelling to work" scenario. This scenario represents a 20 Km long road connecting a residential town to a city. Every morning, the habitants of this town must travel to the city to reach their workplaces. Each habitant owning a car can drive alone to work but he/she can also share the car with other habitants, thus lowering the expenses and the CO_2 emissions. Besides, there is the possibility to travel by train, which in the experiments is considered to emit no CO_2 and to cost 1 €/trip. Cars travel at an average speed of 100 Km/h and the train does at 60 Km/h, including all possible stops. However, as the road has a limited flow, when too many cars try to enter the city at the same time they will create a traffic jam, which may produce long delays. We have also set to 5 minutes the delay associated with both catching the train and picking-up each extra passenger in a shared car.

J-MADeM has been used in this scenario to model the main decision that habitants make every morning. That is, which transport to use for travelling to work: alone in their own car, sharing a car or by train. Citizens are randomly organized in decision groups meaning their family, friends, neighbors, etc. As we have fixed the maximum capacity of cars to 4 people, this is also the size of the decision groups. Therefore, the allocations used to represent each travel alternative for each group in this scenario are as follows:

$$alloc_i = [travel\_by(agent_1, vehicle_1), ..., travel\_by(agent_4, vehicle_4)] \tag{1}$$

where $agent_i$ are the group members and $vehicle_i \in \{car_1, ..., car_4, train\}$ is the transport chosen by each member (logically, car_i belongs to $agent_i$). It should be noticed that, even though every habitant can travel in any car, it is a must that the owner of a car also travels in the car to be a valid allocation.

J-MADeM then collects the preferences of the group about every possible alternative. To express their personal preferences according to different points of view, each habitant computes the utility functions defined in equation 2. Function UF_{eco} represents economy and it calculates the monetary cost of each allocation. Function UF_{tmp} informs about the travel time associated to the allocation and, finally, function UF_{CO_2} models its ecological impact in terms of the kilograms of CO_2 emitted to the environment. Consumption and travel times are estimated by remembering the previous travel experiences of the habitant with a similar vehicle-partners configuration. Utility functions represent costs in euros to be able to properly combine them in the J-MADeM process. Finally, J-MADeM selects the winner allocation, which is passed to the traffic simulator in the environment. For the winner determination, we use the Utilitarian collective utility function as an appropiated social welfare to reflect the aggregate impact of the kind of allocations considered.

Table 4 Utility weights used for defining different types of societies

Type	UF_{tmp}	UF_{eco}	UF_{CO_2}
Individualist	1	0.1	0.1
Egalitarian	1	0.5	0.4

$$\begin{aligned} UF_{eco}(alloc_i) &= (Consumption(alloc_i) * PricePerLitre)/Partners(alloc_i) \\ UF_{tmp}(alloc_i) &= Time(alloc_i) + Partners(alloc_i) * PickUpTime \\ UF_{CO_2}(alloc_i) &= (Consumption(alloc_i) * CO2PerLitre)/Partners(alloc_i) \end{aligned} \tag{2}$$

Other works [14] have assumed that agents use different world views to interpret the climate change and, consequently, they have distinguished different types of policies based on cultural perspectives:

- *Hierarchical*: It assumes that nature is stable in most cases but it can collapse if we go beyond the limits of its capacity.
- *Egalitarian*: It assumes that the nature is highly unstable and the least human intervention may lead to a collapse.
- *Individualist*: It assumes that the nature provides plenty of resources and it will remain stable under human interventions. Essentially, it encourages strategies that maximize the economic growth.

In order to model the individualist and the egalitarian perspectives in the "travelling to work" scenario, we use the weights that J-MADeM allows to associate to each utility function. Thus, we can simulate the behavior of an individualist and an egalitarian society by using the utility weights in table 4. In the individualist perspective, UF_{eco} and UF_{CO_2} have very low weights, so are negligible. In the egalitarian perspective, UF_{temp}, UF_{eco} and UF_{CO_2} have comparable weights and all of them have influence in the final decision.

5 Results

This section reports the first results obtained when running the "travelling to work" scenario with 32 habitants for a period of 100 cycles or days. As mentioned, we have simulated the behavior of two types of societies: a society of individualist and a society of egalitarian agents. The outcomes produced by these societies are observed in terms of the average travel time per habitant; the amount of CO_2 emitted to the environment; and the usage of the urban transportation, e.g., the average of passengers per car; and the number of habitants travelling in each type of vehicle.

As shown in Figure 1, individualist habitants are mainly interested in reducing the travel time. Hence, they usually prefer to travel by car (see the high number of agents using this type of vehicle in Figure 2).

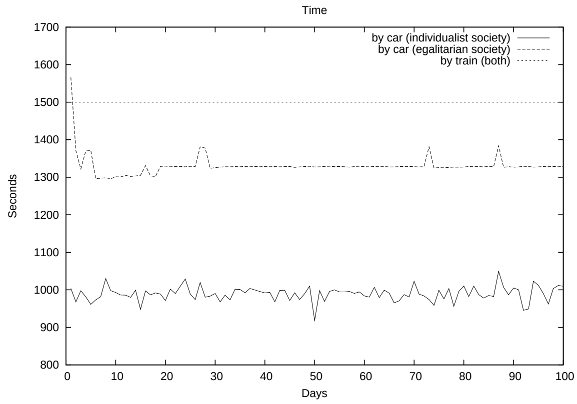

Fig. 1 Average travel time in seconds for the individualist and egalitarian societies.

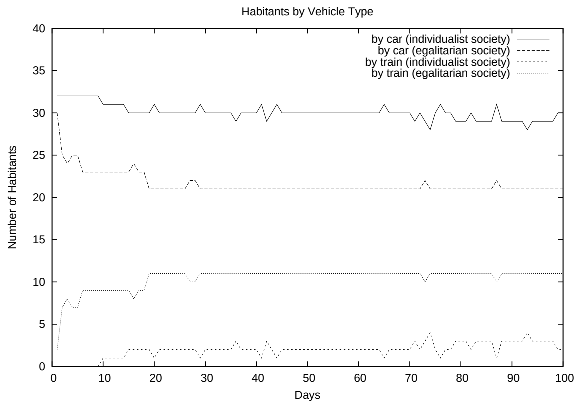

Fig. 2 Habitants per type of vehicle in the individualist and egalitarian societies.

Besides, they rarely share their car with another partner as demonstrated by the low values in figure 3. Thus, this behavior is eventually reflected in the amount of CO_2 emitted by individualists which is higher than the pollution derived from the egalitarian society (Figure 4).

On the other hand, the average travel time of egalitarian citizens is logically higher (see figure 1) since they are also interested in balancing the $C0_2$ emissions and the monetary cost derived from their actions (see table 4). They manage to do this by increasing the degree of car sharing. For instance, when travelling by car, they normally share it with 2 other passengers (see figure 3). Additionally, a 30% of the habitants decides to travel by train (see figure 2). As a consequence of this behavior, the kilograms of $C0_2$ finally emitted by the egalitarian society is considerably reduced (see figure 4).

Although not included in this paper, we have also computed the delay incurred by both societies to verify that the simulation framework has been properly adjusted. The delay is calculated (for each day and agent) as the difference between the desired

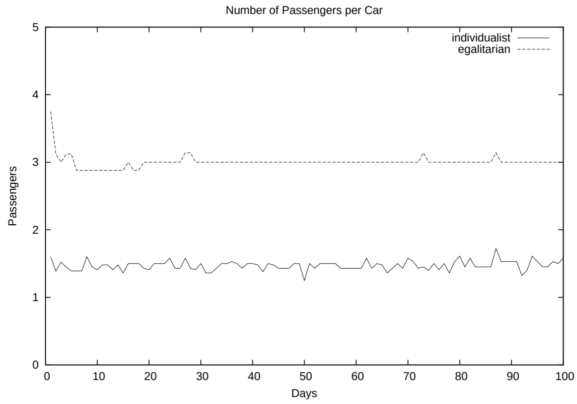

Fig. 3 Average passengers per car in the individualist and egalitarian societies.

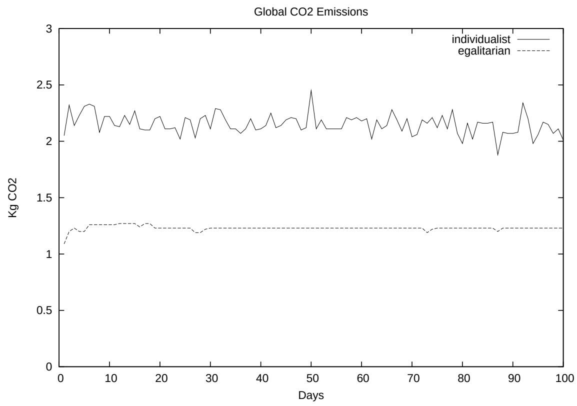

Fig. 4 Total amount of kilograms of CO_2 emitted each day (cycle) by the individualist and egalitarian societies.

time to be at work and the arrival time coming from the simulator. The experiments carried out produce an average delay that converges quickly to a small negative value (around 1 minute), which indicates that the habitants are arriving just before they planned. This situation reveals that the scenario has been properly parameterized as different behavior emerge from the societies and both of them arrive on time.

6 Conclusions and Future work

In this paper we have presented an urban mobility simulation framework developed over Jason that allows to model the mobility within a metropolitan area. The system uses the Jason Multi-modal Agent Decision Making (J-MADeM) library to model and implement the social decisions made by each habitant about how to get to work every day, e.g., by train, by car, sharing a car, etc. Therefore, the proposed approach focuses on the decision making aspects of this problem at a micro level, instead of focusing on the classical spatial or other macro level issues. The first results show the behavior of two societies of individualist and egalitarian citizens, which affect the average travel time, the use of the urban transportation and the amount of CO_2 emitted to the environment.

There is still work in progress to achieve the goal of developing a decision support platform for metropolitan planning. First, we are analyzing more complex scenarios that involve the use of new transports such as the bus or the bike. Second, we plan to extend the configuration files to include features such as the use of tolls or high-occupancy vehicle lanes. Regarding the infrastructure, we are currently studying the scalability of multi-agent systems in Jason so that we can run large-scale simulations.

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