

## Simulation of Carpooling Agents with the Janus Platform

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### Abstract

Carpooling is an emerging alternative transportation mode that is eco-friendly and sustainable as it enables commuters to save time, travel resource, reduce emission and traffic congestion. The procedure of carpooling consists of a number of steps namely; (i) create a motive to carpool, (ii) communicate this motive with other agents, (iii) negotiate a plan with the interested agents, (iv) execute the agreed plans, and (v) provide a feedback to all concerned agents. The state-of-the-art research work on agent-based modeling is limited to a number of technical and empirical studies that are unable to handle the complex agent behavior in terms of coordination, communication and negotiations. In this paper, we present a conceptual design of an agent-based model (ABM) for the carpooling that serves as a proof of concept. Our model for the carpooling application is a computational model that is used for simulating the interactions of autonomous agents and to analyze the effects of change in factors related to the infrastructure, behavior and cost. In our carpooling application, we use agent profiles and social networks to initiate our agent communication model and then employ a route matching algorithm, and a utility function to trigger the negotiation process between agents. We plan to, as a part of the future work, develop a prototype of our agent-based carpooling application based on the work presented in this paper. Furthermore, we also intend to carry out a validation study of our results with real data.

**Keywords:** *Carpooling Problem, Multi-agent simulation, Organizational Model, Janus Platform*

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### 1. Introduction

Nowadays, carpooling is an emerging transportation mode that is eco-friendly and sustainable as it enables commuters not only to decrease the travel cost, such as fuel, toll and parking costs, of the carpooling participants but also reduces emissions and traffic congestions. Carpooling, sometimes also known as ride-sharing, is the sharing of a car between people (agents) from a certain origin to a specific destination. Thus, in order to study the carpooling concept, we should take into account the interactions of two or more agents throughout the carpooling process. The procedure of carpooling consists of a number of steps namely (i) create a motive to carpool, (ii) communicate this motive with other agents, (iii) negotiate a plan with the interested agents, (iv) execute the agreed plans, and (v) provide a feedback to all concerned agents. Creating a motive means that a traveler (agent) may choose to carpool because of the availability of travel resources, time, monetary and route cost constraints.

Moreover, change in some socio-economic factors such as the increase in fuel price or establishment of a new traffic policy, may initiate more carpooling. Once the decision has been

made to carpool, the traveler (agent) will try to find one or more potential partners (agents). The carpool initiating agent will send a request to other interested agents in its vicinity. If one or more agents who receive this request are willing to carpool, then they start the negotiation phase. In this phase, these agents will negotiate about sharing their travel resources and optimizing total costs and daily schedules. After reaching a compromise, these agents can carpool. Meanwhile, an agent can appraise its partners according to their degrees of faithfulness to the carpooling. We call this degree of faithfulness the agent reputation. This reputation factor can serve as a criterion for the selection of a potential partner for carpooling.

An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents with a view to assessing their effects on the systems as a whole [1]. ABM is now widely used for modeling increasingly complex systems [2]. Application of ABM is not only limited to the computer science domain. Currently, many research areas such as transportation behavior modeling need to analyze and model the complex phenomenon of interactions between different entities. While traditional modeling tools cannot catch the complexity, ABM is able to do it through modeling the interaction of autonomous agents and deducing

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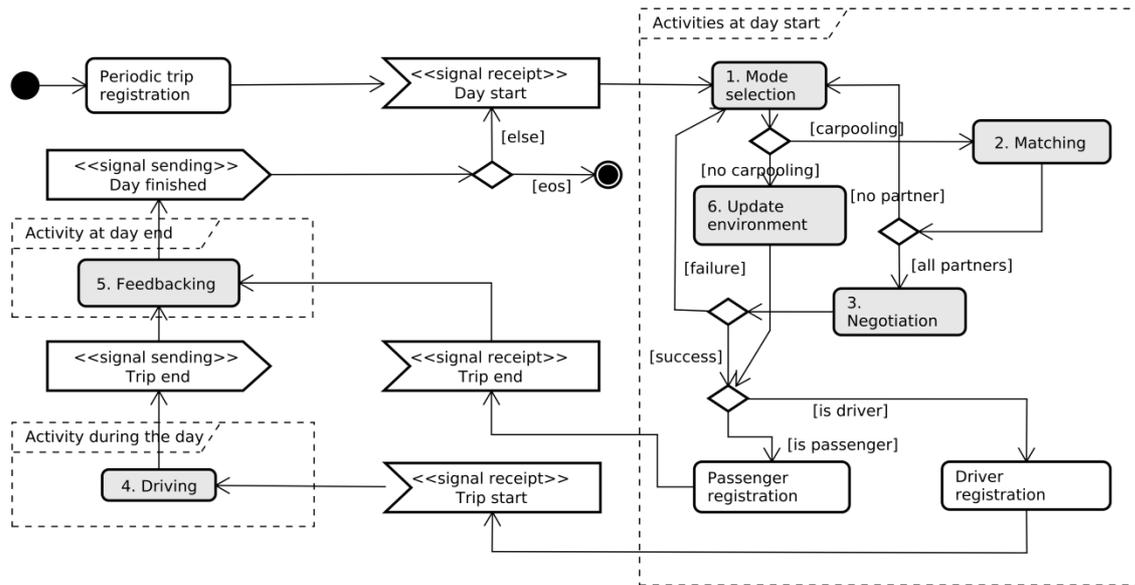


Fig. 1. Diagram of the activities of a carpooling agent.

the rules for such a system. We, therefore, in this paper propose an agent-based interaction model for the carpooling application.

This paper briefly describes a conceptual design of the carpooling application, initially proposed by [3,4] and using an agent-based model on the Janus platform. A simulation model needs to be created to support the individual behaviors of the participants. The contribution of this paper is the design and the implementation of an agent-based model upon the Janus multiagent platform. This platform permits to individuals to (i) select the best transport mode according to their characteristics; (ii) maintain a social network; (iii) negotiate for carpooling; (iv) carpool the driver and the passengers of a car. In the rest of this paper, we present some related work on the carpooling concept and ABM in section 2. In section 3, we explain our ABM for the carpooling application with details about the activities and the roles of the agents, and of the environment. We discuss in section 4 several implementation notes. Section 5 is dedicated to our concluding thoughts and ideas for future work.

## 2. Background

Related research on the carpooling concept is largely separated into two parts: (i) a technical study, and (ii) an empirical study. The first one focuses on the development of carpooling support systems with techniques of travel route matching [5, 6]. In the second part, the overall trend of carpooling — or of interrelationship between willingness-to-carpool and the socio-economic attributes of the carpooling participants — is treated in general [7, 8]. The studies mentioned previously are limited and do not consider the potential agent (participants) interaction to perform carpooling.

Most transportation-related applications of ABM are related to vehicle routing, pedestrian-flow simulation or demand modeling efforts [9]. Among these applications two of the more widely known are TRANSIMS and MATSim ABM simulation platforms. TRANSIMS, developed by Los Alamos Lab, is designed to supply transportation planners with more delicate information about traffic impacts, energy consumption, land-use planning and emergency evacuation [10]. MATSim is also a large-scale agent-based simulator

similar to TRANSIMS, but runs simulations faster due to a simplified traffic simulator [11]. Those applications only consider the whole effect of each agent's action in a system and cannot handle a detailed agent-to-agent or agent-to-environment coordination, communication and negotiation.

According to James Odell [12], “the environment provides the conditions under which an entity (agent or object) exists.” The author distinguishes between the physical environment and the communication environment. The physical environment provides the laws, rules, constraints and policies that govern and support the physical existence of agents and entities. The communication environment provides (i) the principles and processes that govern and support exchanges of ideas, knowledge and information, and (ii) the functions and structures that are commonly deployed to exchange communication, such as roles, groups and interactions protocols between roles and groups. James Odell [12] defines an agent's social environment as “a communication environment in which the agents interact in a coordinated manner.” This approach is shared by Ferber et al. [13], Cossentino et al. [14], and Galland et al. [15] who proposed to integrate the environment with organizational models. The Janus platform [16, 17] provides an efficient implementation of agent-based and organizational concepts based on the Capacity-Role-Interaction-Organization metamodel [14]. In the rest of this paper, the graphical notation is inspired from [14].

## 3. Carpooling Model

An agent is defined as someone who lives in our study area and executes his or her own daily schedule in order to satisfy his or her needs. A schedule is a combination of a number of trips associated with a number of activities. In our model, we consider the socio-economic attributes, including age, gender, income, education, relationship (within a family), job, vehicle and driving license ownership, as a set of input data. These schedules and attributes may be supplied by FEATHERS [18], an activity-based traffic demand model, which is developed by the IMOB Institute. The environment is established as the spatio-temporal aggregate where an agent lives and executes its own daily schedule.

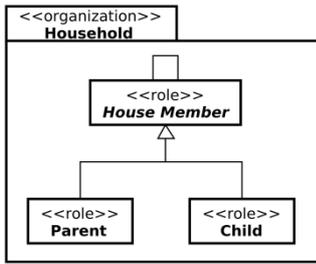


Fig. 2. Household Organization

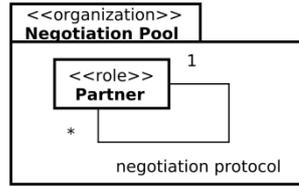


Fig. 3. Negotiation Organization

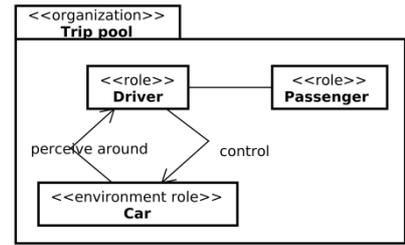


Fig. 4. Trip Execution Organization

Agents follow a number of steps, including (i) goal setting, (ii) scheduling based on a given resource and environment, and (iii) execution of their schedule. Figure 1 describes the activities of an agent during the simulation. The following sections detail the global behavior of the agent and its activities.

The behavior of each agent is described by an activity diagram illustrated by Figure 1. First people post information about each trip they periodically plan to execute in the “Periodic trip registration:” those data consist of source and destination locations, earliest and latest departure and arrival times, the maximal detour distance that is acceptable and the availability of a car (possibility to drive). Note a particular driver license owner can be unavailable for driving on a specific day of the week because the family car on that day is in use by her/his partner. Each day, a person has the following activities:

1. Mode selection
2. Partner Matching
3. Negotiation
4. Execution of the trip
5. Day activity feedback
6. Environment updating

### 3.1. Mode Selection

The agent is selecting its preferred transport mode. Here, the FEATHERS data are used to determine the mode choice stochastically. If the agent decides to carpool, it goes in activity 2; otherwise it runs its activity in activity 6.

### 3.2. Partner Matching and Selection

An agent explores the set of known agents (family members, acquaintances, colleagues...) first: this is called *local network exploration*. When no partner is found in this phase, *global exploration* is performed by searching for a partner in the set of previously unrelated individuals via a global directory (i.e. a website).

The matching of partners is applied in both local and global exploration phases. In both cases, matching precedes the negotiation phase where final decisions to carpool are taken. A person looks for other individuals to cooperate while executing its periodic trip (periodicTripEx). Local exploration within the private social network (PrivNet) is applied before the global exploration. PrivNet is represented by an organization (Figure 2) in which each agent is playing a role, and has relationship with the other members of the organization. If carpool candidates can be found within an agent’s PrivNet, they will be contacted first (as preferred candidates). Global exploration is applied only in a second stage when no suitable pool was found in PrivNet. In the Global exploration phase, a global matching service provides advice about which pools an individual should negotiate with [20]. This corresponds to the use of an online service by to explore the set of formerly unknown carpooling candidates. Two people may carpool

together if there CP = {L, SR, I, R} are matching. Location (L) is matching the start location of the agents. Spatial Relevance (SR) is the match between the paths from the origin to the destination of all interacting agents. Interests (I) and Requirements (R) are matching the interests and the requirements of each agent in their profiles, respectively.

### 3.3. Negotiation to Carpool

The negotiation is the process during which the members of a pool are negotiating the details of their periodicTripExs (time window, who are the driver and the passengers...) If the negotiation fails, the agent goes back to the activity 1; otherwise to the activity 4. The negotiation is based on a specific protocol. According to our organizational approach, all agents involved in a specific negotiation are members of the same organization “Negotiation Pool” (Figure 3). The negotiation protocol is described as a sequence of messages exchanged by the different participants, as illustrated by Figure 5. This negotiation protocol is re-launched with different proposed time windows until all the participants were found.

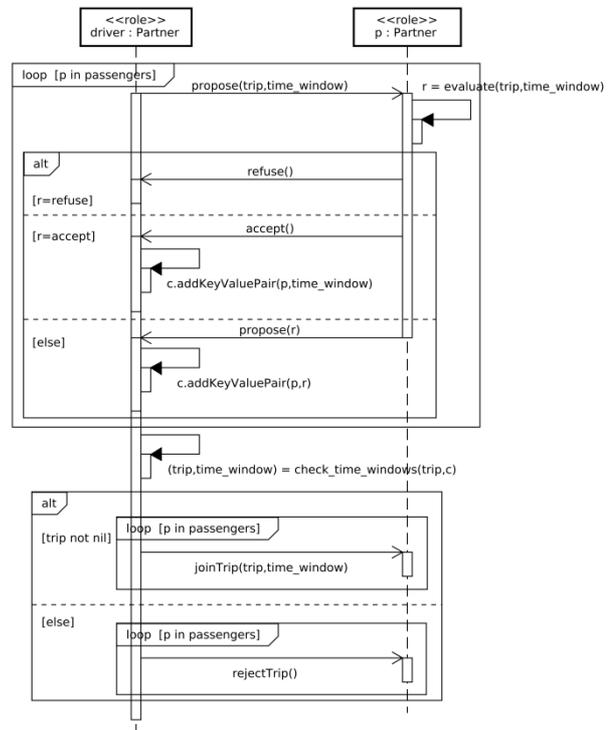


Fig. 5. Negotiation Protocol

### 3.4. Execution of the Trip

The driving activity corresponds to the execution of the trip. The driver controls its car (with the carpooled passengers

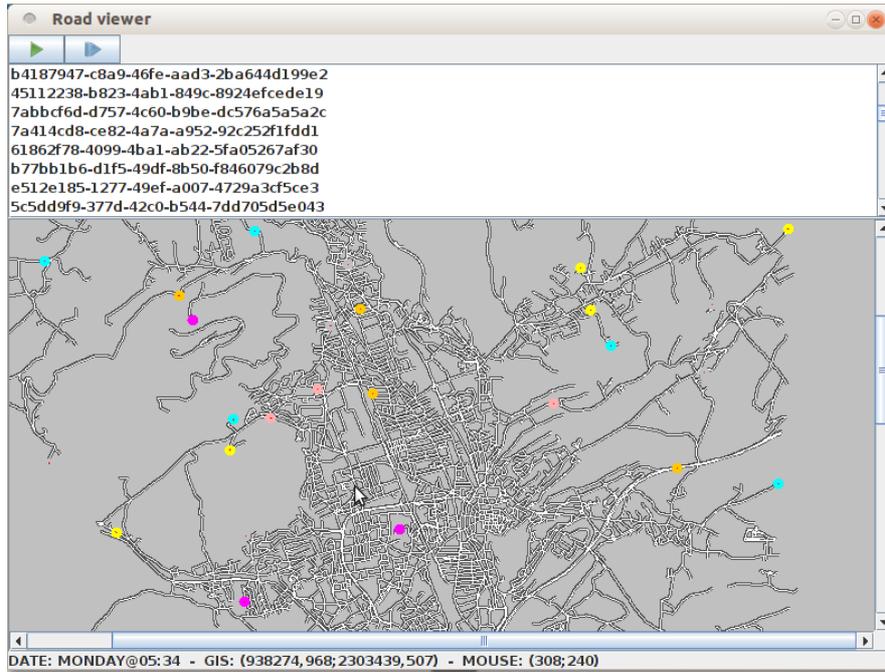


Fig. 6. Screenshots of the Simulator

inside) on the roads. The road network is represented by a graph built from geographic data. The Janus platform provides an environment model able to support the displacements of the cars on the roads [15]. Figure 4 presents the organization that is supporting the trip simulation. All the agents in a trip pool must play a role in an instance of this organization. The behavior of the Driver role is composed of two layers: (i) the path planning; and (ii) the path following and collision avoidance. The path planning is dynamic: the driver adapts its path according to its perceptions from the environment jams, road works...) with a variant of the D\* algorithm [19]. The D\* algorithm has two advantages: it enables path re-computation during the simulation according to a new state of the environment; and it is suitable for a partial knowledge of the environment's state. After the driving agent has updated its path, he follows it, and he avoids collisions with the other cars around. A standard Intelligent Driver Model is used to adapt the velocity of the car according to the ahead vehicles and to the road signs: the traffic lights and stop signs are assimilated to immobile vehicles until the driver decided to pass through. The other road signs are used to update the variables of the driving model (cruise velocity...). After the pool's vehicle has reached its goal, all the agents of the pool execute the activity at activity 5 (Figure 1). The algorithm followed by the driver is:

```
repeat
  // Ensure that the path to follow
  // is not empty
  if path = <> then
    path ← <position>
  end if
  if path = <s> or (path = <s>.e and
    -isFreePath(s)) then
    // Update the path according
    // to the D* algorithm.
    path ← { path.<s> | ∃s ∈ roads, ∀w ∈
      roads, isConnectable(path,s)
      = true and
      isConnectable(path,w) = true
```

```
and distance(s, goal) ≤
  distance(w, goal) }
end if
// Get the objects in the field of view
p ← getPerceivedObjects(path, roads)
updateAttributesAccordingTo(p)
// Get the closest object, the most
// on the right side of the agent if
// multiple close objects are found
o ← {a|∀(a,b) ∈ pxp, distance(position,
  b) ≥ distance(position, a) and
  ((getPosition(a)-position).
  (getPosition(b)-position)) ≥ 0 }
if o then
  // Apply the IDM algorithm
  a ← followerDriving(o,
    acceleration, speed,
    position)
else
  // Apply cruise speed
  a ← freeDriving(acceleration,
    speed, position)
end if
// Apply Newton's laws
speed ← speed + (a.Δt)/2
position ← position + speed.Δt
// Estimate the immobility duration
if speed > 0 then
  waitingTime ← 0
else
  waitingTime ← waitingTime + Δt
end if
until position = goal
```

### 3.5. Feedback

Feedbacks are computed at the end of the day according to the activities of the day, and given to the carpoolers. This activity is the last of the day for a carpooling agent.

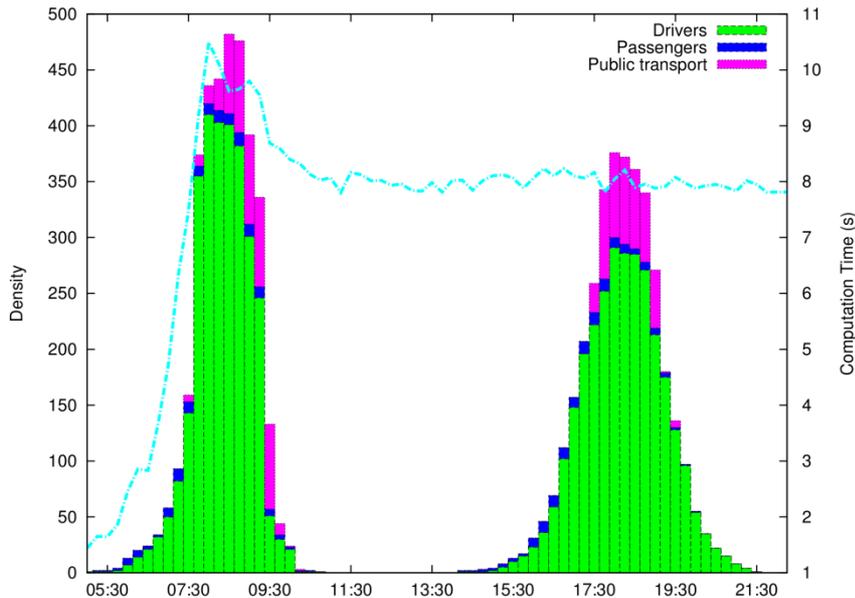


Fig. 7 Selected transport mode histogram, and computation time (blue curve) for the reference day

### 3.6. Environment Updating

The updating of the environment is the optional activity that permits to a non-carpooling agent to register its mobility behavior in the environment in order to influence the driving simulation of the carpooler agents. Individual vehicles may be generated in the microscopic simulation model used in activity 4. This activity is the last of the day for a non-carpooling agent.

If an individual joins a pool, (s)he is added to the PrivNet for all other participants in the pool (if still required) so that if  $i_0$  and  $i_1$  cooperate in a pool,  $(i_0, i_1)$  and  $(i_1, i_0)$  belong to each others private networks. Because links never are removed from the PrivNet, if  $i_0$  and  $i_1$  ever carpoled,  $i_1 \in \text{PrivNet}(i_0)$  and  $i_0 \in \text{PrivNet}(i_1)$ . Candidates register, join and leave pools at random moments in time. As a consequence the main data structures dynamically change due to events external to the matching process.

## 4. Implementation and Experimental Results

The experimentations were done on a population of 3000 people. One of the major goals of our experimentations is to compute and possibly optimize the (complex) agent-based modeling and simulation of the driving behaviors. The trips are extracted from the data gathered by public interviews in the city of Belfort (France). Figure 6 illustrates the simulator windows: the lower-left window shows the roads, and the upper-right window displays the parameters of the simulation. The experiment aims to determine the proportion of drivers and passengers for every quarter of an hour during the reference day.

Figure 7 shows the histograms for the distribution among the transport modes for every quarter of an hour during the reference day. 83% of the simulated people are drivers; 4% are passenger; 13% is using the public transport mode. The average number of people per carpooling pool is of 2. The population that is using the public transport mode corresponds to the people who have not succeeded their carpooling negotiations. It is mainly due to too constrained time windows

of their trips. Therefore, they prefer to select the single-vehicle, when they have a driver license, or the public transport modes, when they have not a driver license.

Figure 7 gives the average computational times for the simulation of a day on an Intel Core i7 CPU 960 at 3.20GHz, four cores, with Windows Seven (64 bits). Because the JaSim environment model is based upon the Influence-Reaction model [15], which permits to handle and solve the conflicts among simultaneous actions, the scheduling of the agents is a standard loop (each loop represents  $\frac{1}{2}$  second during the day). This approach does not cause a causality problem among the agent actions during the simulation. Our simulator may be improved on several points: (i) the quality of the simulation's results, and (ii) the global performance of the simulator. The algorithms deployed in our model are designed according to the simplicity principle, and are easily replaceable by any other (compatible) negotiation protocols available to the agent-based community. The global exploration is skipped in this study because we do not have an online system for carpooling in place currently. We have presented the details of our approach for global exploration in [20], and we intend to work on it as a part of the future work. The microscopic simulation of the vehicles may be replaced by a mesoscopic or macroscopic simulation model to improve the performances of this module. Performance is a crucial issue because the aim of the agent model is to serve as an active synthetic population to exercise the global advisor software. Wall clock time available for testing is limited and large agent communities are required for realistic evaluation. Hence, performance issues will get priority focus. In the case of a microscopic simulation, the agent scheduler used on the Janus platform may be replaced by an asynchronous scheduler (based on operating-system threads). This solution enables to run groups of agents in parallel in place of the current sequential approach. The current implementation is a proof-of-concept. All the algorithms must be tuned and redesigned to improve their performances. Our model and its implementation reproduce the behavior of a population in a carpooling problem. The microscopic simulation permits to reproduce the trip execution with high level of details (e.g. traffic jams).

## 5. Conclusion

In comparison to the state-of-the-art research work, the work/study presented within this paper has a number of advantages. Some of them are (i) the ability to analyze various effects of agent interaction with a detailed view on both communication and negotiation aspects, and (ii) the ability to simulate learning, adaptation and behavior reproduction of agents through modeling their interactions. Our simulation model on the Janus platform provides a solution to a complex simulation but needs a lot of computing resources (e.g. processing time, memory, and data storage) because of the high number of agents to simulate, and the big data processing for each agent. The agent-based model described constitutes an active synthetic population that can be used to exercise a global matching advisor for carpooling. Such advisor consists of complex mechanisms, including machine learning. Furthermore, it requires a critical mass of customers to operate efficiently. Exercising the advisor is useful for testing and for transient phenomena analysis. Like all models that cover real-world transportation problems, the simulation model proposed in the paper (i) requires a large amount of detailed and accurate input data, including agent's socio-economic attributes and road network information, and (ii) has scalability issues that are still to be solved. Indeed, it is necessary to consider a sufficiently large region to evaluate the carpooling process. Apart from scalability issues, future research will focus on enhancing the procedure for negotiation between agents.

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