An Agent-based Negotiation Model for Carpooling: A Case Study for Flanders (Belgium)

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ABSTRACT

In order to commute by carpooling, individuals need to communicate, negotiate and coordinate, and in most cases adapt their agenda (daily schedule) to enable cooperation. Through negotiation, agents (individuals) can reach complex agreements in an iterative way which meet the criteria for the successful negotiation. The procedure of negotiation and trip execution in the carpooling consists of a number of steps namely; (i) explore the social network, (ii) negotiate agenda to reach complex agreements, and (iii) long term trip execution. This paper presents a conceptual design of an organizational-based and agent-based model (ABM) of a set of candidate carpoolers that serves as a proof of concept and is an extension of a simple negotiation model for carpooling. The proposed model is used for simulating the interactions of autonomous agents with their agenda and explore social networks to initiate agent communication to trigger the negotiation process. The schedule adaptation depends on the preferences among feasible schedules of the individuals, generally depends on both the time of day and on the duration of the participation. In this simulation of the evolution we consider a daily schedule that consists of three activities (home, work and home) and a chain of two intermediate trips (home-to-work and work-to-home) only. We carried out a validation study of our results with real data collected in Flanders, Belgium. From the simulation's discussions, it is possible to understand the causes why people can adapt their daily schedule to enable cooperation in order to carpool. The future research will mainly focus on enhancing the mechanism for negotiation between agents.

Keywords: Negotiation, carpooling, negotiation model, agent-based social simulation, Agent technology, Organizational model, Janus platform.

INTRODUCTION

Carpooling is an emerging transportation mode that is eco-friendly and sustainable as it enables commuters to save the travel time, travel cost (fuel, toll and parking costs) and resource of the carpooling participants; it also reduces emission and traffic congestion. Change in some socio-economic (SEC) factors such as the increase in fuel price, in parking costs, or in the implementation of a new traffic policy, may cause the initiative to carpool. Furthermore the SEC attributes, including age, gender, income, education, relationship, job, vehicle and driving-license ownership can play vital role to find the favorable individuals for the carpooling. In order to carpool, individuals need to coordinate, negotiate and in most cases adapt their daily schedule to enable cooperation. Information propagation between agents can be carried out using the interaction between agents in their social group. Feedback information from social interaction can be used by the individuals' schedule executor to adapt their daily schedules (*7,21*).

Negotiation is a dialogue among parties possibly having conflicting interests and is intended to reach an acceptable agreement between partners or to collectively search for a coordinated solution to a problem (*23*). Each negotiation involves a small number of participants but the daily schedules can be interconnected by cooperation (*7, 21*). While traditional modelling tools cannot handle the complexity of negotiation in the carpooling, agent-based models (ABMs) are able to do so through modelling the interaction of autonomous agents (*17*).

The ABM aimed at simulating the actions and interactions of autonomous agents are not limited to the computing but are also used in the non-computing related scientific domains including biology, ecology and social science *(25)*. With the agent-based social simulation (ABSS) we can explore different outcomes for phenomena, transportation, market mechanisms, cooperation and escalation and spreading of conflicts, where we might not be able to view the outcome in real life. The ABSS can provide valuable information on the society and on the outcome of social actions or phenomena. Currently many research areas including transportation behavior need to analyze and model complex phenomena of interactions between different autonomous entities (*17*).

The aim of this research is to generalize the concept of communication, negotiation and coordination of a single-trip negotiation mechanism into a multiple trip negotiation model by taking the possibility of flexible activity scheduling into account. It also focuses on the simulation aimed at the setup of the framework and of a network of the carpooling candidates. The agents (individuals) may communicate with the individuals of their interest within a small group by taking SEC factors (vehicle and driving-license ownership) into account. Furthermore they negotiate about trip timing in order to adapt their daily schedule. This represents an extension of the simple but analytically tractable single-trip negotiation model *(12)* for carpooling. We consider a daily schedule consisting of three activities, one of which may be flexible, and a chain of two intermediate trips.

The model is based on an agent-based and organizational meta-model (*27*), in which the role and organization are first class entities. In the proposed conceptual model agents are the individuals, who negotiate to reach an agreement to carpool. The carpooling related actions performed by agents are divided into different phases: exploration, negotiation and trip execution. During the exploration the agent looks for other individuals to cooperate while executing its periodic trip and explore their social network by sending requests for carpooling. In the negotiation, agents can reach complex agreements depending on the "negotiation mechanism", used to match with partners, and on the behavior of the agents involved in the negotiation process. For the trip execution, after finding matching partners, agents carpool for a specified time period. The Janus (*26*), multi-agent based platform is used; it provides an efficient implementation of organizational-based and agent-based concepts.

RELATED WORKS

According to literature review, the agent-based models are also used in non-computing related scientific domains and can provide valuable information on society and the outcomes of social actions or phenomena. A detailed literature review on technical *(18,19)*, focuses on the development of carpooling support systems, and empirical, interrelationships between willingness to carpool and socio-economic attributes of carpooling, is presented.

Galland et al. *(8)* presented a conceptual design of an ABM for the carpooling application, that is used for simulating the interactions of autonomous agents and to analyze the effects of change in factors of infrastructure, behavior and cost. This model used agents' profiles and social networks to initialize communication and then employ a route matching algorithm, and a utility function to trigger the negotiation process between agents. Authors showed computation time of carpoolers by taking different number of agents as input.

Knapen et al. *(7)* presents an automated, Global Car Pooling Matching Service (GCPMS), advisory service to match commuting trips by carpooling, where the candidates can register for their personal profile and a set of periodically recurring trips. The probability for successful negotiation is calculated by means of a learning mechanism; the probability values vary over time because they depend on the actor's evolving personal profile, on the trip characteristics and on the negotiation feedback. As a significance, the matcher needs to deal with dynamically changing graph w.r.t. topology and edge weights. Authors (1) proposed to an agent-based model simulating the customer community in order to exercise GCPMS for testing and validation.

Knapen et al. *(10)* studied the problem of finding an optimal route for carpooling and proposes an algorithm to find the optimal solution for the join tree. Authors proposed that the home, work and parking locations are possible transferal where one can join or leave a carpool. Each individual declares the maximal time and/or distance that is acceptable to move from origin to destination. The combined route that consists of join part, join the main drivers' car at several locations and time, and fork part, successively leave the car at destination otherwise continue carpooling, respectively.

Research presented in *(11)* resulted in a negotiation mechanism to synchronize agenda schedules , based on ideas drawn from the A* shortest path algorithm, which described a group negotiation protocol for agreement. A group can consist of two or more agents, each agent is assumed to specify its most preferred option first and to specify new consecutive proposals, having private utility function, in non-increasing order of preference. The protocol initiator makes use of a proposal evaluation function that is based on the assumption. Versions using preference feedback by agents and conflict resolution by the initiator are reported to result in nearly optimal solutions using a quite small number of negotiation rounds.

Kamar and Horvitz *(13)* presented computational methods for controlling cooperation in which an agent-based model directing to optimally combine demand and supply for repeated ride-sharing. The methods are encouraged and evaluated in the domain of ridesharing, using GPS records of travelling data. The authors focus on the mechanisms required to model users collaborating on joint plans and focus on the economic value of the common plans. Authors focused on the fairness of the payment system but did not study the rideshare demand and supply change in time.

Manzini and Pareschi *(14)* demonstrated that the carpooling is an effective strategy to reduce transport volumes, costs and related hill externalities. The authors presented a Graphical User Interface (GUI) based interactive system to solve the carpool problem that can be applied to company employees. The proposed decision support system is based on hierarchical clustering models which helps the mobility manager to generate the pool and to design realistic paths for shared vehicles.

PROPOSED NEGOTIATION MODEL FOR CARPOOLERS

The long term agent-based negotiation model using the organizational concepts for cooperative travelling is simulated to consider the individual behaviors during the carpooling process using the Janus multi-agent based platform. The goal is to simulate how everyone is deciding to carpool by adapting their daily schedule, and how the carpooling process is executed. From the discussions, it is possible to understand the causes why people can adapt their daily schedule to enable cooperation in carpooling in a given area. The agents can interact with each other autonomously to find matching partners to carpool for multiple days and during multiple consecutive periods in different groups.

In this paper, initially we consider a daily schedule, consisting of three activities, and a chain of two intermediate trips only. We may interpret activity 1 (home activity) as being at home in the morning, activity 2 (work activity) as being at work during the day and activity 3 (home activity) as being at home in the evening. Similarly, trip 1 ($home - to - work$) may represent the commute from home to work in the morning and trip 2 ($work - to - home$) the commute back from work to home in the evening, respectively. In this simulation model, we considered home and work locations, trip start times (morning and evening) and their durations, and activity duration, the socio-economic attributes, including age, gender, job type, vehicle and driving-license ownership as a set of input data. The driver and vehicle selection is based on the inspection of the individual's profiles (car and driving-license ownership). For the "negotiation mechanism" for this simulation model, we consider the utility of the work activity to adapt the daily schedule of an individual discussed in *(1,3)*.

The individual or agent is someone who lives in the study area and executes his or her daily schedule in order to satisfy his or her needs. A daily schedule is a combination of activities and trips with a specified start time and duration of each activity and trip. The modeling structure claims that individuals spend the day taking part in activities and traveling between activities. The schedule adaptation depends on the preference for some specific schedule adaptations.

We assume that the utility derived from taking part in an activity (i.e. work) depends in general on both the time of day and on the duration of the participation. In general, $time\_of\_day$ dependencies arise from the coordination with others and from fixed activity start and end hours *(3)*. The individuals' schedule of a working day remains the same for all the working days. This means that after negotiation the individuals can fix the start times, for the $home - to - work$ and $work - to - home$ trips respectively: those moments in time mark the start and end of the work activity. The parameter $\beta_i \in [0,1]$ expresses the flexibility to adapt to a cooperative schedule between individuals (carpoolers).

For the experiment described in this paper, daily schedules for one working day are supplied by FEATHERS *(6)*, which is an operational activity-based model for the region of Flanders (Belgium). The input for FEATHERS consists of the synthetic population for the study area. This contains SEC data describing each individual so that the distributions fit the census data. Furthermore, it requires an area subdivision into traffic analysis zones (TAZ), a set of decision trees trained using large scale (periodic) travel surveys. Those data essentially specify individual behavior as a function of SEC data and partial schedule characteristics.

Information about flexible working hours is not available from FEATHERS data. We assume that a fraction β_i of the workers in the synthetic population can benefit from flexible work hours. A estimate for β_i was determined from the results mentioned in *(16)* that reports on a survey among 150 effective carpoolers in Flanders.

Overview of the model

Microscopic (re-)routing and traffic simulation are not required in this model. The proposed model has no information about carpool parking; therefore, it is assumed that people board and alight at home and work locations only. The framework is based on traffic flows between traffic analysis zones (TAZ). Each agent follows a number of steps, including the goal setting, exploring, schedule adaptation through negotiation and the execution of their schedule. These steps may be modeled within an activity diagram for specified period (e.g. number of years) in the simulation, which is shown in Figure 1:

1. The upper left block shows the initialization step. FEATHERS is used to generate a schedule for each member of the synthetic population; those schedules represent the planned agendas for mutually independent individuals using an undisturbed transportation network. Those initial daily plans are assumed to be optimal i.e. generating maximal utility. The Data Filter is used to filter the data, generated by FEATHERS, and apply the sample survey results needed by this simulation.
2. The simulation launched each agent with its profile, according to data generated by the FEATHERS framework and survey results of the Flanders region. Through organization-based concept, the agents may be grouped on the basis of their origin and destination locations. In this simulation the *TAZsZoneOrganization* is used to do so.
3. The agents, who want to carpool, explore their social network to find their carpool partners. For this, the agents belong to the same groups may communicate with each other through Agent Communication Language (ACL) by sending and receiving text messages.
4. Through communication, the agents may negotiate on start time of both the trips ($\mathrm{home-to-work}$ and $\mathrm{work-to-home}$), on the vehicle to use and hence on the selection of the driver. The negotiation becomes successful when the negotiators adapt their daily schedule according to the parameter $\beta_i \in [0,1]$ to enable cooperation. Each agent who owns a car and a driving license, may become the driver when carpooling. At negotiation time, each individual specifies the period (number of days) during which to carpool for the trip. The negotiation mechanism is used to achieve such tasks.
5. After the successful negotiation, the agent (invitee), who is able to drive, creates an instance (*CarPoolGroup*) of *CarPoolOrganization* and start his role as *DriverRole*. Then he replies to the inviter (candidate passenger) with an *acceptMessage*, asks him to join the *CarPoolGroup* and start playing the *PassengerRole*.
6. When all the agents finished the daily activities, the organization-based concept (here *NextDayOrganization*) is used solely for synchronization and to start the next day activities. Remember that one group is created for each day only.
7. The driver and passenger leave the carpool group at the end of the agreed carpool period. In case, the driver leaves the carpool group and the remaining group size is exceeds one, then (s)he will hand over the driver responsibility to the senior passenger (having vehicle and driving-license) of the same pool. An individual who once left carpool group, can

become part of the same or any other active carpool group later. The individual can also create a new carpool group with the individuals of his or her interest. A carpool group is destroyed if only one individual is left.

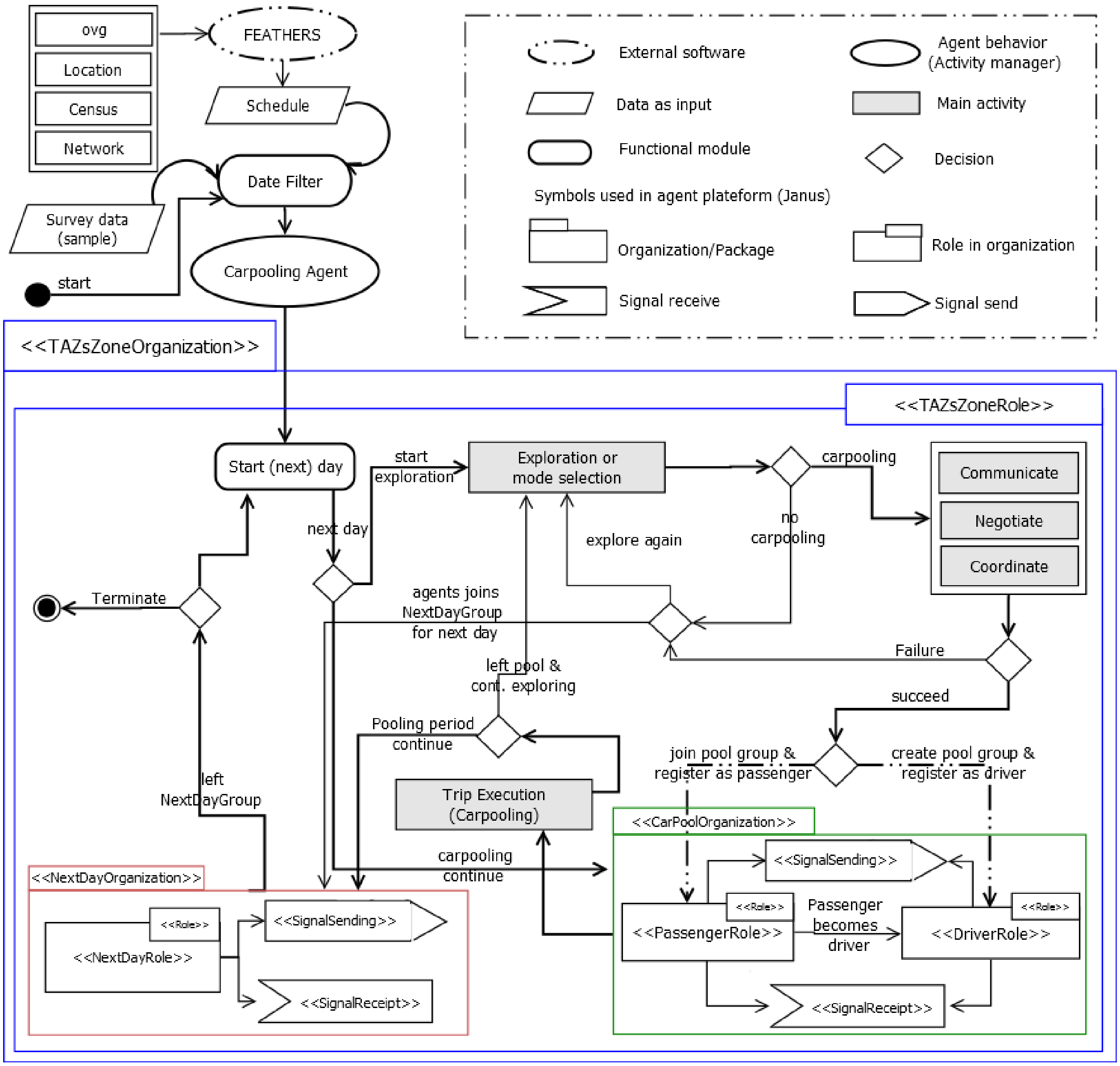

Figure 1: Diagram of the activities of a carpooling agent. The major activities in the *TAZsZoneRole* of *TAZsZoneOrganization* are: *exploration, negotiation and trip execution,* shown with a grey background and described in the text. Within the instance of *CarPoolOrganization* (green border box at the lower right), the driver and passengers can communicate with each other through signals. The *NextDayOrganization* is used to synchronize the day activities and move to the next day of the simulation.

In Figure 1, three major activities are shown in highlighted boxes; exploration, negotiation and trip execution or carpooling throughout the working day.

EXPLORATION

A person looks for other individuals to cooperate while executing his or her periodic trip, which is called exploration. In the simulation each agent starts his/her activities by exploring his/her social network. In this simulation the parameter *probabilityToInvite* is used to decide the agents' preferred transport mode (carpooling). If the value of *probabilityToInvite* is high then more agents may carpool. If the agent decides to carpool, (s)he may start to explore for partners in the exploration phase, otherwise (s)he continues traveling solo using his own car or on any other transportation mode. In this simulation this agent may remain in the exploration phase throughout the simulation period (because (s)he is unable to find a carpool partner).

NEGOTIATION

There are three activities in the negotiation process; communication, negotiation and cooperation. The agents who belongs to the same *TAZsZoneGroup* (which means they share the HOME and WORK locations) can communicate with each other by using ACL. Each agent can send and/or receive messages to/from the other agent. There are three kinds of messages used in this simulation, *CarpoolRequestMessage*, *AcceptMessage* and *RejectMessage*. The agents may negotiate on trip (morning and evening) departure times and also who will become the driver. During the negotiation process the agents may adapt their daily schedule to enable cooperation according to negotiation mechanism.

NEGOTIATION MECHANISM

The matching is applied in the negotiation phase where final decisions to carpool are taken. During the communication process, agents negotiate about the preferred trip (morning and evening) start times and on about who will be the driver. Each person can only drive his own car. The driver and vehicle selection is based on the inspection of the individual's profiles (car and driver license ownership). But the schedule adaptation depends on the preferences among feasible schedules of the individuals.

Consider *N* agents $a_1, a_2, \ldots a_N$. The preferred activity start time for an agent (a_i), is denoted by PST_{ai}. The effective trip start time TST_{trip}. The preferred trip start time is $PST_{trip,ai}$. The person is prepared to allow a tolerance period $TW_{ai}^{+/-}$ for the start time of the work activity. $TW_{trip,ai}^{+/-}$ is the tolerance of the trip start time; if travel time is considered to be constant $TW_{ai}^{+/-} = TW_{trip,ai}^{+/-}$.

The fraction of people having flexible work times is denoted by *F*. For each individual $p \in F$ the trip start time is constrained by $PST_{trip} \leq TST_{trip} \leq PST_{trip}$ for both the morning and the evening trips. For people have fixed working hours, the following constraints apply:

$TST_{trip,HW} \leq PST_{trip,HW}$ for the morning trip (Home to Work)

$PST_{trip,WH} \leq TST_{trip,WH}$ for the evening trip (Work to Home)

The flexibility cases are visualized in Figure 2. The negotiated trip start time for a given carpool is the average of the individuals preferred trip start times:

$$TST_{trip} = \frac{1}{N} \sum_{j=i,N}^{1} PST_{trip,aj} \quad (1)$$

Let β_i = *1* if and only if agent a_i has flexible work times i.e. for $a_i \in F \subset A$: otherwise β_i = *0.*

The negotiation among agents $a_1, a_2, \ldots a_n \in A$ succeeds if and only if:

$$\forall_{\substack{i \\ a_i \in A}} : \begin{Bmatrix} (TW^{-}_{tripHW,ai} \leq TST_{tripHW} - PST_{tripHW,ai} \leq \beta_i \, TW^{+}_{tripHW,ai}) \land \\ (\beta_i \, TW^{-}_{tripWH,ai} \leq TST_{tripWH} - PST_{tripWH,ai} \leq TW^{+}_{tripWH,ai}) \end{Bmatrix} \quad (2)$$

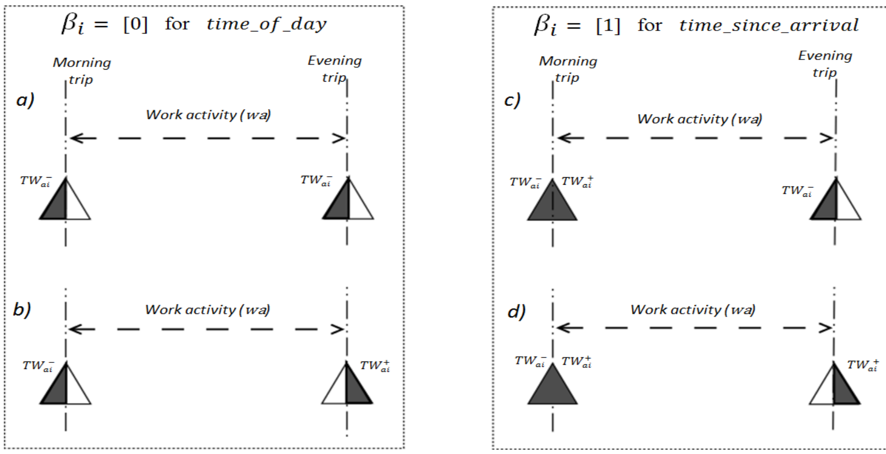

Figure 2: Diagram shows the possibility of flexible work activity scheduling between the trips (morning and evening) of an individual. The highlighted (in black color) side of triangle shows the flexible side of the time window. The parameter β = 0 means that person has no flexible work times (shown in left block), while β = 1 means that the person has flexible work times (shown in right block).

The possibility of scheduling of the work activity of an individual for which $\beta_i = 0$ is shown in Figure 2 (a) and (b); the case for $\beta_i = 1$ is shown in Figure 2 (c) and (d). If an individual does not compromise on utility loss by changing the activity duration, then the $TW^{+/-}_{trip,ai}$ of $trip$ 2 depends on the $TW^{+/-}_{trip,ai}$ of $trip$ 1.

TRIP EXECUTION (CARPOOLING)

The carpooling activity corresponds to the execution of the trip. The driver controls his or her car (with the carpooled passengers inside) on the roads. The road network is not considered in this simulation, we assign only trips between origin and destination. Figure 2 presents the CarPoolOrganization that is supporting the trip simulation. All the agents in a trip must play a role in an instance of this CarPoolOrganization. The driver of the trip will play the *DriverRole* and the passenger will play the *PassengerRole* in *CarPoolGroup* of CarPoolOrganization. When the driver decides to leave the pool, he will assign the driving responsibilities to the senior passenger (the one playing the *PassengerRole* for the longest period) of the *CarPoolGroup* and leaves the *DriverRole*. On the other hand the senior passenger will start playing as *DriverRole* and will leave the *PassengerRole* of the same *CarPoolGroup*. During the carpool lifetime, they can also communicate with the other agents who want to join the carpool.

ORGANIZATIONAL CONCEPTS IN AGENT-BASED NEGOTIATION MODEL

According to the CRIO (Capacity, Role, Interaction and Organization) meta-model *(27)*, an organization is defined by a collection of roles that take part in organized institutionalized patterns of interactions with other roles in a common context. A group, used for partitioning organizations, is an organizational entity in which all members are able to interact according to predefined interaction definitions and protocols. A role is an expected behaviour, a set of role tasks ordered by a plan, and a set of rights and obligations in the organization context. The goal of each Role is to contribute to the fulfilment of, a part of, the requirements of the organization within which it is defined. The aim of an organization is to fulfil some requirements *(26)*. Every agent is able to play a role inside the group of an organization.

The agents negotiate to find an acceptable agreement to carpool and execute their own daily schedule in order to satisfy their needs. In the simulation, agent's behavior is modeled by a finite state machine. The finite state machines are used in the *CarpoolingAgent*.class, the original agent class, and *TAZsZoneRole*.class, in which the agent is playing *TAZsZoneRole* of the *TAZsZoneOrganization*. The states in agent class are; *JOININGTAZsGROUP* and *RUNNINGAGENT* as shown in Figure 3.

1. **JOININGTAZsGROUP**: Each agent once in its lifetime, joins a *TAZsZoneGroup* which is an instance of *TAZsZoneOrganization.* The simulator contains at most one *TAZsZoneGroup* for each pair (A,B) of TAZ. An agent joins the group for (A,B) if and only if he lives in A and works in B.
   If there are '*n'* locations, at most (*n * n) TAZsZoneGroups* will be created.
   Immediately after the agent creates or joins a *TAZsZoneGroup*, it starts playing the *TAZsZoneRole* in its *TAZsZoneGroup* and changes its state to *RUNNINGAGENT.*
2. **RUNNINGAGENT**: All the agents will remain in this state throughout the simulation period.

The simulation model consists of three organizations as shown in Figure 3: *TAZsZoneOrganization*, *PoolGroupOrganization* and *NextDayOrganization.*

TAZsZoneOrganization

The *TAZsZoneOrganization* is used to limit the communication between agents. In *TAZsZoneRole,* the agents can communicate, negotiate and only among all agents playing the *TAZsZoneRole* within the same *TAZsZoneGoup*. The states in *TAZsZoneRole* are; *EXPLORE, WAIT, DRIVER, PASSENGER* and *IDLE* as shown in Figure 3. An agent performs following activities in different states within *TAZsZoneRole.*

1. **EXPLORE**: Exploration is the act of searching for the purpose of discovery of information, resources, or for people interested in cooperation. In the *EXPLORE* state, each agent (inviter) may search for a partner (invitee) by sending *CarpoolRequest* message to a randomly chosen agent, of the same *TAZsZoneGroup*. Emission of an invitation, on given day, depends on the given *probabilityToInvite* parameter. As soon as an invitation has been emitted, the sender enters the *WAIT* state, waiting for the invitee's response. In the *EXPLORE* state, an agent can receive *CarpoolRequest* message from another agent; if the invitation is decent, then the agent will reply with *AcceptMessage*, and changes its state to the *DRIVER* state. Otherwise, it will reply with a *RejectMessage* and remains in the same state and continues exploration. The decision depends on the "negotiation mechanism".

2. **WAIT**: In the *WAIT* state, if the invitee's response is an *AcceptMessage* then the *inviter* tries to join the *CarPoolGroup*, the *invitee* belongs to, and then the *inviter* changes its state to *PASSENGER*. If the response is a *RejectMessage*, the inviting agent changes its state to *EXPLORE* again in order to try to find a partner. If the agent received a *CarpoolRequest* or other irrelevant message, then it simply replies with a *RejectMessage* and it remains in the *WAIT* state.
3. **DRIVER**: In *DRIVER* state the agent plays the *DriverRole* in *CarPoolGroup* and besides this the agent can receive *CarpoolRequest* messages and reply with either *AcceptMessage* or *RejectMessage* on the basis of *inviter's* profile and the car capacity. If the pool period for the driver expires, then the agent will leave its *DriverRole*, hand over the driver responsibility to the senior passenger of the same *CarPoolGroup* and change its state to *EXPLORE*. The Driver destroys the group when he is the only one left in the *CarPoolGroup* after all passengers have quit.

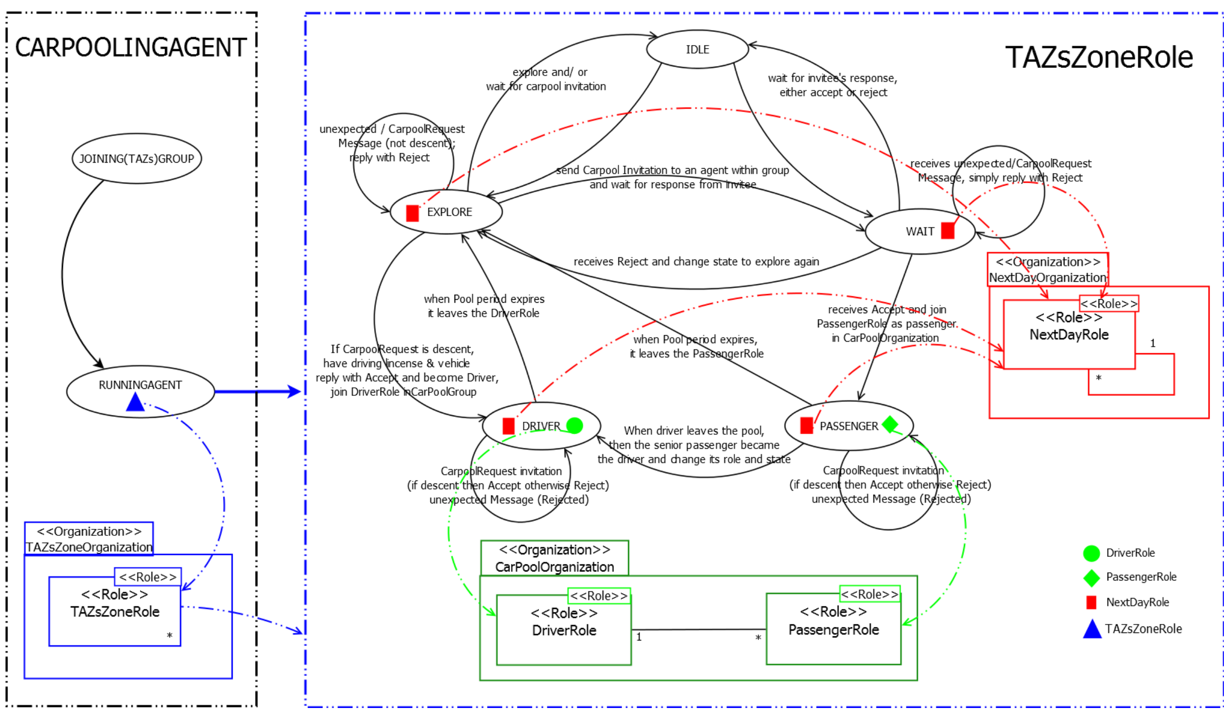

Figure 3: State-transition and organizational diagram of an agent in the simulation. In the *RUNNINGAGENT* state of the carpooling agent, the agent may perform different activities in the different states of *TAZsZoneRole* of the *TAZsZoneOrganization*. The agent may create or join the instances of *CarPoolOrganization* and *NextDayOrganization* and may play the specific roles.

4. **PASSENGER**: In *PASSENGER* state the agent continues to play the *PassengerRole* in the *CarPoolGroup* until the pool period for the passenger expires. While being a passenger, the agent can also receive *CarpoolRequest* messages from *inviters* and can reply with either *AcceptMessage* or *RejectMessage* on the basis of the *inviter's* profile and the car capacity. The Passenger can also destroy the group like driver do.
5. **IDLE**: After finishing the daily activities, the agent will transit to the *IDLE* state and will wait for other agents to finish their daily activities. All agents need to move to the next day simultaneously because of the conjunction of following reasons: (1) individuals

carpool for a well-defined individual-specific period that is determined at the moment of negotiation and (2) individuals can be member of carpools only sequentially and (3) neither carpools nor individuals keep track of a carpool calendar and (4) new individuals can join a carpool on any day.

CarPoolOrganization

A *PoolGroupOrganization* contains the roles; *DriverRole* and *PassengerRole*. Agents that are member of a group implementing the *PoolGroupOrganization* constitute a closed community for communication. Each time a non-carpooling agent accepts a carpooling invitation, it creates a *CarPoolGroup* in which it becomes the driver and starts playing as the *DriverRole*. Then it replies invitor to the inviter with an AcceptMessage. This allows the inviter to join the group and to start playing the *PassengerRole*. If the pool period of any agent of *CarPoolGroup* expires, then the agent simply leaves the role.

NextDayOrganization

When the agent finished the daily activities, it will play the *NextDayRole* in *NextDayGroup* represented by NextDayOrganization and waits for other agents to finish their daily activities. In this case the organization concept is used solely for synchronization in simulated time. As soon as the last agent joins the *NextDayGroup*, it will signal all other agents to leave the group and itself then also immediately leaves the *NextDayGroup* to start the next day activities. Remember that one group is created for each day only. The first agent, who finished the day activities, is responsible to create the group and the following agents just join the same group (created by the first agent).

RESULTS AND DISCUSSIONS

The proposed model was run for the synthetic data, created by the FEATHERS activity-based model for the Flanders region. The input data file contains *9,139,001* activities of the *2,395,509* inhabitants in Flanders. The area is subdivided into *2386* zones. The data contains *1,157,134* requiring morning and evening trips. People working in the zone they live are not considered to be carpooling candidates since a zone covers 5[km^2] only. According to the data some individuals performed more than one activity, either at the same work location (*68,379 work activities*) or different work locations (*171,762 work activities)*. Finally, *916,993* people having a single work location that is not the home location, were found. According to data there are *289,486* home and work combinations; it means that for the *TAZsZoneOrganization*, *289,486 TAZsZoneGroups* will be created. Each agent is assigned to exactly one such group. Within those groups, agents can communicate, negotiate and coordinate with each other for the sake of effective trip start times (for morning and evening) and also who will be driver of the car.

For the first experiment, we took data of the first *65,000* individuals from the sorted data file mentioned above, according to the home and work combinations. The simulation was run for *150* working days, to analyze the evolution of participation in carpooling. We took flexible time windows of *10[min]*, *20[min]* and *30[min]*, to enable coordination between individuals to carpool. Four people at most can share a car for a carpool trip (driver included). An exploring individual is allowed to contact 5 other people at most during every simulated day. The individual's preference to send carpooling invitation depends on value of the parameter

ProbabilityToInvite. If the *ProbabilityToInvite* is 100% then (s)he must send carpooling requests otherwise (s)he can prefer not emit any request. Note that the negotiation will become successful only when the individuals' preferred trip start times are compatible within the carpool for both the trips (morning and evening). A carpooler (either driver or passenger) can determine his or her pooling period (for how many days (s)he will carpool) by selecting a number randomly from 30 to 60. Obviously, a carpool is composed only if a driver (having a vehicle and a driving-license) is available. During the carpool lifetime, the carpoolers can also communicate with the other individuals who want to join the carpool group.

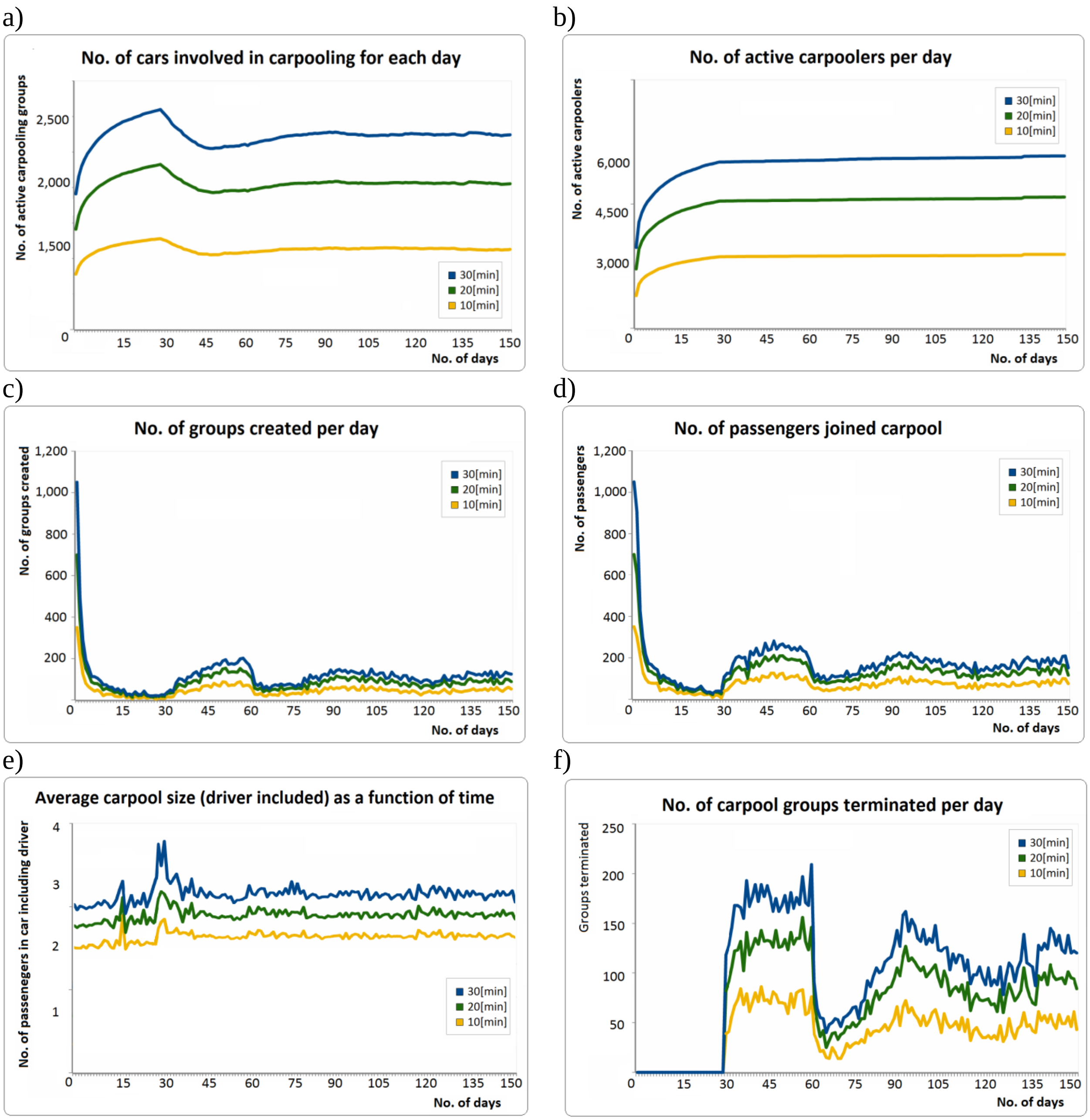

Figure 4: (a) and (b) represent the active cars and the active carpoolers separately per day throughout the simulation period. (c) and (d) show the number of drivers and passengers

selected for each day respectively and (e) determines the average size of the car per day. (f) shows the destruction of carpool groups per day.

According to the results shown in Figure 4 (a); the line graph investigates the number of active carpool groups over 150 working days of the carpoolers. The horizontal axis shows the working days and the vertical axis represents the number of active carpool groups for each day. The graph contains three lines, a blue, a green and an orange colored lines representing the active carpool groups for the flexible time window of *30[min]*, *20[min]* and *10[min]* respectively. On average, a larger time tolerance window allows for more carpooling. For each curve, the active carpool groups stood at the initial days of the simulation because the carpool groups are always created up to *30* days. Note that the carpool period of each individual is from *30* to *60* days. From *30* to average of the carpool period days (depends on the behavior of the individuals), the curves show a dramatic decrease because new carpoolers seem to join existing groups rather than create new ones (see corresponding pool size increase in diagram (d). This happens for the reason that the possibility to join existing groups is more than the creation of the new carpool groups. The gradual increase occurred after the 45 days because the possibility to join existing group is less due to the limited car capacity. When the possibility of creation of new carpool groups and destruction of the existing groups remains same, the remaining curve leveled off with minor fluctuations up to the end of the simulation.

The graph in the Figure 4(b) representing the active carpoolers throughout the simulation period for the flexible time window of 30[min], 20[min] and 10[min] respectively. Note that the simulation starts without any carpooler. For each time window, the number of active carpoolers rapidly increases at the start of the simulation up to the 30 days, because every non-carpooling individual tries to join carpool. After 30 days, the increase rate is lower up to the end of the simulation. The gradual increase took place because the formation of the new and join the existing carpool groups is more than the individuals left.

The graphs show the number of car drivers and passengers joining a carpool at each day of the simulation in the Figure 4(c) and (d). Those values are proportional to the derivatives of the curves (a) and (b) respectively. Initially large numbers of cars and people start to get involved in carpooling. After the first days the number of new people and car drops. Due to the limited carpool period, the gradual increase and decrease occur between 30 and 60 days. After about 90 days, the values remain almost constant up to the end of the simulation period.

The graph in the Figure 4(e) shows the average carpool size as a function of time. The carpool size gradually increases up to 30 days from the start of the simulation. After 30 days the carpool curve shows some spikes. This is explained as follows: after leaving the existing carpool group, there is more possibility for the carpoolers to join another existing or the same carpool group instead of creating the new carpool group. After a few days the carpool size remains the same because the formation of the new and join the existing carpool groups is equals the number of individuals left.

The graph in the Figure 4(f) explain the termination of the existing carpool groups. The curves showed that there is no group destruction up to 30 days because of the minimum carpool period. There is dramatic group destruction from 30 to 60 days and after day 60, it dramatic decrease and then gradually increased up to the day 90. By viewing the curves microscopically, after a few pool periods, the curves remained same up to the end of the simulation.

Carpooling requires time flexibility. For time windows of 10[min], 20[min] and 30[min] we observed that respectively 5.09%, 7.03% and 9.23% of the commuters started to carpool within the simulated period. The Flemish travel survey (OVG, 2013), shows that 9.51% of the

1,600 respondents carpool for home work commuting (8.85% for the OVG, 2012). The average occupation is 2.46 persons per car (OVG, 2013). This shows that when the time window is larger, the chances for negotiation success are greater than when using the smaller time window.

CONCLUSION AND FUTURE WORK

In order to build more realistic models to predict the effect of travel demand management (TDM) measures, it is required to take mutual dependency of individuals into account. As a consequence, agent-based models are becoming required tools in the domain of transportation. Modeling the interaction between individual agents increasingly important in recent research. An agent-based framework using organization as a fundamental concept has been setup to evaluate the evolution of a carpooling society under several conditions. For a simple negotiation model, the evolution over time of carpooling has been shown. The model is to analyze various effects of agent interaction and behavior adaptation. This paper extends the concept of communication, negotiation and coordination in a single-trip negotiation mechanism into a multiple trip negotiation model (involving both morning and evening commuting trips) by taking the possibility of flexible activity scheduling into account. The experiment also tries to limit the amount of communication between agents by restricting communication to groups based on the home and work locations. The agents negotiate on trip (morning and evening) departure times. During the negotiation process the agents may adapt their daily schedules to enable cooperation. The data used for implementation created by the FEATHERS activity-based model apply to the Flanders region. The simulation model on the Janus platform provides a solution to the complex problems of mutual adaptation. Running the full scale model requires a lot of computing resources (processing time, memory and data storage) because of the high number of agents to simulate, and the big data processing for each agent.

Future research will mainly focus on the development of behaviorally sound negotiation protocols. Finally distributed solutions will be considered to tackle performance issues.

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