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Agent-based Simulation Model for Long-term Carpooling: Effect of Activity Planning Constraints

Iftikhar Hussain[a,]*, Luk Knapen[a], Stephane Galland[b], Tom Bellemans[a], Davy Janssens[a] and Geert Wets[a]

[a]*Transportation Research Institute (IMOB), Hasselt University, Wetenschapspark 5 bus 6, 3590 Diepenbeek, Belgium*
[b]*Multiagent Group, IRTES-SET, Université de Technologie de Belfort-Montbéliard, 90010 Belfort cedex, France*

Abstract

In order to commute by carpooling, individuals need to communicate, negotiate and coordinate, and in most cases adapt their daily schedule to enable cooperation. Through negotiation, agents (individuals) can reach complex agreements in an iterative way, which meets the criteria for the successful negotiation. The procedure of negotiation and trip execution in the long-term carpooling consists of a number of steps namely; (i) decision to carpool, (ii) exploration and communication, (iii) negotiation, (iv) coordination and schedule adaptation, (v) long term trip execution (carpooling), (vi) negotiation during carpooling and (vii) carpool termination and exploration for new carpool. This paper presents a conceptual design of an agent-based model (ABM) of a set of candidate carpoolers. A proof of concept implementation is presented. The proposed model is used for simulating the interactions between autonomous agents. The model enables communication to trigger the negotiation process; it measures the effect of pick-drop and shopping activities on the carpooling trips. Carpooling for commuting is simulated: we consider a set of two intermediate trips (home-to-work and work-to-home) for the long-term carpooling. Schedule adaptation during negotiation depends on personal preferences. Trip timing and duration are crucial factors. We carried out a validation study of our results with real data (partial) collected in Flanders, Belgium. Simulation results show the effect of constraining activities on the carpooling trips. The future research will mainly focus on enhancing the mechanisms for communication and negotiation between agents.

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Keywords: Negotiation; carpooling; commuting; Agent technology; Organizational model; Janus platform.

* Iftikhar Hussain. Tel.: +32-11-269169; fax: +32-11- 26 91 99.
E-mail address: iftikhar.hussain@uhasselt.be

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1. Introduction

Carpooling is considered to be an effective alternative transportation mode that is eco-friendly and sustainable as it enables commuters to share travel expenses, save on fuel and parking costs, improve mobility options for non-drivers and it also reduces emission and traffic congestion. Change in some socio-economic characteristics (SEC) such as the increase in fuel price, in parking costs, or in the implementation of a new traffic policy, may prove to be an incentive to carpool. Strict timing constraints in the schedule of the day however, have the opposite effect. In order to commute by carpooling, individuals need to communicate, negotiate and coordinate, and in most cases adapt their daily schedule to enable cooperation[1,8].

While traditional modeling tools cannot handle the complexity of negotiation for carpooling, agent-based models (ABMs) are able to do so through modeling the interaction of autonomous agents[7]. The ABM aimed at simulating the actions and interactions of autonomous agents, are not limited to computer science but are also used in other domains including biology, ecology and social sciences. Currently many research areas including transportation behavior need to analyze and model complex interactions between different autonomous entities[7].

The aim of this research is to generalize the concept of communication, negotiation and coordination in a *multiple trip negotiation model* by taking the possibility of flexible activity scheduling into account. It also focuses on the setup of the simulation framework and the network of the carpooling candidates. The agents can communicate with the individuals sharing the same home and work locations within a small group by taking SEC (vehicle and driving-license ownership) into account. Furthermore they negotiate about trips (home-to-work and work-to-home) timings in order to adapt their daily schedule. A daily schedule for each individual is considered. They consist of different activities, one of them must be (flexible) work activity.

The model is based on an agent-based and organizational meta-model[12], in which the role and organization concepts 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 two main categories: exploration (communication and negotiation) and trip execution (coordination, negotiation during carpooling and carpooling). During the exploration the agent looks for other individuals to cooperate on commuting trips during a period of multiple months. Agents explore their social network by sending requests for carpooling. While negotiating, agents can reach complex agreements depending on the *matching mechanism* (discussed in section 3.3), used to match with preferences, which are expressed by all negotiating partners. For the trip execution, carpoolers need to coordinate with each other for the long-term carpooling. Carpoolers may (re)negotiate timing and/or (re)schedule their agenda when someone joins or leaves the carpool. The Janus[11], agent based platform is used; it provides an efficient implementation of organizational-based and agent-based concepts.

This paper is organized as follows; first the related work on carpooling and ABM are briefly described in section 2. Section 3 covers the long-term carpooling behavioral model. Section 4 explains the experimental setup and some results. Finally, conclusions and future work are presented in section 5.

2. Related Work

According to literature, 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 [9,10,] focuses on technical development of the carpooling support systems, and empirical, interrelationships between willingness to carpool and socio-economic attributes of carpooling, is presented.

Galland et *al.*[2] 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 routing 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.

Hussain et *al.*[6] proposed a single trip negotiation model for carpooling using a simple negotiation mechanism. The first implementation used home and work locations as well as preferred trip start times and carpool periods determined by uniformly sampling given sets. The authors extended the single-trip negotiation mechanism into a multiple trip negotiation model[4] by taking the possibility of flexible activity scheduling into account and limit the interaction between agents within small groups.

Ronald et *al*.[5] presented an agent based model that focuses on the negotiation methodology. The proposed model includes a well-defined and structured interaction protocol; integrating the transport and social layer. A utility function is presented on the basis of individual and combined attributes. The agents negotiate on the type, location and the start time of social activity.

Hendrickson and Plank[3] studied the flexibility in trip departure times of the individuals focusing on fixed home-work trips. The authors developed a multinomial logit model to estimate the relation and significance of different attributes influencing choice of the transport mode and trip departure time. The authors proposed an equation to define the personal utility or preferences for a given set of departure times for the work trip.

3. Agent-based Simulation Model

The long term agent-based model for cooperative travelling is simulated to account for individual specific behavior during the carpooling process. The goal is to simulate the interactions of autonomous agents, to enable communication to trigger the negotiation process and to measure the effect of constraining (pick-drop and shopping) activities on the carpooling trips. The purpose is to find out how much people need to adapt their daily schedule to enable cooperation and how the carpooling process is executed. The agents can interact with each other autonomously to find matching partners in order to co-travel in several different consecutive carpools each of which corresponds to a multi-day period.

The procedure of negotiation and trip execution in the long-term carpooling consists of a number of steps (described in the section 1 and illustrated by Figure 1) namely; (i) decision to carpool, (ii) communication and exploration, (iii) negotiation, (iv) coordination and schedule adaptation, (v) long term trip execution (carpooling), (vi) negotiation during carpooling and (vii) carpool termination and exploration for new carpool.

In this simulation model of carpooling evolution, the commuting trips in daily schedules (home-to-work *HW* and work-to-home *WH*) is specifically detailed and discussed related to the long term carpooling. The set of other activities including pick-drop, shopping etc. are also considered to measure the effect of their presence on the carpooling for commuting trips. Home and work locations, trip start times (*HW* and *WH*) and their durations, and activity duration, the socio-economic attributes, including vehicle and driving-license ownership are used as input data. The driver selection is based on the inspection of the individual's profiles (car and driving-license ownership). In this simulation model, "negotiation mechanism" is used to adapt the trip start times of an individual.

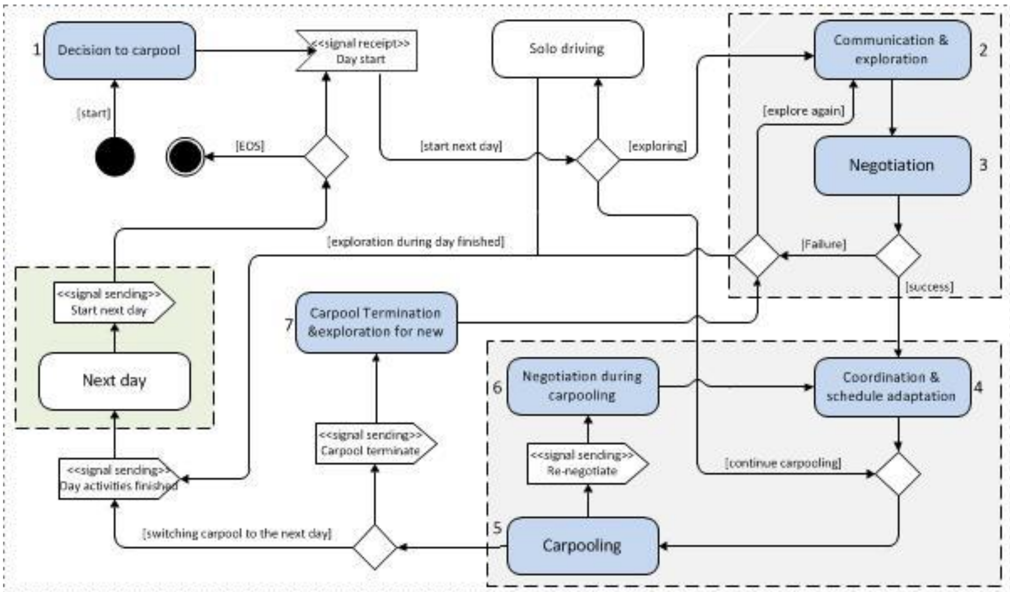

Figure 1: Activity diagram of an agent.

For the experiments described in this paper, the operational activity-based model for the region of Flanders (Belgium) FEATHERS[14] is used to generate a schedule (planned agenda) for each member of the synthetic population. Mutually independent individuals using an undisturbed transportation network are concerned. The initial daily plans are assumed to be optimal, i.e. generating maximal utility and hence to reflect the owner's preferences.

The conceptual model for long-term carpooling consists of seven steps (see Figure 1). In what follows, each of these steps is described in more detail.

3.1. Decision to Carpool

In this step, participants can determine their trips and schedule for the long-term carpooling. There are many carpooling services online that can be used via smart phones, web and social platforms. With just a few clicks, drivers can offer available seats and passengers can book a ride. Once your profile has been created, you can indicate your trip and schedule on most of the carpool applications. You can also indicate whether you want to be driver, passenger or both; enter your origin address and choose from your groups destination addresses; enter your work schedule and how long this trip offer is valid.

In the simulation model proposed in this paper, people decide to select carpool partners from the group of individuals who share the home and work locations with them. It is assumed that people board and alight at home and at work locations only. The framework is based on traffic flows between traffic analysis zones (TAZ).

The simulation launches each agent with its profile, according to data generated by the FEATHERS framework. Through organizational-based concept, the agents are grouped using their origin and destination locations to limit the communication requirements. Each agent once in its lifetime joins such group (*TAZsZoneGroup*) which is an instance of the given organization (*TAZsZoneOrganization*) (see Figure 2). The simulator contains at most one group for each pair *(A,B)* of TAZ. An agent joins the group for *(A,B)* if and only if (s)he lives in *A* and works in *B*.

If there are *'n'* locations, at most $n\ (n-1)$ groups will be created.

Immediately after the agent creates or joins such group (*TAZsZoneGroup*), it starts playing the role (*TAZsZoneRole*) in that group. Within those groups, agents can communicate, negotiate and coordinate with each other to determine effective trip start times (for both morning and evening) and to agree who will be the driver.

3.2. Exploration and Communication

The agents, who want to carpool, explore their social network to find their carpool partners. For this, the agents belonging to the same group may communicate with each other by sending and receiving text messages. Through communication, the agents may negotiate on start time of both the trips (*HW* and *WH*), on the vehicle to use and hence on the selection of the driver (we assume that the vehicle owner is the driver).

In the simulation, if the agent decides to carpool, (s)he may start to explore for partners in the exploration phase, otherwise (s)he continues traveling solo. This agent may remain in the exploration phase throughout the simulation period (in case (s)he is unable to find a carpool partner).

The agent's behavior is modeled by a finite state machine. Each agent can send and/or receive messages to/from the other agents of the *TAZsZoneGroup* (which has agents playing the *TAZsZoneRole*), as shown in the Figure 2. Following messages are used: *CarpoolRequestMessage*, *AcceptMessage* and *RejectMessage*.

An agent performs the following activities in different states within an instance of *TAZsZoneOrganization*.

1. In the EXPLORE state, each agent (*inviter*) may search for a partner (*invitee*) by sending a carpool invitation to a randomly chosen agent. For every simulated day, emission of invitations 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 the carpool invitations.
2. In the WAIT state, if the invitee's response is an *AcceptMessage* then the inviter tries to join the *CarPoolGroup* the invitee belongs to. 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. In the WAIT state, any incoming invitation is rejected.
3. In the DRIVER state the agent plays the *DriverRole* in *CarPoolGroup*, can receive *CarpoolRequest* (invitation) messages and replies with either *AcceptMessage* or *RejectMessage* depending on the inviter's profile and the remaining car capacity. If the pool period for the driver expires, then the agent will leave its *DriverRole* and change its state to EXPLORE.

4. In the 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 handles carpool invitations in the same way as a driver.

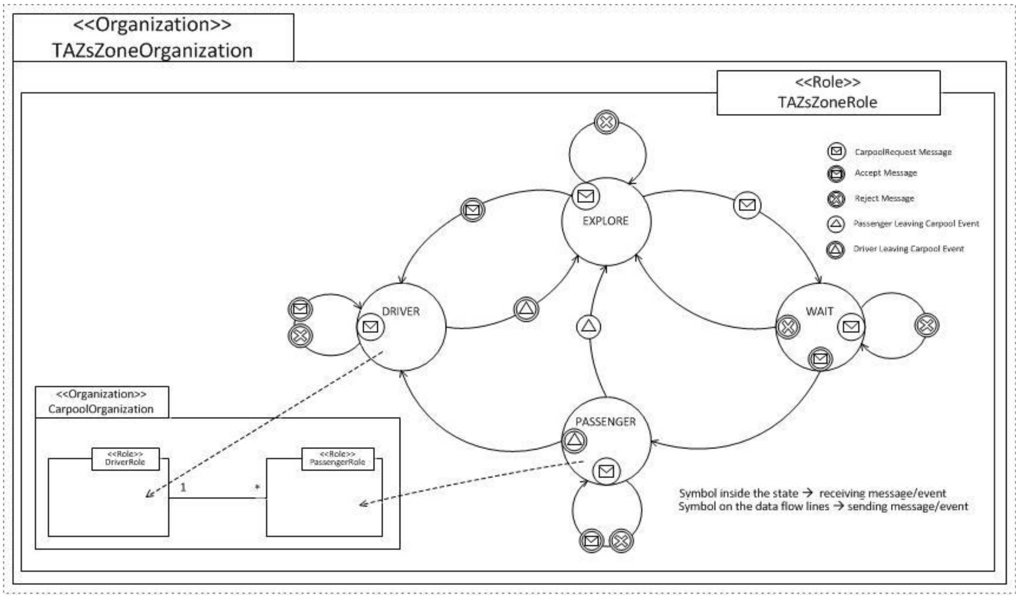

Figure 2: Organizational and state diagram of an agent;

Handling incoming invitations during the carpool lifetime, requires additional negotiation among the carpoolers and the new candidates to join the pool.

3.3. Negotiation

The matching is applied in the negotiation phase where final decisions to carpool are taken. The agents negotiate on trip (*HW* and *WH*) departure times and also about who will become the driver. The driver and vehicle selection is based on the inspection of the individual's profiles. The schedule adaptation depends on the preferences among feasible schedules of the individuals. The negotiation will become successful only when the individuals' preferred trip start times are compatible within the carpool for both the trips (*HW* and *WH*).

Consider *N* agents $a_1, a_2, \ldots a_N$. For an agent a_i, the earliest and latest departure times for the home-to-work *HW* and work-to-home *WH* trips are $TW_{HWLower,a_i}$, $TW_{HWUpper,a_i}$ and $TW_{WHLower,a_i}$, $TW_{WHUpper,a_i}$ respectively (lower and upper bounds for time windows). The preferred trip start time for *HW* and *WH* of an agent a_i are PST_{HWTrip,a_i} and PST_{WHTrip,a_i}. For the carpool, the earliest and latest departure times for the *HW* and *WH* trips are $TW_{HWLower,carpool}$, $TW_{HWUpper,carpool}$ and $TW_{WHLower,carpool}$, $TW_{WHUpper,carpool}$.

In the simplest case, the individual is assumed to accept a symmetric deviation $\pm\Delta T$ w.r.t. the preferred trip start times. In general, this is not necessarily true since preceding or succeeding activities can induce timing constraints.

Assume that a constraining (pick-drop or shopping) activity *ca* immediately precedes the *HW* trip. Let AFT_{ca,a_i} be the finishing time of the *ca* of an agent. Preferred start times PST_{HWTrip,a_i} and PST_{WHTrip,a_i} depend on the AFT_{ca,a_i} as follows. $\overline{\Delta T}$ = PST_{HWTrip,a_i} - AFT_{ca,a_i} where $\overline{\Delta T}$ is the tolerance period before the *HW* trip.

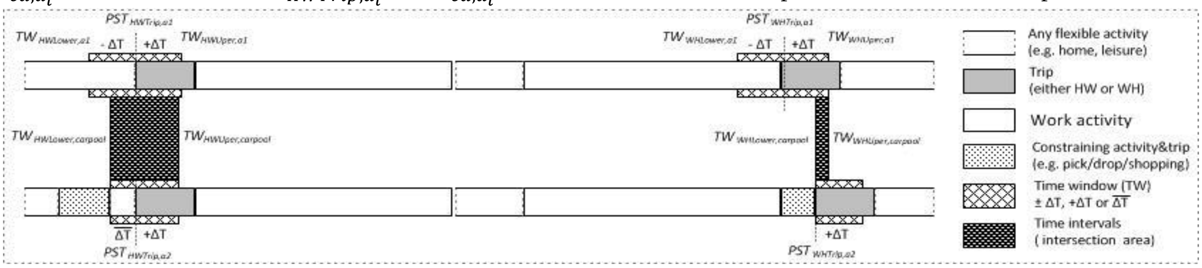

Figure 3: Negotiation on trip (*HW* and *WH*) departure times of two agents.

The possible lower and upper bounds for the *HW* and *WH* trips of an agent are given by the equation.

$$TW_{HWLower,a_i} = \begin{matrix} if\ ca\ \&\ \overline{\Delta T}<\Delta T: & PST_{HWTrip,a_i} - \overline{\Delta T} \\ otherwise: & PST_{HWTrip,a_i} - \Delta T \end{matrix} \qquad TW_{WHLower,a_i} = \begin{matrix} if\ ca: & AFT_{ca,a_i} \\ otherwise: & PST_{WHTrip,a_i} - \Delta T \end{matrix}$$
$$AND$$
$$TW_{HWUpper,a_i} = PST_{HWTrip,a_i} + \Delta T \qquad TW_{WHUpper,a_i} = \begin{matrix} if\ ca: & AFT_{ca,a_i} + \Delta T \\ otherwise: & PST_{WHTrip,a_i} + \Delta T \end{matrix} \tag{1}$$

The negotiation outcome is assumed to be associated to the intersection's length of the time intervals of the individuals. The following equations show the lower and upper bounds for the *HW* and *WH* trips of the carpool; the indices used for the *max()* function range over the set of candidate participants).

$$TW_{HWLower,carpool} = \max_{j=1\ldots N}(TW_{HWLower,j}) \qquad TW_{WHLower,carpool} = \max_{j=1\ldots N}(TW_{WHLower,j})$$
$$AND$$
$$TW_{HWUpper,carpool} = \min_{j=1\ldots N}(TW_{HWUpper,j}) \qquad TW_{WHUpper,carpool} = \min_{j=1\ldots N}(TW_{WHUpper,j}) \tag{2}$$

The available time intervals for the carpool are given by the equations;

$$\text{Time Intervals} = \begin{matrix} \min_{j=1\ldots N}(TW_{HWUpper,j}) - \max_{j=1\ldots N}(TW_{HWLower,j}) & for\ home\text{-}to\text{-}work\ trip \\ \min_{j=1\ldots N}(TW_{WHUpper,j}) - \max_{j=1\ldots N}(TW_{WHLower,j}) & for\ work\text{-}to\text{-}home\ trip \end{matrix} \quad AND \tag{3}$$

An individual decides to join the carpool if and only if the preferred trip start times for both the trips (*HW* and *WH*) within the appropriate intervals.

The individuals' schedule of a working day remains the same for all the working days. If the negotiation becomes successful, the agents may coordinate and adapt their schedule in *step 4 (coordination and schedule adaptation)*, otherwise they may continue to explore for carpool partners in *step 2 (exploration and communication)*.

3.4. Coordination and Schedule Adaptation

The negotiation becomes successful when the negotiators adapt their daily schedule to enable cooperation. In general, during this step, the carpoolers agree on pickup times, pick-up and drop-off order, trip start times (for *HW* and *WH*) of the carpool taking into account the constraints imposed by their agenda. At negotiation time, each individual specifies the period (number of days) during which to carpool for the trip.

After the successful negotiation, the invited agent, who is able to drive creates an instance (*CarPoolGroup*) of *CarPoolOrganization* and starts playing his role *DriverRole*. Then, (s)he replies to the inviter (candidate passenger) with an *acceptMessage*, asks him to join the *CarPoolGroup* and start playing the *PassengerRole*.

When the driver decides to leave the carpool, (s)he will assign the driving responsibilities to the senior passenger (if the carpool size is not less than two persons). The passenger who becomes driver starts playing the role *DriverRole* and leaves the role *PassengerRole* in the same *CarPoolGroup* group. When someone leaves the carpool permanently then the remaining agents may reschedule the trip start times.

3.5. Carpooling (long term trip execution)

The carpooling activity corresponds to the execution of the trips (*HW* and *WH*) over multiple days. The model assumes that travel times are insensitive to the level of carpooling (i.e. carpooling does not significantly decrease congestion). Travel times between locations have been computed a priori and are assumed to be time independent. This is to be refined by making the negotiation aware of time dependent travel time. 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 carpoolers can find partners at the beginning and throughout the carpool lifetime.

3.6. Negotiation During Carpooling

During the carpooling trips, the carpoolers need to communicate and negotiate with each other when someone wants to join or decides to leave the carpool. The agent (either driver or passenger) can receive carpool invitations and reply with either accept or reject messages on the basis of the inviter's profile and the car capacity. Either driver or passenger may negotiate on start time of both the trips (*HW* and *WH*).

When someone (either driver or passenger) leaves the carpool, the remaining carpoolers re-negotiate (according to *step 3*) and may adapt their carpool trip start times for both the trips. When changes in the carpool happen the agents may reschedule the carpool in *step 4* and continue carpooling.

3.7. Carpool Termination and Exploration for New Carpool

Drivers and passengers leave the carpool group at the end of the agreed participation period. In case, the driver leaves the carpool group and after re-negotiation the remaining group size exceeds one, then (s)he will hand over the driver responsibility to the senior passenger (having vehicle and driving-license) of the same carpool. 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 or if no persons with a car and a driving license are available. If an agent leaves the carpool, (s)he immediately explores and communicates in *step 2* of the simulation model.

4. Simulation Experiment and Discussion

The proposed model was run for data created by the FEATHERS activity-based model for the Flanders region. For the experiments, data of the first *30,000* individuals from a set of selected zones is used. An exploring individual is allowed to contact 5 other people at most during every simulated day. If the *ProbabilityToInvite* is 100% then (s)he must send carpooling requests. Otherwise, (s)he can decide not to emit any request. A carpooler determines the number of working days to carpool by selecting a number randomly from 30 to 60. Obviously, a carpool is composed only if a driver is available. Four people at most can share a car (driver included).

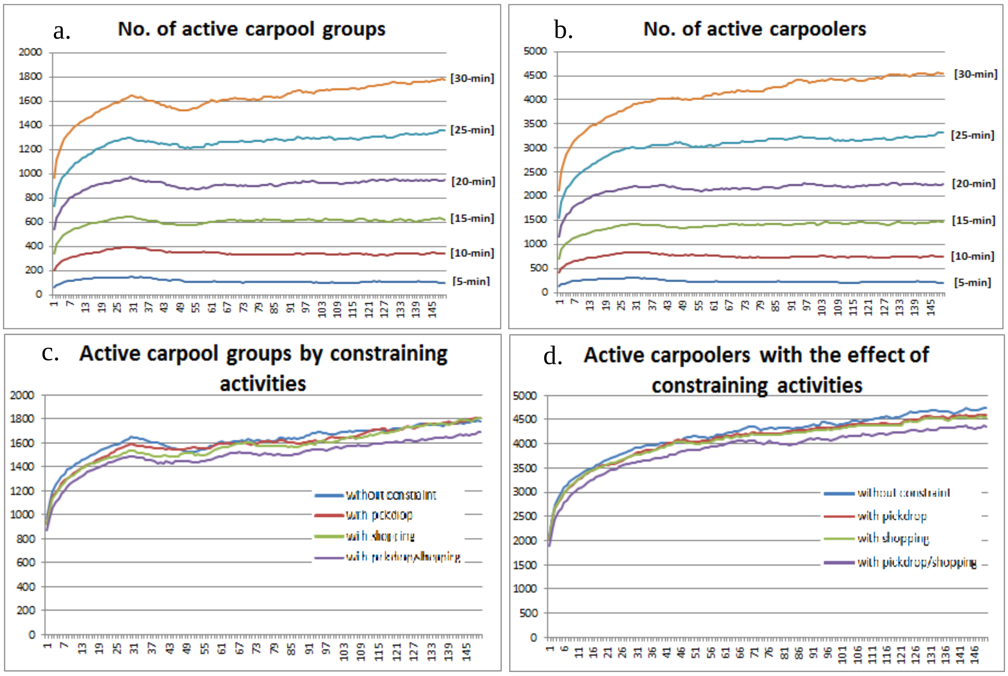

Figure 4: The number of active carpools (a) and carpoolers (b) for different time windows and without constraining activities. The number of active carpools (c) and carpoolers (d) with constraining activities.

Figure 4 (a) shows the results for a simulation where the trip timing was not constrained by any other activity. Individuals could adapt the trip start time with a specific window. Time windows of *5[min]*, *10[min]*, *15[min]*, *20[min]*, *25[min]* and *30[min]* were used. The line graph shows the number of active carpool groups over 150 working days. The horizontal axis shows the working days and the vertical axis represents the number of active carpool groups for each day. It is observed that on average, a larger time tolerance window allows for more carpooling. During the first 30 days the number of groups monotonically increases since the shortest possible carpooling period lasts for 30 days. After 30 days, the curves show a decrease because new carpoolers seem to join existing groups rather than create new ones. It seems to be easier to join an existing group than to create a new one: the number of carpools decreases but the number of participants does not decrease in that period. A gradual increase of the number of carpool groups occurs again after 45 days because the possibility to join existing carpool group becomes less due to the limited car capacity (car saturation effect)

The graph in Figure 4(b) shows the number of active carpoolers throughout the simulation period. For each time window, the number of active carpoolers rapidly increases at the start of the simulation up to about 30 days. After 30 days, the increase rate is lower up to the end of the simulation. The share of carpooling individuals seems to have converged after 100 simulated working days except for the 30[min] case.

Figure 4 (c and d) show the effect of constraining activities. All individuals used a *30[min]* time window for the trip start times. In the FEATHERS schedules 5% of the individuals have a *pick/drop* activity immediately preceding the commuting trips (*HW* and/or *WH*). Furthermore, 7% of the individuals are constrained in a similar way by a *shopping* activity. The graph shows that the constraining activities reduce the probability for negotiation success. Both the number of carpools and carpooling participants continue to increase up to the end of the simulation period.

5. Conclusion and Future Work

Modeling the interaction between individual agents becomes progressively important in recent research. An agent-based framework (for long term carpooling) using the Janus organization concept has been setup to evaluate the evolution of a carpooling society under several conditions. The model aims to analyze various effects of agent interaction and behavior adaptation. This paper covers the concept of communication, negotiation and coordination for the long term carpooling of a multiple trip model and takes the possibility of flexible activity scheduling into account. The experiments also try 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 and on the driver assignment within the carpool group. During the negotiation process the agents may adapt their daily schedules to enable cooperation. The simulation model on the Janus platform provides a solution to the complex problems of mutual adaptation. The data used for implementation have been created by the FEATHERS activity-based model for the Flanders region. The results show (1) that when the time window is larger, the chances for negotiation success are greater, and (2) that the constraining activities limit the chances for negotiation success.

Out-of-home activities immediately preceding the commuting trips were assumed to be fixed in time which is a strong constraint. Future research will focus on the effect of schedule adaptation. And enhancing the mechanisms for communication and negotiation between agents.

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