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Negotiation and Coordination in Carpooling: An agent-based simulation model

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ABSTRACT

Carpooling enables commuters to share travel expenses, save costs, improve mobility options and reduces emission and traffic congestion. In order to commute by carpooling, individuals need to communicate, negotiate and coordinate, and in most cases adapt their schedule to enable cooperation. This paper presents the design of an agent-based model by defining different phases and steps to move from solo driving to carpooling. It analyzes various effects of agent interaction and behavior adaptation of a set of candidate carpoolers. The start of the carpooling process depends on the individuals' objectives and intention to carpool. Through negotiation and coordination, individuals can reach complex agreements in an iterative way. The success of negotiation highly depends on the lifestyle factors that influence the departure time decision, on the individuals profile and on the effect of constraining activities. The carpooling social network was established using results predicted by the FEATHERS, an operational activity based model for Flanders (Belgium). From the simulation's discussions, it is possible to portray the real picture of the potential carpoolers throughout their carpooling period. The simulation results show that 9.33% of the commuters started to carpool with the time window of $\pm\Delta T$ = 30[min.] and the average occupancy of a car is 2.4 persons per car. When the time window is larger, the chances for negotiation success are greater than when using the smaller time window. Hence, the carpooling requires time flexibility. The Janus (multi-agent) platform is used for simulating the interactions of autonomous agents.

Keywords: Commuting, carpooling, coordination and negotiation, trip start time, schedule adaptation, agent-based modeling.

INTRODUCTION

Carpooling is considered to be an effective alternative transportation mode that is eco-friendly and sustainable. It enables commuters to share travel expenses, save on fuel and parking costs, improve mobility options and it also reduces emission and traffic congestion. In order to commute by carpooling, individuals need to communicate, negotiate and coordinate, and in most cases adapt their schedule to enable cooperation. Furthermore the social economic characteristics (SEC), including age, gender, income, education, relationship, job, vehicle and driving-license ownership can play vital role to find the favorable individuals for the carpooling. Each negotiation involves a small number of participants but the schedules can be interconnected by cooperation (*1*,*2*). While traditional modeling tools cannot handle the complexity of communication and negotiation for carpooling, agent-based models (ABMs) are able to do so through modeling the interaction of agents. The ABMs 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 interactions between autonomous entities (*3*).

The aim of this research is to investigate the effect of communication, negotiation and coordination for carpooling 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. To perceive the results, the carpooling related actions performed by each individual are divided into following steps: (i) network identification, (ii) exploration and communication, (iii) negotiation, (iv) coordination and schedule adaptation, and (v) trip execution (carpooling). These steps exemplify a model which represents an extension of the simple but analytically tractable negotiation model (*4*,*5*) for carpooling. During the exploration the agent looks for other individuals to cooperate on commuting trips. The success of negotiation highly depends on the lifestyle factors and on the effect of constraining activities that influence the departure time decision. The decision of driver selection is based on individual profile (owning a vehicle and a driving-license). For the trip execution, carpoolers need to coordinate for the long-term carpooling. The daily schedule of each individual is considered, which repeats over the specified period.

The model is based on an agent-based and organizational meta-model (*6*), in which the role and organization are first class entities. The agents (individuals) can communicate with the individuals sharing the same home and work travel analysis zones (TAZ) within a small group by taking SEC into account. Furthermore they negotiate about trips (home-to-work and work-to-home) timings in order to adapt their schedule. The Janus (*7*), multi-agent based platform is used; it provides an efficient implementation of agent-based and organizational-based concepts.

This paper is organized as follows; first the related work on carpooling and agent-based modeling are briefly described. First part of the model covers the practical concepts and the second part explains the technical part of the carpooling model. Finally, simulation results are presented followed by conclusions and suggestions for future work.

RELATED WORK

In recent years, agent-based simulation has come into the field of transportation science because of its capability to analyse aggregated consequences of individual specific behaviour variations. ABM can provide valuable information on the society and the outcomes of social actions or phenomena. The empirical, interrelationships between willingness to carpool and SEC of carpooling, and different types of negotiation techniques and models are presented.

The agent-based negotiation models for carpooling are studied by different authors. Hussain *et al.* (*5*) proposed a single trip negotiation model for carpooling using a simple negotiation mechanism. The authors measured the direct interaction between agents from whole carpooling social network. The first implementation used home and work TAZ as well as preferred trip start times and carpool periods determined by uniformly sampling given sets. Hussain *et al.* (*4*) extended the single-trip negotiation mechanism into a multiple trip negotiation model by taking the possibility of flexible activity scheduling into account and limit the interaction between agents within small groups based on home and work TAZ. Hussain *et al.* (*8*) extended the negotiation model by applying constraining activities. Authors used daily schedule of each individual. Galland *et al.* (*9*) presented a conceptual design of an ABM for the carpooling application, that is used for simulating the 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.

In the context of travel demand, cooperation aspects apply to joint activity execution and joint trip execution. Ronald *et al.* (*10*) presented an agent based model that focuses on the negotiation methodology for joint activity execution. 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. Luetzenberger *et al.* (*11*) introduced an approach which considers a driver's mind and examines the effect of environmental conditions. Authors planned to integrate the agent interactions necessary when carpooling. Kamar and Horvitz (*12*) described an ABM aiming to optimally combine demand and supply in an advisory system for frequent ride-sharing. The authors focused on the mechanisms required to model users cooperating on joint plans and focused on the economic value of the shared plans. Knapen *et al.* (*1*) presented an automated, Global Car Carpooling Matching Service (GCPMS), advisory service to match commuting trips for carpooling. The probability for successful negotiation is calculated by means of a learning mechanism. The matcher needs to deal with dynamically changing graph w.r.t. topology and edge weights.

Varrentrapp *et al.* (*13*) provided an informal and formal declaration for the long-term carpooling Problem. The soundness of the problem formulation is discussed and some properties are verified. Finally the problem is proved to be NP-complete. This research assumed that carpools are stable in time and that every member in turn acts as the driver. Manzini *et al.* (*14*) described an interactive system to support the mobility manager (officer) operating on the long-term carpooling problem. The proposed methods and models make use of clustering analysis. The basic hypothesis is that in a group the driver of the shared car turns among the participants. Clustering procedures using methods available in standard decision support system are proposed. After clustering, for each driver a *traveling salesman problem* is to be solved.

Hendrickson and Plank (*15*) studied the flexibility in trip departure times of the individuals focusing on fixed home-work trips. The authors developed a multinomial logit model (MNL) 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. For the departure time choices Hussain et *al.* (*16*) acquired the Hendrickson's MNL for the work trips. Authors used coefficients of the shared mode only, and make it continuous, by taking different departure time intervals of one min instead of 10 min.

AGENT-BASED MODEL FOR CARPOOLING

An agent-based model for cooperative travelling is simulated to account for individual specific behavior during the carpooling process. The purpose is to find out how much people need to adapt their daily schedule to enable cooperation in a given area and how carpooling participation evolves over time. 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 simulation is aimed to find out how carpool groups are formed and what is the share of carpooling among the available transportation modes, given behavioral constraints with respect to timing.

In this simulation model of carpooling evolution, the commuting trips in daily schedules (home-to-work *HW* and work-to-home *WH*) are 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*), trip durations, activity duration, the SEC, 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). The "*preference time function*" is used to adapt the trip start times of an individual. The selection of the most preferred trip departure time partly derived from existing departure time studies, is based on a number of factors namely; (i) travelling factors, (ii) socio-economic factors and (iii) time pressure factors. For the departure time choices, we acquired the Hendrickson's multinomial logit model (MNL) (*15*) for the work trips and also extend the work presented in (*20*) by applying constraining activities before or after the trips.

For the experiments described in this paper, the operational activity-based model for the region of Flanders (Belgium) FEATHERS (*17*) is used to generate a planned agenda for each member of the synthetic population. Those schedules represent the planned agendas for mutually independent individuals using an undisturbed transportation network. The initial daily plans are assumed to be optimal, i.e. generating maximal utility and hence to reflect the owner's preferences.

The 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 activity locations.

Microscopic (re-)routing and traffic simulation are not required in this model because the main focus of the model is on negotiation about future trips. 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 estimated travel times for traffic flows between traffic analysis zones (TAZ). Those travel times are assumed to be common knowledge owned by the participating agents. Each agent follows a number of steps, including goal setting, exploring, schedule adaptation through negotiation and the execution of their schedule. These steps are modeled for a specified time period (e.g. number of years) according to the activity-diagram, shown in Figure 1:

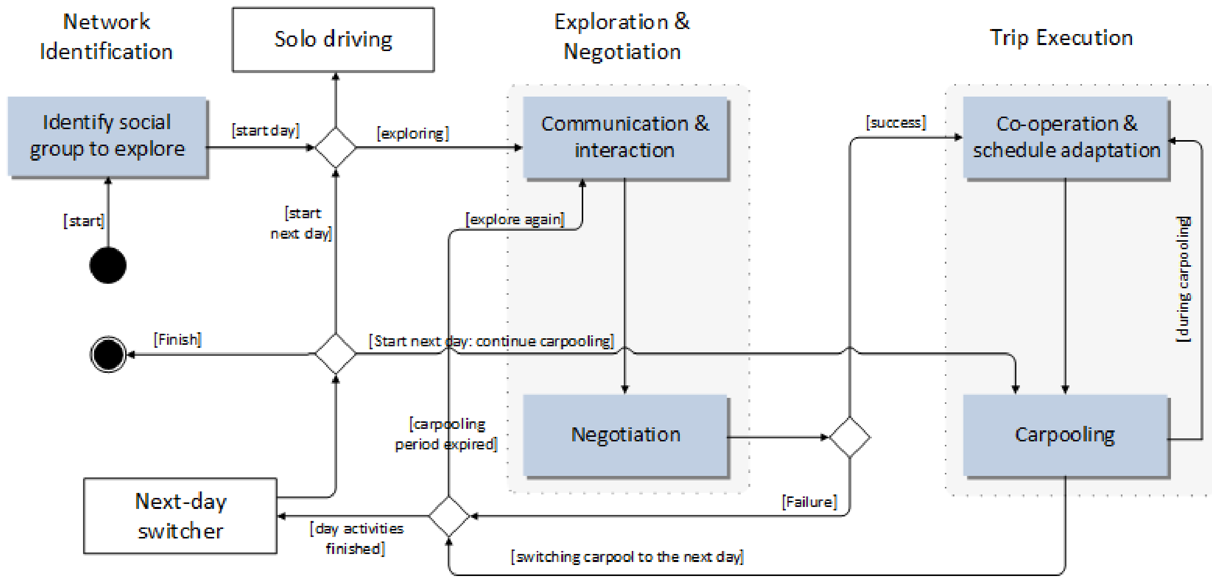

Figure 1: Activity-diagram of an agent: agents may repeat their activities in exploration & negotiation and trip execution phases during the simulation period.

Network Identification: Carpooling Social Network

The *carpooling social network* is made up of nodes representing individuals and links defined by one or more specific types of interdependency. It slightly differs from general social networks:

1. First, the *carpooling social network* considers not only socio-demographic attributes but also spatiotemporal attributes i.e. activity or trip start times and home and work locations.
2. Secondly, carpooling social network is specifically aimed at carpool partner selection and interaction between participants.

(a) Carpooling social network is divided into TAZ and further divided into components (groups).

(b) Interaction of agents in a given zone (the similar colored agents has similar trips within a TAZ).

Figure 2: Carpooling social network: (a) social network is divided into TAZ and further divided into components (groups) according to trip similarity; (b) interaction of agents in a given zone (agents and their relationship-lines are shown with the same color).

We assume that if an individual has either any similar features, such as job, age and education, or the home or work locations, with others then they seem to have any relationship with each other. In this model, the strength of relationship can be measured by calculating the number of similar attributes for the agents. It is quite difficult to find an ideal carpool partner from a large space of network. We first divide the partial area into TAZ and then the population is further divided into different groups based on the trip similarity (same origin and destination) relationships (Figure 2 (a)). We assume that the individuals who live closer to each other, have strong relationship for carpooling. Within these social groups, individuals can interact and negotiate with each other to enable carpooling (Figure 2 (b)).

The social network is subdivided into disconnected components, each one of which corresponds to a particular TAZ pair *(A,B)*. 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, the social network contains at most $n (n - 1)$ components.

Interaction and Communication

Each agent looks for other individuals to cooperate while executing its periodic trips by exploring the *carpooling social network*. Only agents sharing the home and work locations respectively (so that their trips are similar) can interact with each other. This constraint was removed in the new model which is being evaluated at the time of writing.

The relationship information of the carpoolers can provide *the path*, *profile* and *the time interval* similarities. Initially each agent has a basic set of communication characteristics such as common interests and requirements. In order to interact, the interests and requirements for the respective agents need to match sufficiently well. Interests and requirements are conveyed by means of a *CarpoolInvitation* message:

```
CarpoolInvitation = {interests, requirements}
```

where common *interest* is intention to carpool, and *requirements* are the traveling route, time and the traveling cost.

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 schedule adaptation depends on the preferences among feasible schedules of the individuals. The negotiation for both the trips (*HW* and *WH*) will become successful only when the preferred trip start times are mutually compatible among all candidates within the carpool.

This model comprises the symmetrical commuting trips and assumed to be realistic: although it induces more stringent timing constraints, it avoids multi-party negotiations which require a large mental effort.

Negotiation for driver and vehicle selection

The driver and vehicle selection is based on the inspection of the individual's profiles. Each agent who owns a car and a driving license, may become the driver when carpooling.

Negotiation for trips departure time

Preference Time Function

Several factors affect the preference function for the trip departure time of an agent:

1. The SEC (i.e. the ratio of travelling cost to annual income) helps to quantify the concept of value of time for departing at a particular time in the given time interval.
2. The individuals' tolerance level for arriving late or early for a specific activity indicates the level of rigidity in the starting times of different activities.

In order to construct a behaviorally accurate method for trip start times, Hendrickson's MNL departure time choice model (*15*) for work trips is used. Hendrickson and Plank used dataset gathered in Pittsburgh, PA for the express purpose of analyzing dynamic level of service variations and departure time decisions. Collecting the dataset involved independent measurement of travel times and transit wait times for travel to the Pittsburgh Central Business District. The Hendrickson's base model included up to twenty eight alternatives, indicating combinations of four modes (drive alone, shared ride, transit with walk access and transit with auto access) and seven different departure time intervals of 10 min each. People do not have a constant level of preference for every moment in the entire feasible time interval due to many factors (i.e. time pressure).

The equation *(1)* is used to determine the actual utility value of a particular agent to depart at a specific time in its available time window.

Consider N agents $a_1, a_2, \ldots a_N$. The departure time $t_1, t_2, t_3 \ldots, t_T$ available among the set of departure times T. The utility or preference $V_{a_i t_j}$ for a particular time t_j of an agent a_i is specified to be:

$$\begin{aligned} V_{a_i t_j} = -2.09 - 0.008\left(FFTT_{a_i}\right) - 0.021\left(CONG_{t_j}\right) - 0.699\left(\frac{COST}{INCOME}\right)_{a_i t_j} \\ - 0.095\left(ACC_{a_i t_j}\right) - 0.088\left(WAIT_{a_i t_j}\right) - 0.148\left(LATE_{a_i t_j}\right) \\ + 0.0014\left(LATE_{a_i t_j}\right)^2 - 0.01\left(EARLY_{a_i t_j}\right) - 0.00042\left(EARLY_{a_i t_j}\right)^2 \end{aligned} \tag{1}$$

where the coefficients are taken from Hendrickson's study for the specific mode (shared transport) and the variables are defined as follows for a_i:

$FFTT_{a_i}$:	Free flow Travel Time in carpool vehicle (i.e. 75% of travel time during peak time and 90% otherwise). A negative coefficient is expected because increasing travel time would discourage carpooling.
$CONG_{t_j}$:	Portion of travel time associated with congestion at departure time (i.e. 25% of travel time during peak time and 10% otherwise).
$(\frac{COST}{INCOME})_{a_i t_j}$:	Ratio of annual cost of carpooling to income level per annum. It depends on the time-of-day because toll and parking charges are included and those can be time-of-day dependent.
$ACC_{a_i t_j}$:	Walking time at the end of a transit trip associated with departure time. $ACC_{a_i t_j}$ provides a measure of the accessibility of transit service to the traveler, and is included for the transit with walk access mode. The subscript t_j allows for variation in access time associated with different departure times.
$WAIT_{a_i t_j}$:	Waiting time w.r.t. individual's most preferred time to depart.
$LATE_{a_i t_j}$:	Number of minutes late arrival at work associated with the departure time. $\left(LATE_{a_i t_j}\right)^2$ is used to more accurately represent individual perceptions of late arrival at work.
$EARLY_{a_i t_j}$:	Number of minutes early arrival at work associated with the departure time. For the co-efficient of $EARLY_{a_i t_j}$ (i.e. we took 0.01) a smaller magnitude than that of $LATE_{a_i t_j}$: this is done because late arrival at work is felt to be more onerous than early arrival. $\left(EARLY_{a_i t_j}\right)^2$ as with $\left(LATE_{a_i t_j}\right)^2$, but a negative

coefficient is anticipated to reflect the increasing disutility associated with earlier arrivals at the work place.

The departure time choices are treated as a simultaneous interactive decision based upon maximization of individual travelers satisfaction with each departure time combination. The probability of an individual selecting departure time alternative $P_{a_i t_j}$ of the carpool is given by equation *(2)*;

$$P_{a_i t_j} = \frac{exp(V_{\ a_i t_j})}{\sum_T exp(V_{\ a_i T})} \tag{2}$$

The probability can be calculated for the discrete cases mentioned by Hendrickson. The results have been used to construct the continuous preference function for the morning case shown in Figure 3. This was done because, for the simulation, we need to calculate the individual probability value for each possible trip start time in the candidate specific time window (e.g. the optimal time window $\pm\Delta t$ *=30* minutes). The preference function for the evening case (*WH* trip) was created by mirroring the function for the *HW* trip around the time value for which the maximum probability is reached.

a) Probability curve for *HW* trip b) Probability curve for *WH* trip

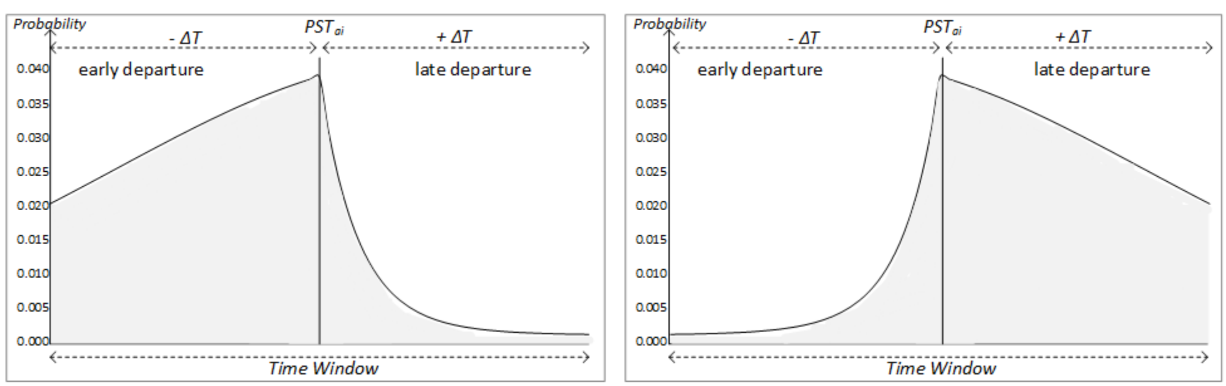

Figure 3: Departure time probability curve of morning (left-side) and evening (right-side) trips for an agent a_i.

Time Intervals Similarities

After the assignment of an individual preference function based on the factors elaborated above for each agent, a negotiation mechanism is employed in order to determine the carpool trip departure time.

For an agent a_i, the earliest and latest departure times for the trip are TW_{L,a_i}, TW_{U,a_i} (lower and upper bounds for the time window). The preferred trip start time of a_i is PST_{Trip,a_i}.

In the simplest case, the individual is assumed to accept a symmetric maximum deviation $\pm\Delta T$ w.r.t. the preferred trip start time. In general, this is not necessarily true since preceding or succeeding activities can induce timing constraints. The possible cases for the constraining activities are:

1. The possible lower and upper bounds for the preferences of a_i for both the trips (*HW* and *WH*) without any constraining activities are given by the equation *(3)*.

$$\begin{aligned} TW_{L,a_i} &= PST_{Trip,a_i} - \Delta T \\ TW_{U,a_i} &= PST_{Trip,a_i} + \Delta T \end{aligned} \tag{3}$$

2. The equation *(4)* helps to determine the lower and upper limits of the departure time window for the morning trip of a_i who has certain fixed constraining activities before the morning trip. CA_{fTime,a_i} is the finishing time of a constraining activity.

$$\begin{aligned} \overline{\Delta T} &= PST_{HWTrip,a_i} - CA_{fTime,a_i} \\ TW_{HWLower,a_i} &= PST_{HWTrip,a_i} - \overline{\Delta T} \\ TW_{HWUpper,a_i} &= PST_{HWTrip,a_i} + \Delta T \end{aligned} \tag{4}$$

3. When there is a constraining activity scheduled immediately after the work activity at the work location, then the lower bound for the *WH* trip departure time for a_i will be the CA_{fTime,a_i} as in equation *(5)*.

$$\begin{aligned} TW_{WHLower,a_i} &= CA_{fTime,a_i} \\ TW_{WHUpper,a_i} &= PST_{WHTrip,a_i} + \Delta T \end{aligned} \tag{5}$$

4. When the constraining activity scheduled after work activity at any other location different from the work location and if timely arrival is compulsory for that activity. Then the upper bound of time window for a_i will depend on the start time of constraining activity $CA_{startTime,a_i}$ as in equation *(6)*.

$$\begin{aligned} \overline{\Delta T} &= CA_{startTime,a_i} - PST_{WHTrip,a_i} \\ TW_{WHLower,a_i} &= PST_{WHTrip,a_i} - \Delta T \\ TW_{WHUpper,a_i} &= PST_{WHTrip,a_i} + \overline{\Delta T} \end{aligned} \tag{6}$$

The negotiation outcome needs to be within the intersection of the time intervals of the individuals. The following equations *(7)* show the lower and upper bounds for the trip of the carpool; the indices used for the *max()* function range over the set of candidate participants.

The available time intervals for the carpool are given by the equation *(7)* where the index j identifies the carpool participant candidate.

$$\begin{aligned} TW_{L,carpool} &= \max_{j=1 \ldots N}(TW_{L,j}) \\ TW_{U,carpool} &= \min_{j=1 \ldots N}(TW_{U,j}) \end{aligned} \tag{7}$$

The probability density for the trip start time for an individual is determined by normalization of the preference function so that its integral equals one. The probability that a start time can be found for a particular agent in the period of time that suits every candidate, is given by the integral of the probability density for that participant over the intersection of all feasible intervals. For practical reasons integration is done numerically assuming that the probability is constant in every one-minute period. The probability to find a trip start time that suits everyone, is given by the product probabilities to find a suitable solution for each carpool participant in the intersection of the time intervals;

$$P_{carpool} = \prod_{i=0}^{n} \sum_{j=TW_{L,carpool}}^{TW_{U,carpool}} \left(P_{a_i t_j}\right) \tag{8}$$

The negotiation is assumed to succeed if and only if

$$P_{carpool} > \ threshold \tag{9}$$

As soon as it becomes clear that candidates will carpool, the trip start time needs to be determined. Therefore, the preference function is used. For every agent, the preference for a given departure time is proportional to the probability that the person will select that time (because of the normalization mentioned above).

$$V_{a_i t_j} = k(P_{a_i t_j}) \tag{10}$$

We assume that the combined preference for all carpoolers is the product of the preference values.

$$V_{carpool,t_j} = \prod_{i \in carpool} k(V_{a_i t_j}) \tag{11}$$

The effective trip start time $TST_{carpool}$ of the carpool is the point in time resulting in the largest collective preference value; it is given by;

$$TST_{carpool} = \underset{j=TW_{L,carpool}\ to\ TW_{U,carpool}}{arg\ max} (V_{carpool,t_j}) \tag{12}$$

For the evening (*WH*) trip, we took the probabilities of the departure time alternatives of the morning trip (*HW*) but mirrored in time (see Figure 4).

In the simulation, for the start time of *HW* and *WH* trips, the negotiation succeeds if and only if;

$$\prod_{i=0}^{n} \sum_{j=TW_{HWL,carpool}}^{TW_{HWU,carpool}} (P_{a_i t_j}) > threshold$$
$$AND \tag{13}$$
$$\prod_{i=0}^{n} \sum_{j=TW_{WHL,carpool}}^{TW_{WHU,carpool}} (P_{a_i t_j}) > threshold$$

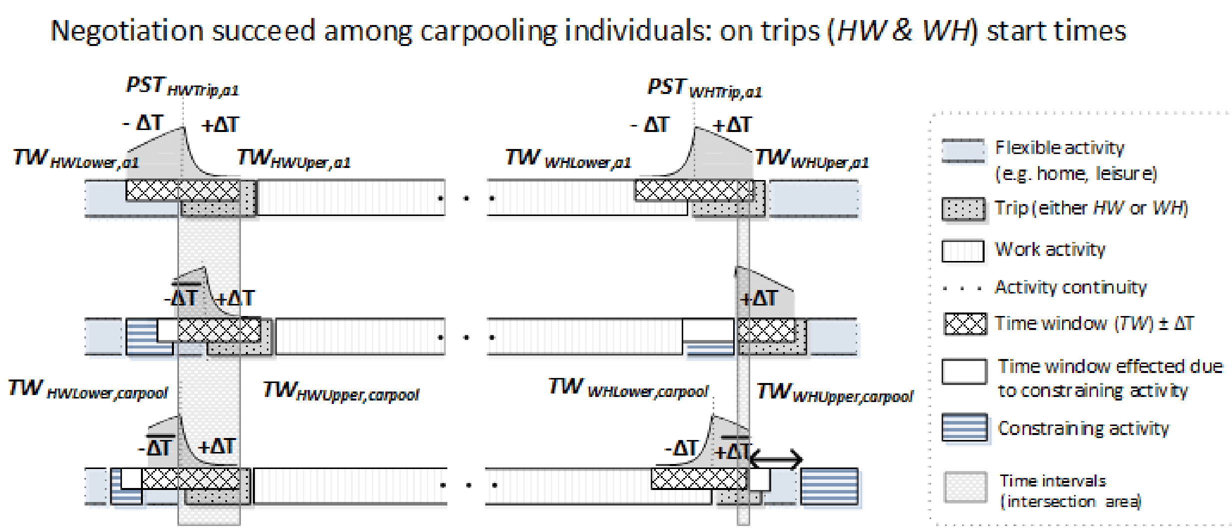

Figure 4: Negotiation success on trips (*HW* and *WH*) departure times for the agents in a carpool by considering all possible constraining activities.

The effective trip start times of the carpooling trips (*HW* and *WH*) are given by the equation *(14)*;

$$\begin{gathered} \underset{j=TW_{HWL,carpool}\,to\,TW_{HWU,carpool}}{arg\,max} (V_{carpool,t_j}) \\ AND \\ \underset{j=TW_{WHL,carpool}\,to\,TW_{WHU,carpool}}{arg\,max} (V_{carpool,t_j}) \end{gathered} \qquad (14)$$

After successful negotiation, the carpool participants adjust their schedule. The individual's resulting schedule applies to every working day during the period of carpooling.

Cooperation 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.

During carpooling, when someone leaves the carpool permanently or new individual joins the carpool then the remaining carpoolers may re-negotiate and adapt their carpool trip start times for both the trips. Note that this negotiation does not necessarily succeed. When the driver decides to leave the carpool, (s)he will assign the driving responsibilities to the passenger (having vehicle and driving license).

Trip Execution or Carpooling

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.

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. Either the driver or a passenger may leave the carpool which requires re-negotiation of start time of both the trips (*HW* and *WH*). Handling incoming invitations during the carpool lifetime, requires additional negotiation between the carpoolers and the new candidates to join the carpool. An individual who once left carpooling, can again interact with the individuals of his or her interest to enable carpooling.

SIMULATION RESULTS AND DISCUSSIONS

The proposed model was run for data created by the FEATHERS activity-based model for the Flanders region. There are about six million inhabitants in the Flanders region. The area is subdivided into *2386* zones. 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 work activity in a day, either at the same work location or different work locations. Each individual considers the full schedule including the constraining activities (before and/or after the commuting trips). Note that the negotiation will become successful only when the individuals' preferred trip start times are compatible within the carpool for both commuting trips (*HW* and *WH*).

For the experiment, we took following data from the sorted data file created by the Feathers, according to the home and work combinations;

No. of individuals:	*30,000* from a set of selected zones
Network exploration:	An exploring individual is allowed to contact *5* other people at most during every simulated day.
Probability to invite	If *100%* then (s)he must send carpooling requests. Otherwise, (s)he can decide not to emit any request.
Carpool period:	A carpooler determines the number of working days to carpool by selecting a number randomly from *30* to *60*.
Carpool size:	Four people at most can share a car (driver included).
Threshold value	*Probability threshold* with constraining activities: *0.8*, *0.7*, *0.6*, *0.5*, *0.4*, *0.3* and *0.2* using a constant *time window* of $\pm\Delta T$ = *30[min.]*.
Time window ($\pm\Delta T$)	*Time window* with constraining activities: *5[min]*, *10[min]*, *15[min]*, *20[min]*, *25[min]* and *30[min]* with the *probability threshold* of *0.3*.
Simulation period:	*150* working days.

The data of selected area is used (Figure 5(a)). The commuting trips for carpooling can be performed throughout or outside of the Flanders region. According to the selected data, the *61* home-work combinations (social groups) created by the simulation and each agent is assigned to exactly one such group. Within these social groups, individuals can interact and negotiate with each other to enable carpooling. The value of the probability to succeed is determined by the level of flexibility in adapting to the trips start times. These probabilities can be termed as threshold points and serve as the success criteria that determine the fate of the negotiation process (Figure 5(b)).

The graph in the Figure 5(c) representing the active carpool groups throughout the simulation period for the time windows of *5[min]*, *10[min]*, *15[min]*, *20[min]*, *25[min]* and *30[min]* respectively with a constant probability threshold of *0.3*. The horizontal axis shows the working days and the vertical axis represents the number of active carpool groups for each day. 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. Starting at the simulated day, the curves show a dramatic decrease before stabilizing because new carpoolers seem to join existing groups rather than create new ones. It seems to more easy to join an existing group than to create a new one. The gradual increase occurring after the *45* days is explained by the decreasing possibility to join an existing because of the limited car capacity. After the initial period, the remaining part of the curves levels off with minor fluctuations up to the end of the simulation.

In Figure 5(d), the line graph shows the number of active carpoolers over *150* working days of the simulation. The graph contains six lines, representing the active carpoolers for the time windows of *5[min]*, *10[min]*, *15[min]*, *20[min]*, *25[min]* and *30[min]* respectively, each one with a constant probability threshold of *0.3*. 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 and nobody leave a carpool. After *30* days, some participants decide to leave a carpool and the increase rate is lower up to the end of the simulation. It can be observed clearly in the Figure 5(d) that when the time window is larger, the chances for negotiation success are greater than when using the smaller time window.

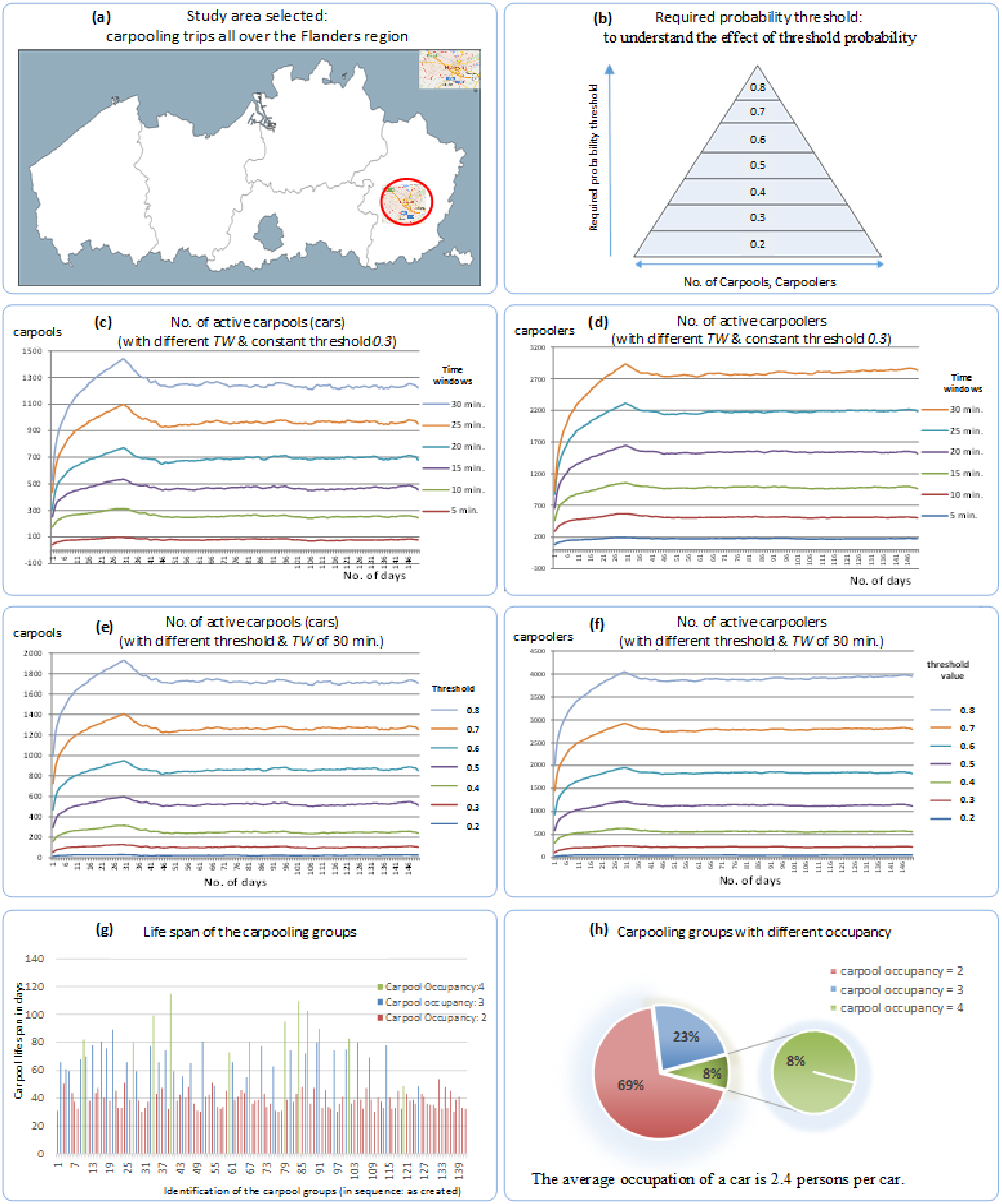

Figure 5: (a) The map of the Flanders region (the selected area is highlighted), (b) the threshold points that serve as the success criteria to determine the fate of the negotiation process, (c) and (d) show the number of active cars and active carpoolers by using different time windows, (e) and (f) represent the active cars and the active carpoolers by using different probability threshold points, (g) shows the life span of carpools, and (h) represents carpools with their occupancy.

The graphs in the Figures 5(e) and 5(f) represent the active carpool groups and active carpoolers for the probability threshold values of *0.8, 0.7, 0.6, 0.5, 0.4, 0.3* and *0.2* respectively and with a constant time window of *30[min]*. The pattern of each curve for the graphs in Figures 5(e) and 5(f) are related to the graphs in Figures 5(c) and 5(d) respectively. It can be observed clearly in the Figure 5(f) that the large numbers of people get involved in carpooling when the threshold probability value is set lower (i.e. *0.2*). For the case of higher threshold probability (i.e. *0.8*) the criteria becomes very strict, hence reducing the number of carpoolers significantly.

Figures 5(g) and 5(h) show the life span of the carpools according to the carpool occupancy. The data of *1000* individuals is used as input. In total *141* carpools were created: *12* of them have an occupancy of *4* agents in each carpool, *32* carpools have an occupancy of *3* agents and the remaining *97* carpools contain *2* agents each. The average life span of carpools with *2*, *3* and *4* person are *38.5*, *69.8* and *91.3* days respectively. In Figure 5(g), the bar chart shows the carpools (in chronological order as they created) with their life spans in the y-axis and the identification number of the carpool in the x-axis. The pool size (occupancy) is represented by the color. The diagram shows that the life span grows with more occupancy. A carpool having an occupancy of two agents is terminated as soon as one of them quits. But when there are three or more members in the carpool then the carpool will continue to exist when a single member quits and someone else (or the same individual) may join the same carpool. This causes high-occupancy carpools to live longer. The pie chart in Figure 5 (h) represents the percentages of carpools with different occupancies (*2*, *3* and *4* persons). According to results: *69%*, *23%* and *8%* with the occupancy of *2*, *3* and *4* persons of the carpools were created.

Carpooling requires time flexibility. For the time windows of *5[min]*, *10[min]*, *15[min]*, *20[min]*, *25[min]* and *30[min]*, and with a constant probability threshold of *0.3*, we observed that respectively *0.66%*, *1.66%*, *3.2%*, *5.13%*, *7.33%* and *9.33%* of the commuters started to carpool within the simulated period. The Flemish travel survey (OVG (*22*), 2013), shows that *9.51%* of the *1,600* respondents carpool for home work commuting (*8.85%* for the OVG, 2012). The average occupation of a car is *2.4* persons per car (*2.46* persons per car for the OVG, 2013). If we use the *time window=30[min]*and *threshold=0.3* then the result looks nice (according to OVG, 2013).

The current model requires that all carpool participants share the origin TAZ as well as the destination TAZ respectively. The model extension that is currently going on no longer suffers from this constraint; it allows the path of one participant to be a sub-path of the path of another participant. The car trip (and timing for passenger boarding and alighting) then depends on the selection of the driver. This information is used to select the *optimal* driver. The additional results will be published in a follow-up paper. The simulation model has scalability issues that are still to be solved. Indeed, it is necessary to consider a sufficiently large study region.

CONCLUSION AND FUTURE WORK

Modeling the interaction between individual agents becomes progressively important in recent research. As a consequence, agent-based models are becoming required tools in the domain of transportation. An agent-based framework using the Janus organizational-based 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 research covers the concept of communication, negotiation and coordination for the 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. People do not have a constant level of preference for every moment in the entire feasible time interval due to many factors. In order to construct a behaviorally accurate method for trip start times, Hendrickson's MNL departure time choice model for work trips is used. Driver selection depends on the individual profile (having vehicle and driving-license). The schedule (with constraining activities) for each individual is taken from the data have been created by the FEATHERS, activity-based model for the Flanders region. The results show that when we compare the probability of preferences of individuals with lower threshold value and when the time window is larger, the chances for negotiation success are greater.

Future research will mainly focus on the effect of schedule adaptation and enhancing the mechanisms for communication and negotiation between agents. The sets of agents working in a particular traffic analysis zone and living in spatially dispersed zones, is important to be considered in the future work.

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