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

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1 **ABSTRACT**

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

20

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

1 INTRODUCTION

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

16 The aim of this research is to investigate the effect of communication, negotiation and
17 coordination for carpooling by taking the possibility of flexible activity scheduling into account.
18 It also focuses on the simulation aimed at the setup of the framework and of a network of the
19 carpooling candidates. To perceive the results, the carpooling related actions performed by each
20 individual are divided into following steps: (i) network identification, (ii) exploration and
21 communication, (iii) negotiation, (iv) coordination and schedule adaptation, and (v) trip
22 execution (carpooling). These steps exemplify a model which represents an extension of the
23 simple but analytically tractable negotiation model (4,5) for carpooling. During the exploration
24 the agent looks for other individuals to cooperate on commuting trips. The success of negotiation
25 highly depends on the lifestyle factors and on the effect of constraining activities that influence
26 the departure time decision. The decision of driver selection is based on individual profile
27 (owning a vehicle and a driving-license). For the trip execution, carpoolers need to coordinate for
28 the long-term carpooling. The daily schedule of each individual is considered, which repeats
29 over the specified period.

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

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

40 RELATED WORK

41 In recent years, agent-based simulation has come into the field of transportation science because
42 of its capability to analyse aggregated consequences of individual specific behaviour variations.
43 ABM can provide valuable information on the society and the outcomes of social actions or

1 phenomena. The empirical, interrelationships between willingness to carpool and SEC of
2 carpooling, and different types of negotiation techniques and models are presented.

3 The agent-based negotiation models for carpooling are studied by different authors.
4 Hussain *et al.* (5) proposed a single trip negotiation model for carpooling using a simple
5 negotiation mechanism. The authors measured the direct interaction between agents from whole
6 carpooling social network. The first implementation used home and work TAZ as well as
7 preferred trip start times and carpool periods determined by uniformly sampling given sets.
8 Hussain *et al.* (4) extended the single-trip negotiation mechanism into a multiple trip negotiation
9 model by taking the possibility of flexible activity scheduling into account and limit the
10 interaction between agents within small groups based on home and work TAZ. Hussain *et al.* (8)
11 extended the negotiation model by applying constraining activities. Authors used daily schedule
12 of each individual. Galland *et al.* (9) presented a conceptual design of an ABM for the carpooling
13 application, that is used for simulating the autonomous agents and to analyze the effects of
14 change in factors of infrastructure, behavior and cost. This model used agents' profiles and social
15 networks to initialize communication and then employ a routing algorithm, and a utility function
16 to trigger the negotiation process between agents.

17 In the context of travel demand, cooperation aspects apply to joint activity execution and
18 joint trip execution. Ronald *et al.* (10) presented an agent based model that focuses on the
19 negotiation methodology for joint activity execution. The proposed model includes a well-
20 defined and structured interaction protocol: integrating the transport and social layer. A utility
21 function is presented on the basis of individual and combined attributes. The agents negotiate on
22 the type, location and the start time of social activity. Luetzenberger *et al.* (11) introduced an
23 approach which considers a driver's mind and examines the effect of environmental conditions.
24 Authors planned to integrate the agent interactions necessary when carpooling. Kamar and
25 Horvitz (12) described an ABM aiming to optimally combine demand and supply in an advisory
26 system for frequent ride-sharing. The authors focused on the mechanisms required to model
27 users cooperating on joint plans and focused on the economic value of the shared plans. Knapen
28 *et al.* (1) presented an automated, Global Car Carpooling Matching Service (GCPMS), advisory
29 service to match commuting trips for carpooling. The probability for successful negotiation is
30 calculated by means of a learning mechanism. The matcher needs to deal with dynamically
31 changing graph w.r.t. topology and edge weights.

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

41 Hendrickson and Plank (15) studied the flexibility in trip departure times of the
42 individuals focusing on fixed home-work trips. The authors developed a multinomial logit model
43 (MNL) to estimate the relation and significance of different attributes influencing choice of the
44 transport mode and trip departure time. The authors proposed an equation to define the personal
45 utility or preferences for a given set of departure times for the work trip. For the departure time
46 choices Hussain *et al.* (16) acquired the Hendrickson's MNL for the work trips. Authors used

1 coefficients of the shared mode only, and make it continuous, by taking different departure time
2 intervals of one min instead of 10 min.

3 AGENT-BASED MODEL FOR CARPOOLING

4 An agent-based model for cooperative travelling is simulated to account for individual specific
5 behavior during the carpooling process. The purpose is to find out how much people need to
6 adapt their daily schedule to enable cooperation in a given area and how carpooling participation
7 evolves over time. The agents can interact with each other autonomously to find matching
8 partners in order to co-travel in several different consecutive carpools each of which corresponds
9 to a multi-day period. The simulation is aimed to find out how carpool groups are formed and
10 what is the share of carpooling among the available transportation modes, given behavioral
11 constraints with respect to timing.

12 In this simulation model of carpooling evolution, the commuting trips in daily schedules
13 (home-to-work *HW* and work-to-home *WH*) are specifically detailed and discussed related to the
14 long term carpooling. The set of other activities including *pick-drop*, *shopping* etc. are also
15 considered to measure the effect of their presence on the carpooling for commuting trips. Home
16 and work locations, trip start times (*HW* and *WH*), trip durations, activity duration, the SEC,
17 including vehicle and driving-license ownership are used as input data. The driver selection is
18 based on the inspection of the individual's profiles (car and driving-license ownership). The
19 "preference time function" is used to adapt the trip start times of an individual. The selection of
20 the most preferred trip departure time partly derived from existing departure time studies, is
21 based on a number of factors namely; (i) travelling factors, (ii) socio-economic factors and (iii)
22 time pressure factors. For the departure time choices, we acquired the Hendrickson's
23 multinomial logit model (MNL) (15) for the work trips and also extend the work presented in
24 (20) by applying constraining activities before or after the trips.

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

31 The agent is someone who lives in the study area and executes his or her daily schedule
32 in order to satisfy his or her needs. A daily schedule is a combination of activities and trips with
33 a specified start time and duration of each activity and trip. The modeling structure claims that
34 individuals spend the day taking part in activities and traveling between activity locations.

35 Microscopic (re-)routing and traffic simulation are not required in this model because the
36 main focus of the model is on negotiation about future trips. The proposed model has no
37 information about carpool parking; therefore, it is assumed that people board and alight at home
38 and work locations only. The framework is based on estimated travel times for traffic flows
39 between traffic analysis zones (TAZ). Those travel times are assumed to be common knowledge
40 owned by the participating agents. Each agent follows a number of steps, including goal setting,
41 exploring, schedule adaptation through negotiation and the execution of their schedule. These
42 steps are modeled for a specified time period (e.g. number of years) according to the activity-
43 diagram, shown in Figure 1:

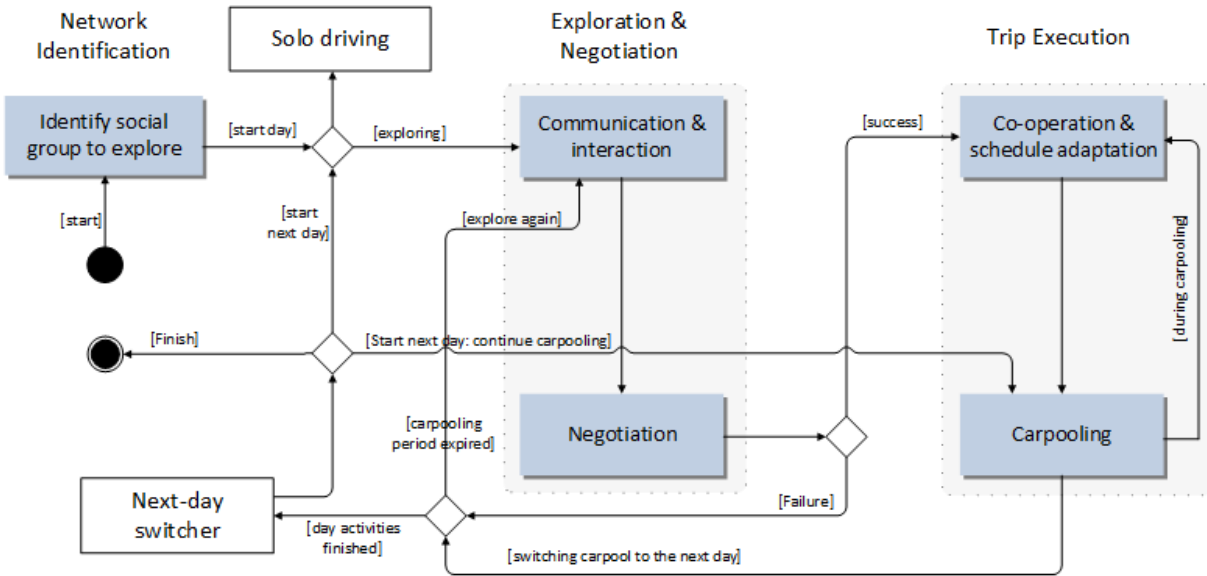


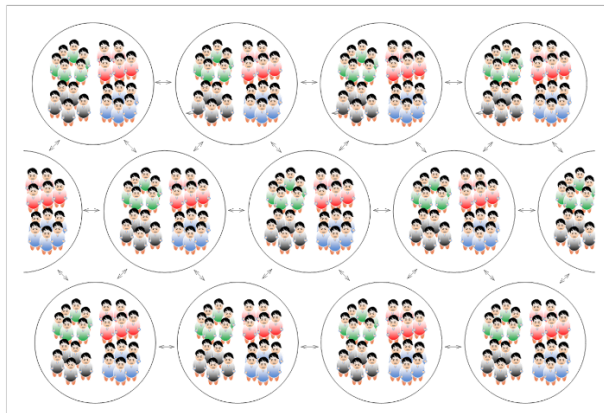
Figure 1: Activity-diagram of an agent: agents may repeat their activities in exploration & negotiation and trip execution phases during the simulation period.

1 **Network Identification: Carpooling Social Network**

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

- 4 1. First, the *carpooling social network* considers not only socio-demographic attributes but
 5 also spatiotemporal attributes i.e. activity or trip start times and home and work locations.
 6 2. Secondly, carpooling social network is specifically aimed at carpool partner selection and
 7 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).

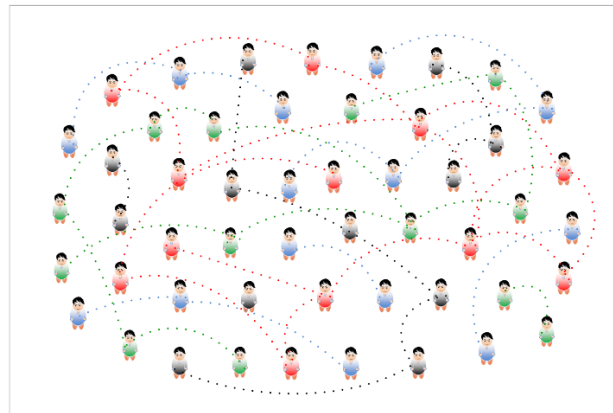


Figure 2: Carpooling social network: (a) social network is divided into TAZ and further divided into components (groups) according to trip similarity; (b) interaction of agents in a given zone (agents and their relationship-lines are shown with the same color).

8 We assume that if an individual has either any similar features, such as job, age and education, or
 9 the home or work locations, with others then they seem to have any relationship with each other.
 10 In this model, the strength of relationship can be measured by calculating the number of similar

1 attributes for the agents. It is quite difficult to find an ideal carpool partner from a large space of
 2 network. We first divide the partial area into TAZ and then the population is further divided into
 3 different groups based on the trip similarity (same origin and destination) relationships (Figure 2
 4 (a)). We assume that the individuals who live closer to each other, have strong relationship for
 5 carpooling. Within these social groups, individuals can interact and negotiate with each other to
 6 enable carpooling (Figure 2 (b)).

7 The social network is subdivided into disconnected components, each one of which
 8 corresponds to a particular TAZ pair (A,B) . An agent joins the group for (A,B) if and only if
 9 (s)he lives in A and works in B .

10 If there are 'n' locations, the social network contains at most $n(n-1)$ components.

11 **Interaction and Communication**

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

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

21 `CarpoolInvitation = {interests, requirements}`

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

24 **Negotiation**

25 The matching is applied in the negotiation phase where final decisions to carpool are taken. The
 26 agents negotiate on *trip (HW and WH) departure times* and also about *who will become the*
 27 *driver*. The schedule adaptation depends on the preferences among feasible schedules of the
 28 individuals. The negotiation for both the trips (*HW* and *WH*) will become successful only when
 29 the preferred trip start times are mutually compatible among all candidates within the carpool.

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

33 **Negotiation for driver and vehicle selection**

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

36 **Negotiation for trips departure time**

37 **Preference Time Function**

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

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

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

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

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

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

16 where the coefficients are taken from Hendrickson's study for the specific mode (shared
 17 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).

$\left(\frac{COST}{INCOME}\right)_{a_it_j}$: 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.

$ACC_{a_it_j}$: Walking time at the end of a transit trip associated with departure time. $ACC_{a_it_j}$ 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.

$WAIT_{a_it_j}$: Waiting time w.r.t. individual's most preferred time to depart.

$LATE_{a_it_j}$: Number of minutes late arrival at work associated with the departure time. $(LATE_{a_it_j})^2$ is used to more accurately represent individual perceptions of late arrival at work.

$EARLY_{a_it_j}$: Number of minutes early arrival at work associated with the departure time. For the co-efficient of $EARLY_{a_it_j}$ (i.e. we took 0.01) a smaller magnitude than that of $LATE_{a_it_j}$: this is done because late arrival at work is felt to be more onerous than early arrival. $(EARLY_{a_it_j})^2$ as with $(LATE_{a_it_j})^2$, but a negative

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

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

$$P_{a_it_j} = \frac{\exp(V_{a_it_j})}{\sum_T \exp(V_{a_iT})} \quad (2)$$

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

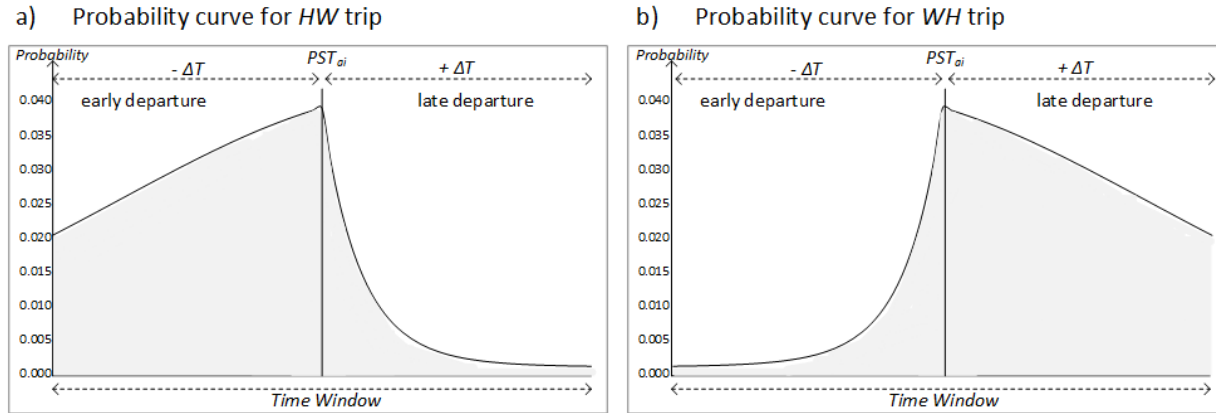


Figure 3: Departure time probability curve of morning (left-side) and evening (right-side) trips for an agent a_i .

12 *Time Intervals Similarities*

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

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

18 In the simplest case, the individual is assumed to accept a symmetric maximum deviation
 19 $\pm \Delta T$ w.r.t. the preferred trip start time. In general, this is not necessarily true since preceding or
 20 succeeding activities can induce timing constraints. The possible cases for the constraining
 21 activities are:

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

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

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

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

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

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

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

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

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

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

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

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

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

- 24 The negotiation is assumed to succeed if and only if

$$P_{carpool} > threshold\quad (9)$$

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

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

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

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

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

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

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

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

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

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

Negotiation succeed among carpooling individuals: on trips (*HW* & *WH*) start times

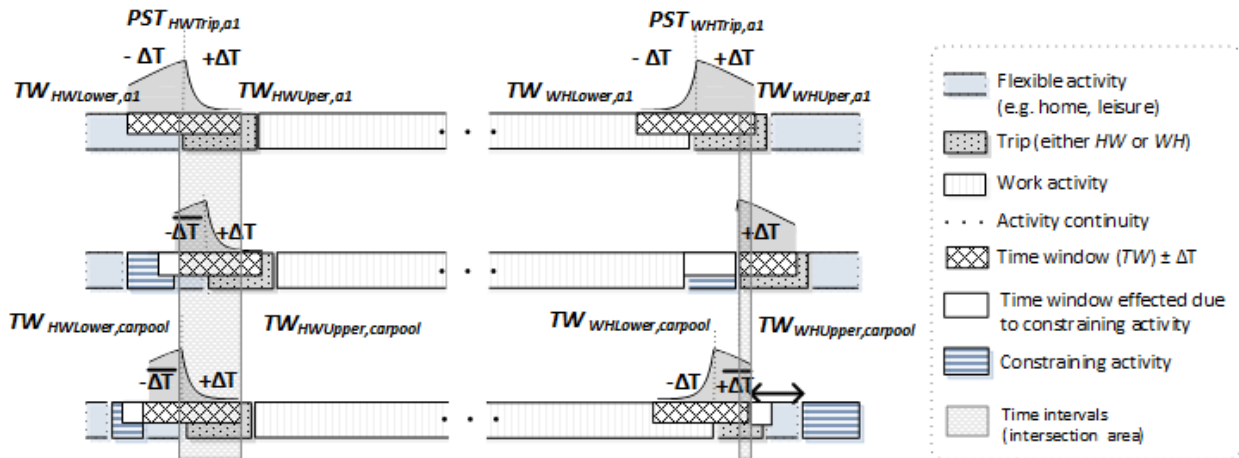


Figure 4: Negotiation success on trips (*HW* and *WH*) departure times for the agents in a carpool by considering all possible constraining activities.

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

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

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

5 **Cooperation and Schedule Adaptation**

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

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

16 **Trip Execution or Carpooling**

17 The carpooling activity corresponds to the execution of the trips (HW and WH) over multiple
18 days. The model assumes that travel times are insensitive to the level of carpooling (i.e.
19 carpooling does not significantly decrease congestion). Travel times between locations have been
20 computed a priori and are assumed to be time independent. This is to be refined by making the
21 negotiation aware of time dependent travel time.

22 During the carpooling trips, the carpoolers need to communicate and negotiate with each
23 other when someone wants to join or decides to leave the carpool. Either the driver or a
24 passenger may leave the carpool which requires re-negotiation of start time of both the trips (HW
25 and WH). Handling incoming invitations during the carpool lifetime, requires additional
26 negotiation between the carpoolers and the new candidates to join the carpool. An individual
27 who once left carpooling, can again interact with the individuals of his or her interest to enable
28 carpooling.

29 **SIMULATION RESULTS AND DISCUSSIONS**

30 The proposed model was run for data created by the FEATHERS activity-based model for the
31 Flanders region. There are about six million inhabitants in the Flanders region. The area is
32 subdivided into 2386 zones. People working in the zone they live are not considered to be
33 carpooling candidates since a zone covers $5[km^2]$ only. According to the data some individuals
34 performed more than one work activity in a day, either at the same work location or different
35 work locations. Each individual considers the full schedule including the constraining activities
36 (before and/or after the commuting trips). Note that the negotiation will become successful only
37 when the individuals' preferred trip start times are compatible within the carpool for both
38 commuting trips (HW and WH).

1 For the experiment, we took following data from the sorted data file created by the
2 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 $\pm\Delta T = 30[\text{min.}]$.
Time window ($\pm\Delta T$)	Time window with constraining activities: 5[<i>min</i>], 10[<i>min</i>], 15[<i>min</i>], 20[<i>min</i>], 25[<i>min</i>] and 30[<i>min</i>] with the probability threshold of 0.3.
Simulation period:	150 working days.

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

11 The graph in the Figure 5(c) representing the active carpool groups throughout the
12 simulation period for the time windows of 5[*min*], 10[*min*], 15[*min*], 20[*min*], 25[*min*] and
13 30[*min*] respectively with a constant probability threshold of 0.3. The horizontal axis shows the
14 working days and the vertical axis represents the number of active carpool groups for each day.
15 For each curve, the active carpool groups stood at the initial days of the simulation because the
16 carpool groups are always created up to 30 days. Starting at the simulated day, the curves show a
17 dramatic decrease before stabilizing because new carpoolers seem to join existing groups rather
18 than create new ones. It seems to more easy to join an existing group than to create a new one.
19 The gradual increase occurring after the 45 days is explained by the decreasing possibility to join
20 an existing because of the limited car capacity. After the initial period, the remaining part of the
21 curves levels off with minor fluctuations up to the end of the simulation.

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

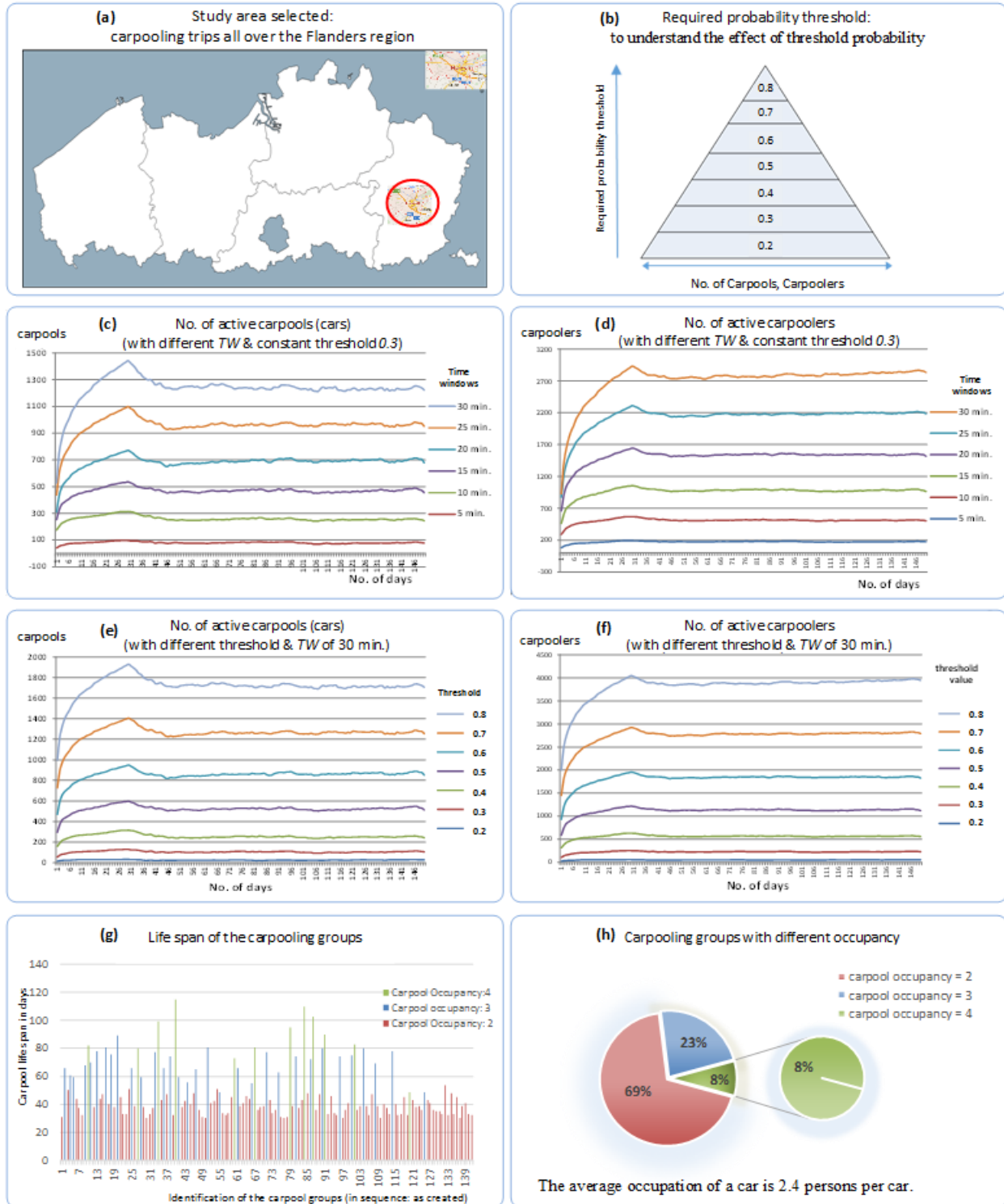


Figure 5: (a) The map of the Flanders region (the selected area is highlighted), (b) the threshold points that serve as the success criteria to determine the fate of the negotiation process, (c) and (d) show the number of active cars and active carpools by using different time windows, (e) and (f) represent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

1 The graphs in the Figures 5(e) and 5(f) represent the active carpool groups and active
2 carpoolers for the probability threshold values of 0.8, 0.7, 0.6, 0.5, 0.4, 0.3 and 0.2 respectively
3 and with a constant time window of 30[*min*]. The pattern of each curve for the graphs in Figures
4 5(e) and 5(f) are related to the graphs in Figures 5(c) and 5(d) respectively. It can be observed
5 clearly in the Figure 5(f) that the large numbers of people get involved in carpooling when the
6 threshold probability value is set lower (i.e. 0.2). For the case of higher threshold probability (i.e.
7 0.8) the criteria becomes very strict, hence reducing the number of carpoolers significantly.

8 Figures 5(g) and 5(h) show the life span of the carpools according to the carpool
9 occupancy. The data of 1000 individuals is used as input. In total 141 carpools were created: 12
10 of them have an occupancy of 4 agents in each carpool, 32 carpools have an occupancy of 3
11 agents and the remaining 97 carpools contain 2 agents each. The average life span of carpools
12 with 2, 3 and 4 person are 38.5, 69.8 and 91.3 days respectively. In Figure 5(g), the bar chart
13 shows the carpools (in chronological order as they created) with their life spans in the y-axis and
14 the identification number of the carpool in the x-axis. The pool size (occupancy) is represented
15 by the color. The diagram shows that the life span grows with more occupancy. A carpool
16 having an occupancy of two agents is terminated as soon as one of them quits. But when there
17 are three or more members in the carpool then the carpool will continue to exist when a single
18 member quits and someone else (or the same individual) may join the same carpool. This causes
19 high-occupancy carpools to live longer. The pie chart in Figure 5 (h) represents the percentages
20 of carpools with different occupancies (2, 3 and 4 persons). According to results: 69%, 23% and
21 8% with the occupancy of 2, 3 and 4 persons of the carpools were created.

22 Carpooling requires time flexibility. For the time windows of 5[*min*], 10[*min*], 15[*min*],
23 20[*min*], 25[*min*] and 30[*min*], and with a constant probability threshold of 0.3, we observed that
24 respectively 0.66%, 1.66%, 3.2%, 5.13%, 7.33% and 9.33% of the commuters started to carpool
25 within the simulated period. The Flemish travel survey (OVG (22), 2013), shows that 9.51% of
26 the 1,600 respondents carpool for home work commuting (8.85% for the OVG, 2012). The
27 average occupation of a car is 2.4 persons per car (2.46 persons per car for the OVG, 2013). If
28 we use the *time window*=30[*min*]and *threshold*=0.3 then the result looks nice (according to
29 OVG, 2013).

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

37 CONCLUSION AND FUTURE WORK

38 Modeling the interaction between individual agents becomes progressively important in recent
39 research. As a consequence, agent-based models are becoming required tools in the domain of
40 transportation. An agent-based framework using the Janus organizational-based concept, has
41 been setup to evaluate the evolution of a carpooling society under several conditions. The model
42 aims to analyze various effects of agent interaction and behavior adaptation. This research covers
43 the concept of communication, negotiation and coordination for the carpooling of a multiple trip
44 model and takes the possibility of flexible activity scheduling into account. The experiments also
45 try to limit the amount of communication between agents by restricting communication to groups

1 based on the home and work locations. The agents negotiate on trip (morning and evening)
2 departure times and on the driver assignment. People do not have a constant level of preference
3 for every moment in the entire feasible time interval due to many factors. In order to construct a
4 behaviorally accurate method for trip start times, Hendrickson's MNL departure time choice
5 model for work trips is used. Driver selection depends on the individual profile (having vehicle
6 and driving-license). The schedule (with constraining activities) for each individual is taken from
7 the data have been created by the FEATHERS, activity-based model for the Flanders region. The
8 results show that when we compare the probability of preferences of individuals with lower
9 threshold value and when the time window is larger, the chances for negotiation success are
10 greater.

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

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