2014•2015
SCHOOL FOR TRANSPORTATION SCIENCES
Master of Transportation Sciences

Master's thesis

Activity-based models: agent negotiation to cooperate for carpooling

Supervisor :
Prof.dr.ir Tom BELLEMANS

Co-supervisor :
De heer Luc KNAPEN

Muhammad Arsalan Khan
Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

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FOREWORD

This thesis was written for my Master degree in Transportation Sciences with specialization in mobility management at the Hasselt University, Belgium. The subject of this thesis is related to carpooling and the simulation of various factors that influence the cooperation of the interested individuals for the execution of a carpool trip. This is a very fascinating research topic as it is a blend of technical and social sciences ranging from pure transportation concepts to human behavioural and habitual characteristics.

After thanking Allah Almighty and my parents for their endless support, I would like to thank a few people without whom this thesis would not have been possible. I am really grateful to my promotor (Prof.ir Dr. Tom Bellemans), co-promotor (ir. Luk Knapen) and supervisor (Iftikhar Hussain) for their guidance, reviews and recommendations. These people were always present to help me with my research whenever I needed them. Working with these people was a steep learning curve for me as they did not only polish my research skills but also gave me an insight into the dimensions of the real world mobility issues.

Muhammad Arsalan Khan
May, 2015

SUMMARY

Carpooling is the co-travelling of people with similar destination in a similar time period and is considered to be an effective alternative transportation mode in order to counter alarmingly increasing traffic congestion and pollution emission levels. Carpooling can be very beneficial not only financially for the involved parties but also in a larger context of preserving environment and social welfare. However, according to different studies there is a very limited interest of people in carpooling especially for longer periods. This is mainly due to the lack of flexibility in people's daily schedule and tightness of the time intervals between certain fixed activities.

Carpooling requires the interested individuals to communicate, negotiate and coordinate, and in most cases adapt their agenda (daily schedule) to enable cooperation. The cooperation and coordination between individuals is dependent on various factors such as communication methods (the medium of interaction employed by the participants), schedule adaptation, the concept of value of time (the monetary value of different trip related factors) and lastly the negotiation process. Through negotiation, agents (individuals) can reach agreements in an iterative way which meet the criteria for the successful negotiation. If the negotiation between individuals succeeds, they enter into an agreement to travel together.

As carpooling involves two or more individuals who have to negotiate and adapt their daily agenda in order to accommodate for cooperation; therefore, modelling the effects of carpooling mechanism is not a straight forward task. For this purpose, agent based models are used to simulate the carpooling behaviour that involves the interaction of autonomous entities termed as agents.

A number of conceptual carpool models have been discussed in the literature review section of the report. A detailed study of the existing agent based carpool models reveals that the models are not accurate as they do not employ a behaviorally correct negotiation mechanism. This is mainly due to the complexity of the actual mechanism and lack of available data which leads to a number of assumptions and simplifications in the models. These models do not represent the actual human behavioral preferences as they consider a uniform and constant probability for trip execution during the entire departure time interval. Therefore, our model aims to extend the previous models by incorporating a more realistic departure time preference function for each agent by considering three different types of factors namely; (i) traveling factors such as free flow travel time, congestion time, waiting time and access time, (ii) socio-economic factors i.e. ratio of travelling cost to annual income, and (iii) time pressure factors i.e. the individual tolerance level for arriving late or early for a specific activity.

Based on the departure time preference function, a negotiation outcome estimation mechanism has been proposed in order to determine the suitable trip departure times for the execution of the carpooling trips. The proposed mechanism makes use of the individual departure time preferences to initially determine the fate of the negotiation process and to eventually find out the most suitable carpool trip departure time. Apart from it, special consideration is also given to the presence of fixed constraining activities in the daily schedules of the people involved in the negotiation process.

The proposed mechanism after detailed analysis in Microsoft Excel and in JAVA environment, has been integrated into the existing agent based carpool model developed at IMOB. The data used for simulation has been created by the FEATHERS activity-based model for the Flanders region.

The improved agent based carpool negotiation model evaluates the evolution of a carpooling society under several conditions with the aim of analysing various effects of agent interactions and behaviour adaptation. The agents negotiate on trip (morning and evening) departure times and on the driver assignment for the long term carpooling involving multiple trips. During the negotiation process the agents may adapt their daily schedules to enable cooperation. The results of the simulation prove that the proposed model represents the real life mechanism more accurately as compared to the model having uniform preferences. The results also demonstrate that the presence of constraining activities further reduce the number of participants in a carpooling activity, eventually also decreasing the number of carpool groups.

It is shown that the agent based models provide a good platform for simulating the real-life carpooling negotiation and cooperation mechanism by using the data generated by activity-based travel demand models such as FEATHERS.

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CHAPTER 1: Introduction

1.1 Scope:

Human race from its beginning has recognized the importance and needs of travelling and transport. The earlier humans mostly on foot realized the need for travelling mainly due to weather conditions and food searching but now the modern race travels a lot as it has become the medium not only to get access to basic necessities of life but also to satisfy leisurely desires. So we can say that over the centuries, along with the modernization of means of transport, the needs and desires of travelling also got revolutionized. All these factors have contributed in a drastic increase in vehicle ownership during the latter half of the previous century. Motorization rate i.e. the number of passenger cars per 1,000 inhabitants; is a common indicator that is used to demonstrate the above mentioned trend. The higher the motorization rate of a certain region is, the higher the level of economic development and quality of life is associated with that particular region. However, this rapid increase in transportation especially focusing on road transport has posed a wide range of severe challenges to the mankind. The increased numbers of cars not only affect the environment associated with extensive use of energy sources, local and global air pollution, but also negatively impact the human life in terms of extravagated congestion levels and increased crash fatalities and injuries.

The ever increasing demands for travelling and the excessive use of motorized transports call for immediate and effective measures to be taken to cope with the situation. The existing infrastructure has already been saturated and there are very limited viable options available for further expansion of these facilities. In this rapidly worsening traffic situation, the decision makers and transport planners have to manage the increasing travel demands efficiently without investing huge amounts of budget in development and expansion of infrastructure facilities. This critical situation requires efficient and innovative measures to be taken in order to minimize the consequences of high traffic volumes and congestion levels. Changing of the mind-sets of the general public regarding more frequent use of alternative transportation modes is the need of the hour. Apart from promoting the use of public transport, carpooling is the most effective and long term measure to reduce not only the traffic volumes but also the fuel usage and emission levels.

Carpooling also termed as car-sharing or ride-sharing, is in fact the sharing of a ride with different travellers having similar destination in a similar time period. Carpooling is an alternative transportation mode that can be beneficial not only for the commuters who can effectively cut down their travelling costs but also can be highly beneficial in reducing the traffic volume and congestion levels especially at peak times of the day, consequently also improving the environmental conditions. However, different studies suggest that only a small percentage of travellers actually travel via a carpool. As is the case in Flanders where there is a very limited interest in carpooling especially for longer periods. According to the OVG (Transport Behaviour Research) Flanders study carryout in the year 2000, it was concluded that only 5 to 7 percent of active workforce carpool at least 1 time per week. The study also revealed that carpooling is more famous among low-income level workers (9%) as compared to the medium and high income level population (5.5%). In USA as well, there has been a decrease in the number of people carpooling over the decades. where only 10% of the total workforce use carpool as their mean of transportation to travel to work *(United States Census Bureau,2009)* as compared to a figure of nearly 20% in the 1980s *(AASHTO,2013)*.

The low participation level in carpooling indicates that there are a number of obstacles that restrain people from engaging in carpooling activities. These may include rigidity in the schedules of the people, lack of coordination among the potential co-travellers or may be simply related to habitual and behavioural mind-set of the population.

Carpooling can be termed as a type of multi-person social activity. The exploration of a person's social network to find the potential carpooling candidates having similar trip timings and locations, is the primary step towards the start of the negotiating process. After exploration, there has to be a clear communication between the driver and other interested individuals in order to ignite the negotiation process for the execution of a carpool trip. Several key factors play their role in determining the fate of a carpooling activity such as waiting time, costs, flexibility in conflicting activities etc. Hence, a lot of negotiation and cooperation has to take place in order to successfully conduct a carpooling activity.

Negotiation is a dialogue among parties possibly having conflicting interests and is intended to reach an acceptable agreement between partners or to collectively search for a coordinated solution to the problem. Each negotiation involves a small amount of participants but the daily schedules can be interconnected by cooperation. While traditional modelling tools (direct communication, website platforms etc.) cannot handle the complexity of negotiation in the carpooling, agent-based models (ABMs) are able to do so through modelling the interaction of autonomous agents. The negotiation between different individuals is nowadays being simulated through agent based models and has become a research topic lately.

1.2 Problem Statement:

Carpooling is the co-travelling of people with similar destination in a similar time period, having multiple benefits ranging from personal travel cost savings to reduction in traffic congestion and pollution emission levels. However, studies show that there is a very limited interest of people in carpooling especially for long-term execution. This may be due to the rigidity or the presence of certain fixed constraining activities in the people's daily schedule.

In order to execute a carpool trip, people need to interact and negotiate with one another. The traditional activity based models consider the personal schedules or daily agenda of the individuals to be independent with no interaction within the social network. However, this assumption cannot be true in the context of joint carpool trips. Therefore, in order to model carpool mechanism efficiently, an interaction and negotiation methodology has to be incorporated. The interaction and negotiation among individuals results in schedule adaptation making the daily agenda of the people inter-dependent and inter-connected.

The agent based models enable the modellers to simulate the interaction and negotiation among the concerned individuals. These state-of-the-art models can simulate the effects and behaviour of different entities termed as agents. The model can illustrate both the effects of the agents on the system as a whole by modelling the interaction among different agents. This can be of particular interest especially in cases where each individual agent has its own interests and preferences. However, most of the research carried out till date regarding simulation of carpool behaviours and activities through agent based models has heavy relied on assumptions and simplifications such as *(Galland et al., 2014)* and *(Hussain et al., 2014)* assume a constant preference to depart throughout the available time window (explained in detail in the literature review). This is done mainly due to lack of available data and the level of difficulty and inconvenience to obtain preferential data from the users. This has resulted in a lot of basic level models with very simple negotiation mechanisms being used. Therefore, there is a need of improving the already proposed agent based carpool models by improving the negotiation mechanism employed by them in order to develop an accurate agent based model simulating the close-to-reality carpool behavior and negotiation mechanism.

1.3 Research Questions:

The aims or the objectives of this particular research can be outlined as following:

- How do people interact with each other to negotiate for carpooling?
- Which factors are relevant during negotiations that involve agenda adaptation?
- What kind of models for negotiation are currently in use?
- What parameters are used in those models?
- How can the present carpool models be improved?
- How can the negotiation mechanism be made behaviourally sound?

1.4 Overview of the Report:

The layout of the report is kept simple and straight-forward. The chapter 1 introduces the topic and classify the aims and objectives of the research. The Chapter 2 discusses in detail the background literature study related to carpooling. It starts with some basic theoretical introduction to carpooling, its benefits and the influencing factors such as the communication and negotiation methodologies. In the latter part of the chapter, the technical side of the topic is explored. The already proposed carpool negotiation models, their components and their limitations have been discussed followed by the discussion of some departure time models. Chapter 3 concludes the findings of the literature review and formulates the research mechanism. Chapter 4 presents the proposed departure time preference function followed by the description of the proposed negotiation outcome estimation method in Chapter 5. Chapter 6 covers the discussion of the preliminary analysis of the method along with the simulation of the mechanism in JAVA. Finally, chapter 7 describes the incorporation of the proposed method into the agent based carpool negotiation model while Chapter 8 presents the results of different simulations. At the end, chapter 9 and 10 conclude the report with some discussion.

CHAPTER 2: Background Study

The background study of the master thesis topic carried out can be broadly classified into two parts i.e. theoretical and technical parts. In the theoretical part, a discussion of the basic carpooling concepts and its benefits have been discussed. Also it is followed by an in-depth explanation of the influencing factors that are involved in the cooperation between the individuals in order to execute a carpool trip. These factors as shown in the flowchart below are: Communication methods (the medium of interaction selected by the participants), schedule adaptation (the willingness of the people to alter their daily agenda in order to accommodate for carpooling), the concept of value of time (the monetary value of different trip related factors) and lastly the negotiation process which has been discussed in detail in the following sections. On the other hand, the technical part comprises of the description of the related scientific work that has been carried out over the years. This includes already proposed carpool models and different types of negotiation techniques and models presented by various authors in their published scientific literature.

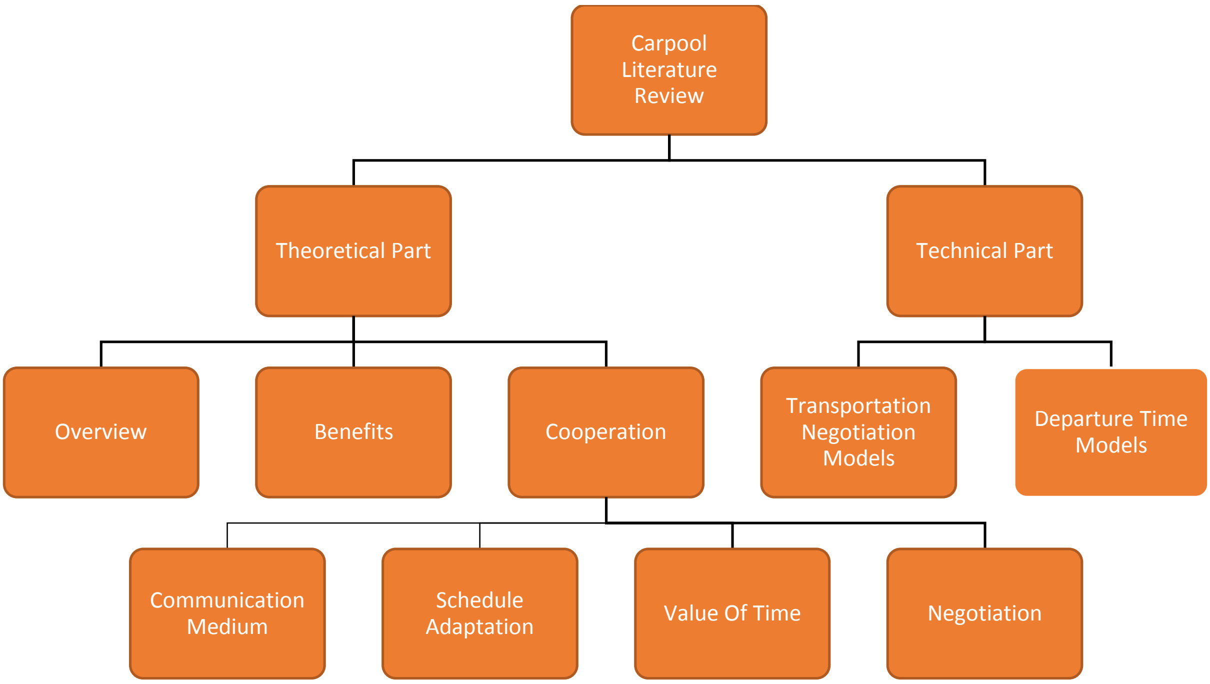

Figure 1. Flowchart of Literature Review

2.1 Carpooling Overview:

As discussed above in the introduction part, carpooling is a form of co-travelling where people having similar destination in a similar time period agree to travel together in the same vehicle. It is a form of cooperation between two or more individuals who agree to travel together for their mutual interests.

Carpooling, also termed as ride-sharing or vanpooling is considered to be an effective alternative transport mode by the transport planners and scientists all over the world in order to tame down the ever increasing traffic congestion and pollution emission levels. The infrastructural capacity all around the world has already reached its peak due to urbanization and rapid increase in motorized transport and there are very limited viable options available for further expansion of these facilities. In this rapidly worsening traffic situation, the decision makers and transport planners have to manage the increasing travel demands efficiently without investing huge amounts of budget in development and expansion of infrastructure facilities.

Apart from promoting the use of public transport, carpooling is the most effective and long term measure to reduce not only the traffic volumes but also the fuel usage and emission levels. Also the people involved can significantly cut down their travelling costs. However, despite of multiple benefits, carpooling still has a very limited number of users such as in Flanders, only 5 to 7% of the commuters actually use a carpool at least one time per week (OVG, 2000). Therefore, this requires different studies and projects to be carried out in order to determine the hindering factors that restrict people from engaging in carpooling activities and also to improve the communication and coordination among the interested individuals.

2.2 Benefits & Incentives:

The individuals interested in order to accommodate for carpooling have to make necessary adjustments and adaptations to their schedules and departure/arrival times and as well-pointed out by *(Shewmake, 2010)*, a certain carpooling individual has to sacrifice route flexibility and privacy to a certain extent while travelling with other commuters.

However, apart from some compromises and sacrifices to personal preferences, any form of co-travelling whether it be carpooling, vanpooling or casual carpooling (slugging) has a wide range of benefits from financial point of view to environmental and social perspectives. The multi-dimensional nature of the benefits of carpooling is the sole reason why it is encouraged and promoted by not only municipal and regional governments but also by large employers and companies that have a significant number of people with similar origin destinations travelling in a similar time period. Regional and municipal governments around the world have already offered incentive programs for people who prefer to travel via a carpool. Many US large cities, universities and public transit providers offer carpooling/ridesharing incentive programs (Ungemah, Goodin, Dusza, & Burris, 2007). Incentives may contain high priority lane usage, toll reductions, reduced parking charges and the options of guaranteed-ride-home and emergency-ride-home insurance. Further, we discuss in detail the advantages of carpooling from different perspectives:

i) Financial Aspect: The financial aspect is the most tempting and encouraging factor for most people to carpool as the carpooling individuals save a lot on the trip costs such as fuel costs, parking costs, roads tolls and taxes. Some employers also offer incentives for their employees who travel via carpool.

ii) Time and Stress Reduction: Carpooling does not only save money for individual travellers but also decrease the travel times. The use of HOV and transit lanes can reduce the travel times significantly. Also, the carpoolers can alter their driving responsibilities which can distribute the stress of driving among different individuals.

iii) Infrastructural Aspect: Carpooling is a promising alternative mode that can control the ever increasing traffic volumes that is saturating the infrastructural capacity. Carpooling can not only reduce the traffic load on the roads but also on parking spaces. As (Dewan & Ahmed, 2007) suggests that carpooling can reduce the parking demand and pressure at the destinations.

iv) Environmental Aspect: The reduction in traffic volumes can result in significant reduction in pollution levels. The decrease in the emission levels of carbon dioxide and other hydrocarbons resulting from the burning of fuel can be very beneficial for our environment.

v) Social Aspect: Apart from the quantifiable benefits, carpooling also helps people make new friends and acquaintances. Also social justice prevails as people who cannot afford to own a vehicle can travel easily in a passenger vehicle.

2.3 Cooperation for Carpooling:

As a carpooling activity always involves more than 1 individual, therefore it predominantly depends on the mutual cooperation and collaboration among the carpooling individuals. The cooperation in terms of carpooling is the agreement among individuals to travel together in order to attain mutual maximum utility. Once a group of individuals decide to cooperate, their period of cooperation could last from medium to long term cooperation and they are expected to behave in a way that maximises their personal as well as collective utility e.g. in terms of value of time, travel costs etc. However, in order to reach to a level where the individuals are willing to cooperate with each other, the interested individuals have to consider various factors and have to go through different phases that are discussed in detail as follows:

2.3.1 Communication methods for Carpooling:

Once an individual decides to select carpool as the preferred transport mode for a certain trip, the next logical step in order to commute by carpool is to explore and start communication with the possible interested carpool candidates by selecting a suitable mean of communication. The individual communicates with the other candidates after exploring the social network and this can be carried out through any preferred medium of communication such as:

i) Direct Communication (In-Person/Call/Text Messages): It is a commonly observed matter that people either looking for potential carpooling candidates or finding an already existing carpool group to join; first explore their own personal social network consisting of family members, neighbours, colleagues and acquaintances. In order to communicate within a personal limited social network, the individuals use the direct means of communication i.e. they contact their possible future carpool partners either in-person or via a phone call or a text message in order to start the negotiation phase to eventually lead to a carpool agreement.

ii) Advisory Service (Website/Application): Normally when an individual fails to find a suitable carpooling partner within his own social network, he/she has to find a possible partner beyond the premises of his own social network. For this purpose, the other option available is to start consulting public services like websites and applications for global exploration.

The advisory services including websites and applications allow the individuals to register their profiles consisting of detailed information such as origin-destination, departure/arrival time intervals, preferred route, vehicle ownership, driving license availability etc. Based on this information, a matching algorithm searches for the similar profiles and provides viable carpooling candidate options to the individual who can then contact and start the communication process with those recommended individuals.

Nowadays, multiple platforms of various types are available to people in order to conduct global exploration for appropriate carpool partners. These platforms may vary on different accounts including differences in services provided (vanpooling, ridesharing etc.), differences in matching algorithm (number and type of parameters used for matching) , differences in target market (individuals or companies) Some of the famous websites include carpool.com, blablacar.com etc.

Apart from it, many studies have focused on building systems and online applications to assist the process of carpooling. (Bellemans et al., 2012) proposes to make use of an agent based model to investigate the effect on carpooling of measures taken by large employers. The authors also discuss the effects of providing a profile matching service to large employers in order to create carpool groups of their employees. The system also makes use of Big Data i.e. GSM and GPS data to determine the traffic patterns. (Kamar & Horvitz, 2009) also propose a mechanism to build an online carpooling application that matches the profiles in real-time based on the GPS traces.

2.3.2 Schedule Adaptation or Time pressure Factor:

The biggest hindering factor in the execution of carpool trips is the lack of flexibility in people's schedule and tightness of the time intervals between certain fixed activities. Schedule adaptation or a certain level of flexibility in the individuals' daily agenda is necessary in order to commute via a carpool. Rescheduling or schedule adaptation is vital for carpooling and is a part of the negotiation process. The schedule adaptation depends on the knowledge of travel times and departure times for a certain activity, which generally depend on the time of day and duration of the activity. The carpooling candidates reach an agreement after a rigorous negotiation procedure in which the individuals share their preferences and in the end accommodate for carpooling by making some adaptations to their daily agenda or schedules. A lot of scientific research has been carried out on scheduling and rescheduling of daily activities e.g. (Nijland, Arentze, & Timmermans, 2008), (Auld, Mohammadian,2009) and (Auld et al., 2009)) describe the phenomena and logical process of rescheduling during the planning phase i.e. activities that have been planned but not yet started. Apart from it, another line of research focuses on the rescheduling that occurs as a result of unexpected events e.g. *(Knapen et al., 2012)* and *(Nijland et al., 2009)*.

The rigidity in the available time windows of commuters termed as time pressure can be due to a number of fixed and rigid daily activities with a short gap between them. The most common example of this phenomena is the pick and drop activities (e.g. children to school) before going to work. In this case, that particular individual has a very brief time window available to negotiate with carpooling candidates. Hence, the chances for a person to accommodate a carpooling activity into his schedule are very slim.

2.3.3 Value of Time:

The concept of value of time in the context of transportation is very critical as it links and merges different factors into a single monetary factor. The value of time has to be taken into account especially in the case of carpooling as the schedule adaptation and the level of cooperation of a certain individual are directly related to the monetary value that person assigns to his available time which obviously depends on the income level (income per hour or per year) of the person.

Based on the monetary cost and other attributes of the trip such as duration, start time, transit etc. along with the income level of the person, a preference function could be defined that yields a single value of probability for each moment in available time window. A number of studies have been carried out to understand and quantify the concept of value of time. *(Abrantes & Wardman, 2011)* presented an analysis of the travel times and the corresponding value of time issues in UK while *(Hendrickson, 1984)* carried out survey study and presented a multinomial logit model in order to determine the influence of different factors including VOT on the mode and time choice for a particular trip.

2.3.4 Negotiation:

Negotiation is the key factor that influences the outcome of a carpool trip planning. A successful negotiation results in a cooperation and coordination among the individuals involved. Negotiation is basically a dialogue among parties possibly having conflicting interests and is intended to reach an acceptable agreement between partners or to collectively search for a coordinated solution to the problem. Each negotiation may involve 2 or more participants and the process gets complicated with the increasing number of participants. The basic goal of any negotiation is to interconnect the daily schedules by cooperation. For this purpose, a negotiation protocol has to be defined that is a basic set of rules to interact and negotiate.

As pointed out in *(Wooldridge, 2002),* agent interactions have several components i.e. the negotiation set, a protocol, strategies, and a rule to determine that the interaction is complete. The negotiation set includes the possible proposals or the alternatives and their attributes. A group of participants deciding to interact with one another following a negotiation protocol have to select their preferences from the given negotiation set according to their personal strategies. At the end, a set of decision rules determines the fate of the negotiation process and it is concluded that whether the participants would enter into cooperation and coordination phase or not. (Ronald, 2012) layouts the full detail of the components and steps involved in agents interaction and negotiation phase.

Negotiation can be of different types having different goals and objectives such as deciding on the activity start time, activity location, route, duration etc. *(Wainer et al., 2007)* proposes a negotiation mechanism focusing on a single issue i.e. to decide the meeting time. However, in reality a multi-issue negotiation approach is carried out where the participants have to negotiate on a number of issues before entering into the cooperation phase. (Fatima et al., 2006) explains three methods for dealing with issues in multi-issue negotiation: all issues are discussed together (package deal), issues are discussed separately and independently of each other (simultaneous), or issues are discussed one after the other (sequential). Although it has been shown that proposing complete deals at each step is computationally more complex, it has advantages such as Pareto optimality (Fatima et al., 2006). (Ronald, 2012) also employs the package deal method in its agent based negotiation model (discussed in detail in the following sections) as the other two negotiation methods dealing with multi-issue negotiation have major drawbacks particularly in case of transportation scenario. In the sequential method, it is very difficult to decide the order of issues that have to be negotiated e.g. whether the participants should decide the location of activity first or the activity partners or available timing first. Similarly, the other method of deciding issues simultaneously and independently of each other is also not a feasible approach as the issues of activity timing and location are often inter-related.

The discussion above already implies that the modelling of negotiation process is not a straight forward task. The traditional transportation models i.e. activity based models did not account for interactions and interdependency of the schedules of people. Therefore, in order to incorporate this phenomena in the modelling process, agent based simulations have played a significant role in which intelligent autonomous agents not only have their own personal schedules but they also interact and negotiate with each other in order to adapt their schedules accordingly. Hence, it can be safely concluded that while traditional modelling tools cannot handle the complexity of negotiation in the carpooling, agent-based models (ABMs) are able to do so through modelling the interaction of autonomous agents.

2.4 Cooperation & Transportation Negotiation Models:

In recent years, various transportation negotiation and cooperation models representing the mechanism of interaction and negotiation among the individuals have been proposed by different scientists all over the world based on human preferential and behavioural studies. Also these studies have had a focus on individuals' daily agendas and the level of flexibility and willingness to alter or adapt the daily schedules or agenda in order to accommodate carpool trips.

As discussed above as well, a proper communication, coordination and negotiation mechanism is required for the planning and execution of carpool trips. In the following section, we will discuss some of the scientific work that has been carried out to characterize the different phases involved in a carpool trip execution particularly focusing on the negotiation scenario.

The mechanisms used in current simulations predict the *outcome of the negotiation process* and do not model the negotiation in detail. There is no bidding and proposal acceptance involved. A consensus state based on individual preference functions (known by all participants) is used. The effect of the activity timing in the agenda is reflected in the domain of the function that specifies the preferred trip start time (i.e. the preference function value is zero for each time value that does not suit the individual). The motivation for this approach is simplicity and low computational requirements (no iterative negotiation steps required). The result is assumed to be sufficiently accurate to evaluate aggregated effects (emergence) such as the level carpooling that can be attained in a particular social group or in a specific region.

(Hussain & Knapen, 2014)[1] proposes an agent based carpool model using a simple negotiation mechanism while also classifying the different phases that an agent goes through to eventually execute a carpool trip. Before having an in-depth analysis of the negotiation mechanism used in the simulation, we discuss the background and details of the proposed carpool model. First of all, any individual or agent who has to make a trip from point A to point B considers the viable options of transportation modes available to him and then subsequently decides the best possible mode. After the selection of carpool as the transportation mode for a particular trip by the concerned individual (agent), that agent has to go through different phases namely; (i) Exploration, (ii) Negotiation, (iii) Trip execution. Every agent who decides to carpool first explores its social network in order to determine or discover the already existing carpool groups or create a new group by identifying other interested individuals having similar trips in spatial and time constraints. After exploration, communication via any preferred platform takes place in order to negotiate the terms for co-travelling such as the trip start time, pick-up location, route selection, cost of trip etc. If the negotiation between two or more agents turns out to be successful, the agents proceed to the next phase i.e. the cooperation or coordination phase. In this phase, the agents are set to act upon the agreed set of protocols and rules that are mutually decided in the negotiation phase.

The figure below shows the activity diagram of the proposed model. As discussed above, the simulation is broadly divided into three phases. The first activity in the process is the exploration of the social networks of that particular agent. However, the most critical phase in determining the fate of a carpooling activity is the negotiation phase. The success or failure of the negotiation between two or more agents decides the subsequent phases. If the negotiation fails, the agents go back to exploration state. Nevertheless, if the negotiation between agents turns out to be successful, the agents enter into the carpooling execution block. In this block, they act upon the already decided set of protocols for the trip execution.

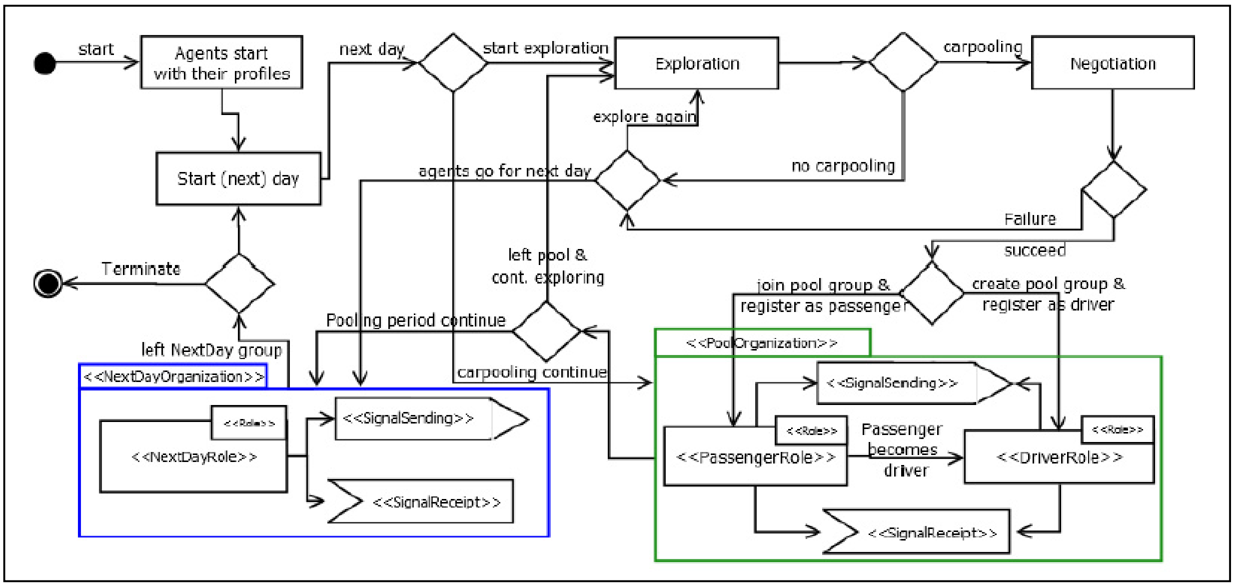

Figure 2. Activity Diagram of Carpool Model
(Source: *Hussain & Knapen, 2014*[1])

The negotiation mechanism used in this particular model for simulation is a simple mechanism that takes the mean of the preferred trip start times of the agents to determine the trip start time as shown in the equation (1) below where t_i is the preferred trip start time of agent a_i and Δt is the tolerance period or time window for that particular agent.

$$\forall_{i}\ a_i \in A : \left| t_i - \sum_{j=i,N}^{1} \frac{t_j}{N} \right| \leq \frac{\Delta t}{2} \qquad (1)$$

This mechanism though mathematically and computationally simple does not reflect the true human behaviour as it considers a uniform and constant preference value for the whole time interval or window of a particular agent while negotiating regarding the trip start time.

The same authors try to improve and extend their agent based negotiation model in their further research. *(Hussain & Knapen, 2014)*[2] extend their model to multiple trips including morning as well as evening trips whereas the initial model only considered the morning trip. Apart from it, the negotiation mechanism introduced in the initial research has also been improved slightly. Although the basic concept employed in the negotiation mechanism remains the same i.e. using the average of the individual preferred trip start times to determine the carpool trip start time, however the level of detail in the negotiation mechanism has been elevated by differentiating between fixed and flexible work timings schedules. The basic equation for determining the combined trip start time remains the same as shown below in equation (2) where TST denotes trip start time while PST denotes the individual's preferred start time:

$$TST_{trip} = \frac{1}{N} \sum_{j=i,N}^{1} PST_{trip,aj} \tag{2}$$

The authors present two separate cases for commuters with the fixed work timings and commuters with flexible work timings. The equations (3) and (4) below represent fixed timing case. The equation (3) requires that for the morning HW trip, the carpool trip start time (TST) should be less than the latest trip start time for the particular agent as there is no room for flexibility available in the schedule due to fixed work timing constraints. Similar is the case for the evening trip that indicates that the person cannot leave earlier than the official leave time due to hard and strict working constraints.

$$TST_{trip,HW} \leq PST_{trip,HW} \text{ for the morning trip (Home to Work)} \tag{3}$$
$$PST_{trip,WH} \leq TST_{trip,WH} \text{ for the evening trip (Work to Home)} \tag{4}$$

The other case for negotiation discussed by the authors is for the flexible work timing situation. The authors introduce a variable β to represent the flexibility in the work timings. β =1 if the work schedule is flexible otherwise β=0. The people having flexible work timings have a certain time window during which they depart for their destination. The trip start time TST should lie within the available time window TW for the agents involved in the negotiation process. The authors demonstrate the process via equation (5) as shown below for both the morning (home-work) as well as evening (work-home) commuter trips.

$$\begin{matrix} \forall_i \\ a_i \in A \end{matrix} : \begin{Bmatrix} (TW^{-}_{tripHW,ai} \leq TST_{tripHW} - PST_{tripHW,ai} \leq \beta_i \, TW^{+}_{tripHW,ai}) \wedge \\ (\beta_i \, TW^{-}_{tripWH,ai} \leq TST_{tripWH} - PST_{tripWH,ai} \leq TW^{+}_{tripWH,ai}) \end{Bmatrix} \tag{5}$$

The figure (3) below show the graphical depiction of the negotiation equations presented by the authors. Diagram shows the possibility of flexible work activity scheduling between the trips (morning and evening) of an individual. The highlighted (in black colour) side of triangle shows the flexible side of the time window. The parameter **β=0** means that person has no flexible work times (shown in left block), while **β=1** means that the person has flexible work times (shown in right block) in which the working hours are counted from the time of arrival. The possibility of scheduling of the work activity of an individual for which βi=0 is shown in Figure 3 (a) and (b); the case for βi=1 is shown in Figure 3 (c) and (d). If an individual does not compromise on utility loss by changing the activity duration, then the $TWtrip$, +/− of $trip$ 2 depends on the $TWtrip$, +/− of $trip$ 1.

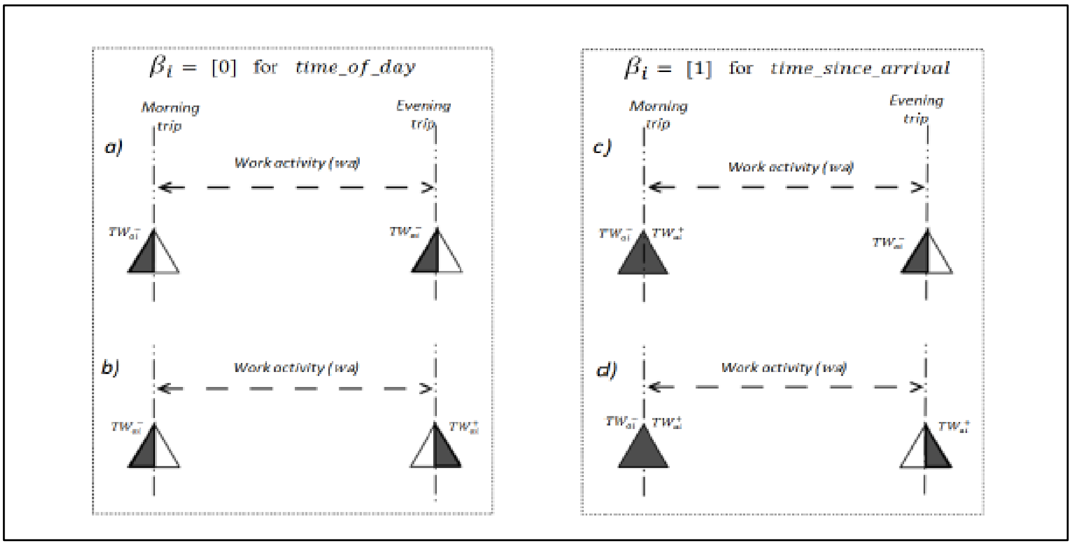

Figure 3. Difference in Available Time Windows of Agents Depending Upon the Schedules
(Source: *Hussain & Knapen, 2014*[1])

The same authors in one of their more recent work have tried to advance their research and have made significant improvements to their model as compared to the initial version. *(Hussain & Knapen, 2015)*[3] enhance their model by introducing the concept of constraining activities in their negotiation outcome estimation mechanism. The fixed activities that cannot be compromised or rescheduled can be said to induce time pressure on the commuters, hence can be termed as *constraining activities*. The new approach takes the additional timing constraints into account. This approach is closer to the actual human behavioural attitude as the departure time preferences vary from person to person for a particular moment in time, however the individuals willing to cooperate with each other will have a suitable time interval e.g. usually a 10 or 15 minute time interval during which all the involved participants will have highest preference to start the combined trip. The set of equations below illustrate the improved estimate of the negotiation mechanism outcome proposed by the authors.

The equation (6) helps to determine the lower and upper bounds for the time window of a particular agent a_i with special consideration given to the presence of constraining activities in the daily agenda of an agent. The time window for the simplest case with symmetrical deviation and no constraining activities is symbolically denoted by ΔT whereas the symbol $\overline{\Delta T}$ represents the time window for the agent that has certain fixed constraining activities present in the daily schedule. $\overline{\Delta T}$ is calculated by taking the difference between the preferred start time PST and the constraining activity finish time AFT i.e. $\overline{\Delta T} = PSTai - AFTai.$ Note that [PST- ΔT,PST+ ΔT] denotes the possible trip start interval when no constraints are considered (not the symmetry about PST).

$$TW_{HWLower,a_i} = \begin{cases} if\ ca\ \&\ \overline{\Delta T}<\Delta T: & PST_{HWTrip,a_i} - \overline{\Delta T} \\ otherwise: & PST_{HWTrip,a_i} - \Delta T \end{cases} \quad TW_{HWUpper,a_i} = PST_{HWTrip,a_i} + \Delta T \quad AND \quad TW_{WHLower,a_i} = \begin{cases} if\ ca: & AFT_{ca,a_i} \\ otherwise: & PST_{WHTrip,a_i} - \Delta T \end{cases} \quad TW_{WHUpper,a_i} = \begin{cases} if\ ca: & AFT_{ca,a_i} + \Delta T \\ otherwise: & PST_{WHTrip,a_i} + \Delta T \end{cases} \tag{6}$$

After the determination of the indvidual lower and upper bounds of the departure time window of the involved agents, the equation (7) serves to find out the overlapping time period from the agents' respective departure time windows. This method as illustrated in the equation (7) is employed for the selection of a suitable trip departure time interval for both the morning as well as evening commuter trips. For the selection of the lower bound of the suitable trip departure time interval, the maximum duration or period length from the individual prefered time windows of the involved agents is nominated while for the selection of the suitable trip departure time's upper bound, the minimum value from the concerned agents's prefered time windows is selected. The equation (8) then helps to state the length of the departure time interval.

$$TW_{HWLower,carpool} = \max_{j=1\ldots N}(TW_{HWLower,j}) \quad TW_{HWUpper,carpool} = \min_{j=1\ldots N}(TW_{HWUpper,j}) \quad AND \quad TW_{WHLower,carpool} = \max_{j=1\ldots N}(TW_{WHLower,j}) \quad TW_{WHUpper,carpool} = \min_{j=1\ldots N}(TW_{WHUpper,j}) \tag{7}$$

$$\text{Time Intervals} = \begin{cases} \min_{j=1\ldots N}(TW_{HWUpper,j}) - \max_{j=1\ldots N}(TW_{HWLower,j}) & for\ home-to-work\ trip \\ \min_{j=1\ldots N}(TW_{WHUpper,j}) - \max_{j=1\ldots N}(TW_{WHLower,j}) & for\ work-to-home\ trip \end{cases} \quad AND \tag{8}$$

The proposed negotiation method is a step forward w.r.t the initial model because of the inclusion of the effects of the constraining activities. However, the model still lacks a personalized preference function for each agent that is close to human behavioural characteristics.

(Galland et al., 2014) proposes an agent based simulation model for the global matching of the potential carpooling candidates. This model also employs a simple negotiation outcome estimation mechanism with constant preference values for the entire preferred time interval for the agents involved in the negotiation process. This is done mainly due to lack of available data and the level of difficulty and inconvenience to obtain preference data from the users. The individuals are assumed to be reluctant and hesitant to enter piece-wise linear utility function to express their preferences for a particular trip start time. Therefore, for practicality issues; the individuals are asked to register only the boundaries of their preferred time interval for the trip departure. The equations below represent a simple mechanism to determine a suitable trip start time for two specific individuals where *tis* is the *time interval similarity* of the two agents A and B having time intervals ($t_{iA.0}$-$t_{iA.1}$) and ($t_{iB.0}$-$t_{iB.1}$) respectively. Basically, *tis* is the overlap of the respective time intervals of the concerned individuals and helps to determine the departure time for a carpool trip.

$$t_0 = \max(t_{i_A,0}, t_{B,0}) \quad (9a)$$
$$t_1 = \min(t_{i_A,1}, t_{B,1}) \quad (9b)$$
$$tis(i_A, i_B) = t_1 - t_0 \quad (9c)$$

However, despite of using a simple negotiation mechanism for simulation model; the author theoretically sketches a methodology to formulate a behaviourally sound negotiation mechanism for simulating the negotiation process between 2 or more individuals/agents. This introduces the concept of defining preference or utility functions for each and every individual involved in negotiating the suitable terms for co-travelling, in this case particularly focusing on the selection of trip departure time.

The set of equations below determine the trip start time preference for the proposed negotiation outcome estimation mechanism mathematically. A group of individuals A and B trying to carpool are designated their personal preference functions f_A and f_B for their specified time intervals [$t_{iA.0}$, $t_{iA.1}$] and [$t_{iB.0}$, $t_{iB.1}$] respectively. The *time interval suitability* S for trip departure time can be determined by integrating the product of the preference/utility functions of the particular agents involved over a specified fixed time interval [0, ∞].

$$t_0 = \max(t_{i_A,0}, t_{i_B,0}) \quad (10a)$$
$$t_1 = \min(t_{i_A,1}, t_{i_B,1}) \quad (10b)$$

$$S(t; C, i_A, i_B, f_A, f_B) = \begin{cases} \int_t^{t+C} f_A(x) \cdot f_B(x) dx & \text{if } t \in [t_0, t_1 - C] \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

The mechanism suggested above illustrates a method to determine the most suitable departure time for a particular trip while maximizing the utilities or satisfaction level for the individuals involved provided the preference function is defined for each one of them. However, the suggested mechanism only theoretically outlines the behaviourally sound methodology as it does not suggest the preference function for the individuals.

The figure (4) depicts the main concept and application of using personalized preference functions as compared to a constant preference function for all agents for the whole time interval. The graphs in the figure compare the two negotiation mechanisms with the first one (left on the figure) being more realistic and behaviourally sound while the other one (right on the figure) depicting a simplified mechanism with an assumption or simplification that the preference of a person remains constant throughout the given time window. Although, the first approach is realistic however it is very difficult and complicated to use this method in matching services as it requires a lot of data and it is not feasible to gather such detailed data as users are never willing to register such time consuming data. This is the reason that a simple negotiation mechanism is used mostly in simulations and models.

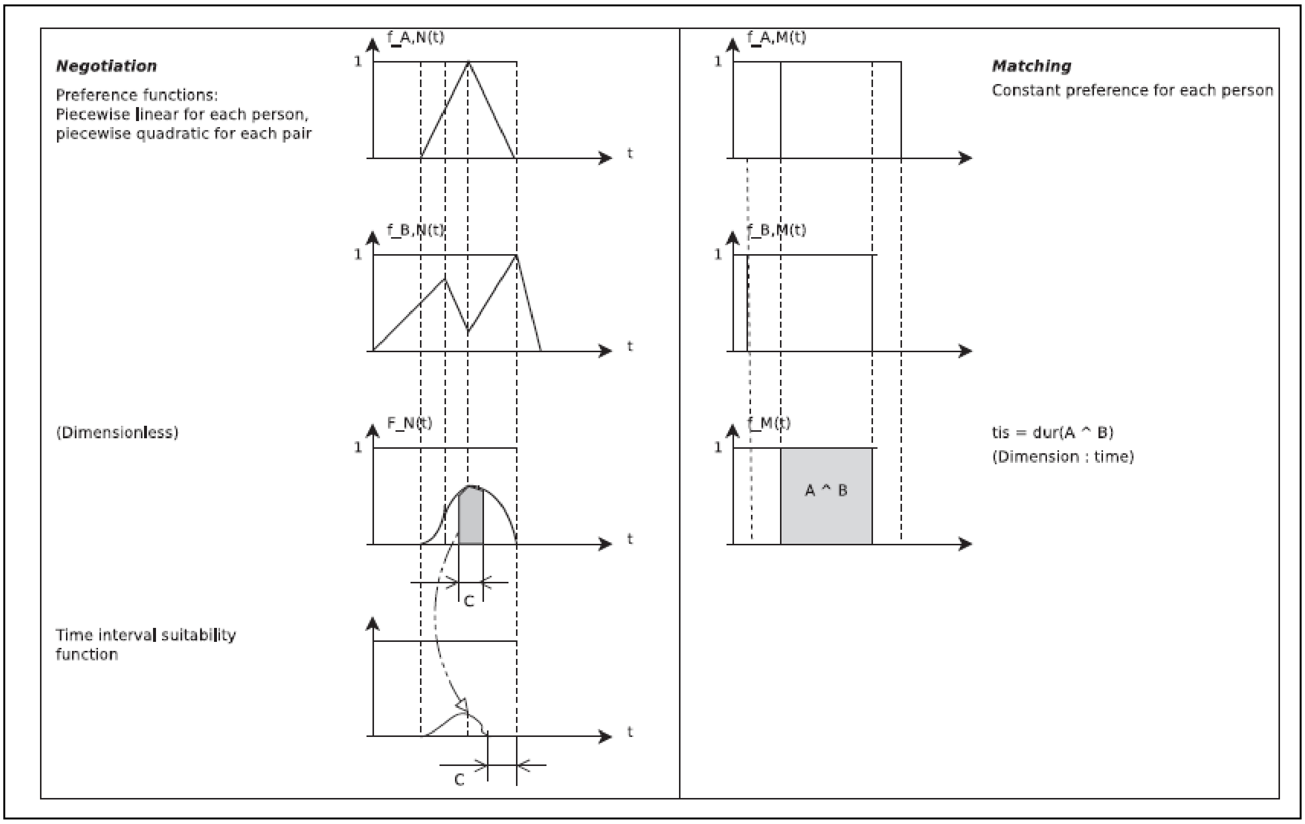

Figure 4. Comparison of Preference Functions for Trip Departure Times
(Source: *Galland et al., 2014*)

Another agent based model is presented in *(Ronald, 2012)* that focuses on the negotiation methodology and the corresponding scheduling and cooperation in the case of jointly execution of social activities. The author also discusses in detail the need for an interactive agent based negotiation model in order to accurately predict the travel demand. The activity based models result in a personal and independent schedule for an individual with no interaction in its social network. **(Zhang and Daly, 2009)** as quoted above as well summarize the need for incorporating the interaction and cooperation measures among the individuals in the transport model as:

> **"**In the context of transportation policies, ignoring such interpersonal Interactions could overestimate the effects of policies and might lead to inappropriate investments. However, the dominating travel behaviour models have mainly built upon individual decision-making theories, which assume that an individual can decide his/her behaviour based on his/her own preference.**"**

After emphasizing on the importance of interaction based model, the author proposes and discusses an agent based model that includes a well-defined and structured interaction protocol integrating the transport layer and social layer in a single model. Each individual is considered to have a certain number of social activities that are mostly performed or at least preferred to be performed with certain people within the personal social network. The individual communicates or interacts with the people within the social network in order to schedule their discretionary social activities at a particular time of day at a particular location. Both the involved parties have influence over each other and the activity is scheduled or rescheduled accordingly.

The model is basically built by first of all defining the agents with each of them having their personal goals to achieve in a specific environment while interacting and coordinating with other agents in their social networks. Specific roles are assigned to the agents with one agent who initiates and finalises the interaction termed as host while the other agents are termed as respondents. The model also considers the relationship among the agents and store their historical and socio-demographic data such as the age, gender, last joint activity, location of activity etc. The agents negotiate about the kind of social activity to jointly execute, the location and timing. For this purpose, a utility function is defined for each agent in the model that is based on a number of factors such as the type of social activity, location, duration, travel time etc. The set of equations below show the utility of an agent to plan and perform a certain social activity with the similar agents. Equation (12a) determines the threshold based on duration and the free available time for an individual while equations (12 c, d and e) account for factors such as last time an individual undertook an activity, visited a specific location or met someone. All these factors contribute towards determining the utility of a social activity for an individual that increases with time if a person has not performed a social activity for a specific time as indicated in equation (12f). Equation (12g) calculates the similarity measures for two individuals based on age and gender classifications while equation (12h) determines the travel cost of the trip that eventually contributes in defining the utility for an agent.

$$U_i(a,l,d,y,j) > r \times u^*(d, w_i, w_{id}) \quad (12a)$$

$$U_i(a,l,d,y,j) = V_i^{ady} + V_i^{al} + V_i^{j} - cost(l) + \epsilon_i^{st} \quad (12b)$$

$$V_i^{ady} = f_t(\alpha_i^{ady}, d - t_i^a) + \epsilon_i^a + \epsilon_i^y \quad (12c)$$

$$V_i^{al} = f_t(\alpha_i^{al'}, d - t_i^l) + \epsilon_i^l \quad (12d)$$

$$V_i^{j} = f_t(s_{ij}, d - t_i^j) + \epsilon_i^j \quad (12e)$$

$$f_t(x,t) = (\frac{2}{1+e^{-xt}}) - 1 \quad (12f)$$

$$s_{ij} = Q_g + Q_a \quad (12g)$$

$$cost_{(l)} = a + b \times ln(tt_{i(l)}) \quad (12h)$$

Source: (Ronald,2012)

The figure below illustrates the architecture of the agents as defined by (Ronald,2012) in the agent based model for simulating the joint social activities. Each agent has its own attributes such as personal schedules, history and a utility as descibed above. The agents then interact with each other in order to execute joint activities and different proposals are presented and evaluated. If an agent agrees to a certain proposal of another agent, the schedule is updated.

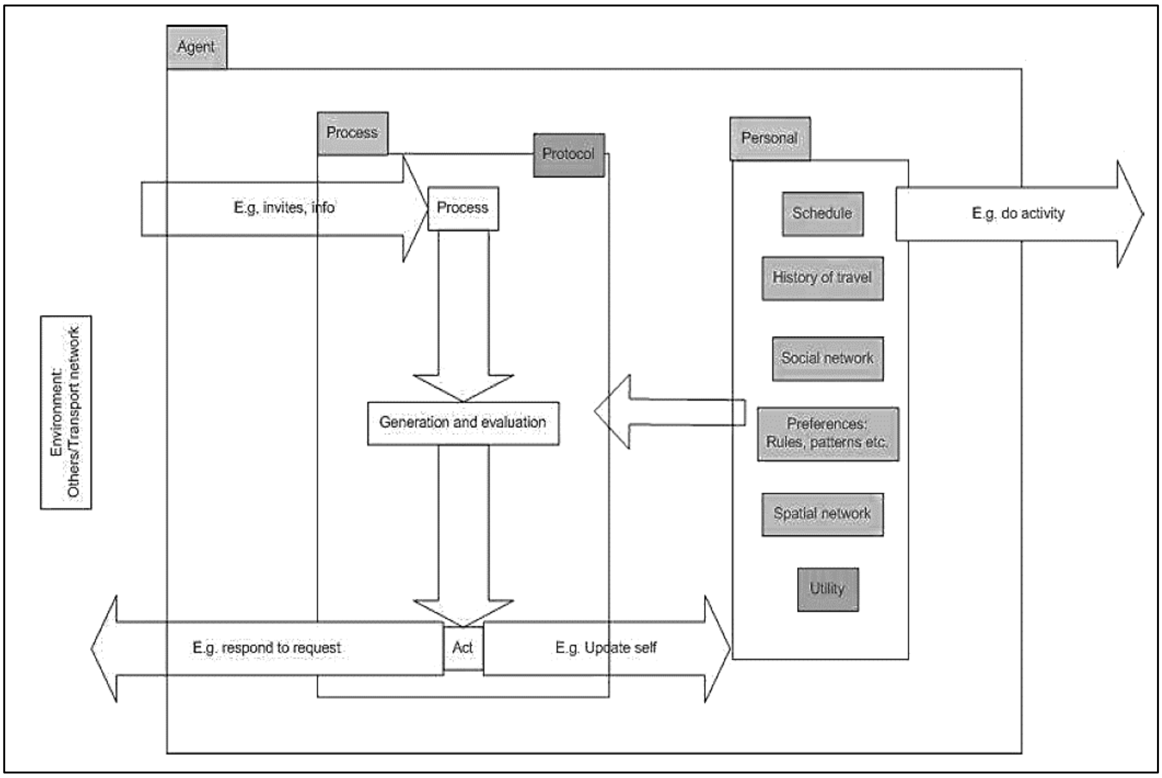

Figure 5. Architecture of an Agent
(Source: *Ronald, 2012*)

The author pays significant attention to the interaction or negotiation protocols in the model. As the negotiation process is mostly multi-issue in case of discretionary social activities, therefore an appropriate methodology of presenting the proposals as a package as discussed in detail above as well has been employed. Apart from it, there are multiple types of interaction protocols as the author broadly classifies them into three types i.e.:

i) <u>Person-first protocol:</u> In this type of negotiation protocol, the person is selected first while the type and attributes of the joint activity are decided after a rigorous multi-issue negotiation process.

ii) <u>Activity-first protocol:</u> This type of protocol involves an individual who has a specific activity to perform. The host sends out a proposal to a possible partner in order to negotiate. If the respondent does not agree, the proposal is sent to another person and so on.

iii) <u>Enumeration protocol:</u> This is a hypothetical interaction protocol with each agent in the population evaluating a complete set of possible activities for all of the agents in their social network. The activity is scheduled if two persons agree on the terms. This method is a representation of what happen in current simple models.

The author selects the person-first negotiation protocol as the base case for her model. An effort is also made to state the importance of negotiation protocols by introducing and comparing them in the model. The comparison study suggests that interaction between agents at micro-level affects the overall outcomes of the model at macro-level. Hence, urging for more research on the topic.

The following figure shows the layout of the agent based model proposed. The input module collects all the relevant data regarding agents, their utilities, history, location etc. The environment module contains the spatial and network attributes while the population module holds the data for the agents and their social networks. All the activities for each agent are stored in the schedule component of the model. Output files containing all the information from all the modules are then used to simulate the interactions and negotiations among the agents.

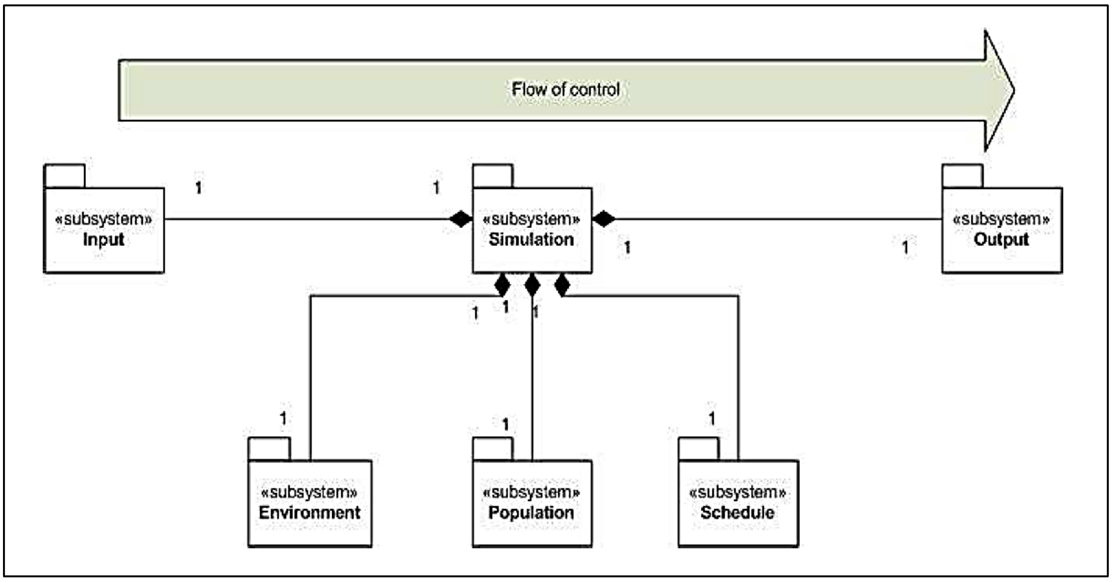

Figure 6. Layout Overview of Agent based Model
(Source: *Ronald, 2012*)

2.5 Departure Time Models:

The agent based models regarding carpool trips have to be based on real life detailed data in order to accurately simulate the real world mechanisms. Different types of scientific studies can be helpful in improving the behaviour mechanisms especially related to interaction and negotiation attributes incorporated in the agent based models. In this section, we focus on a number of studies that have been carried out around the world relating to the departure time selection characteristics of daily commuters traveling to and fro between home and work locations multiple times a week.

One of the pioneers and one of the most detailed departure time studies has been carried out by Hendrickson and Plank in 1984. *(Hendrickson, 1984)* studies the concept of flexibility in departure times of individuals focusing on work-home trips. The author develops a multinomial logit model based on the survey carried out in Pennsylvania, USA to estimate the relation and significance of transport mode and departure time interval choice simultaneously.

The author sets up an experiment in Pittsburgh Central Business District to measure the travel times and peak congestion periods independently along with the conduction of a survey of 1800 workers who travel daily from the outskirts to CBD of the area under consideration. The graph below depicts the quadratic relationship between different departure times and the total travel time. It is clearly evident from the graph that the travel time is maximum if the departure time is at the peak time i.e. around 08:00 A.M and it decreases significantly as the time departure interval moves away either to the left or the right from the peak time.

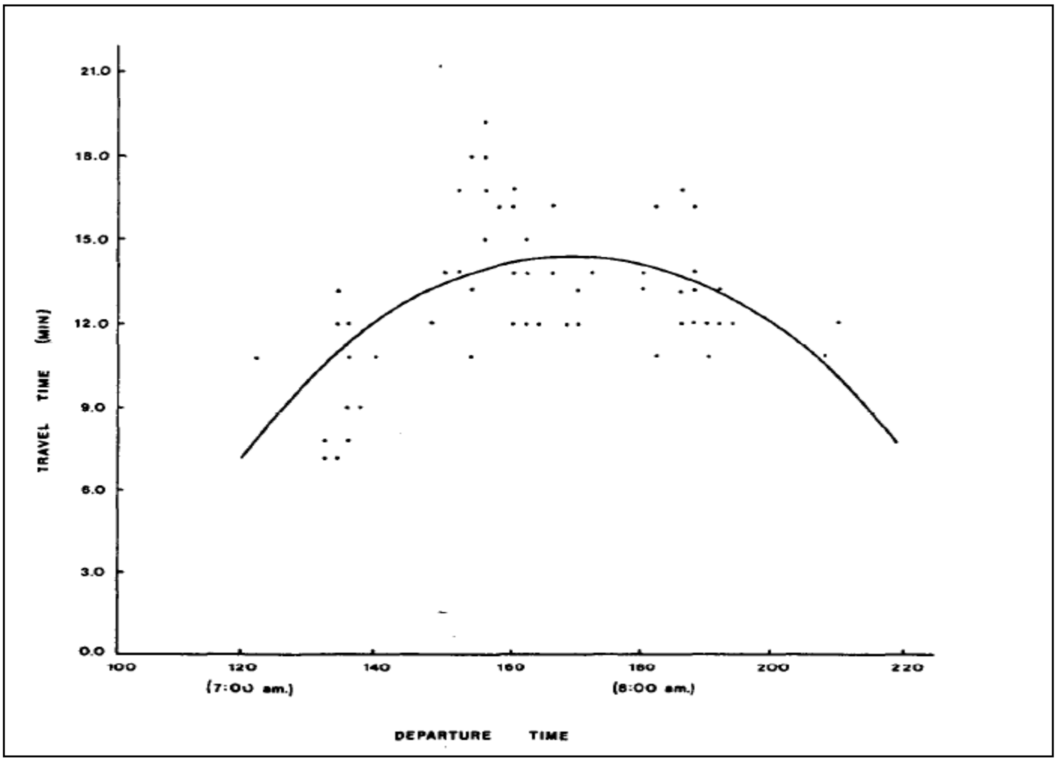

Figure 7. Travel Times for Different Departure Times

(Source: *Hendrickson, 1984*)

The selection of a suitable departure time especially for work trips apart from the prefered transport mode and route choice obviously depends on the activity (work) start time and the level of flexibility or rigidity in work start and end times. The graph in figure (8) shows the common behavioural attribute of the commuters that is all of them arrive at their work location (solid line) on-time or before the official work start time (long dashed line). The mean work start time is around 08:00 and all the workers have the arrival time before it. The graph also shows the desired work start times (short dashed line) and it can be concluded that the majority of the respondents have a desire to have an earlier starting time. Hence, it can be deduced that people almost always want to be on time or early for their work and that being late is not acceptable.

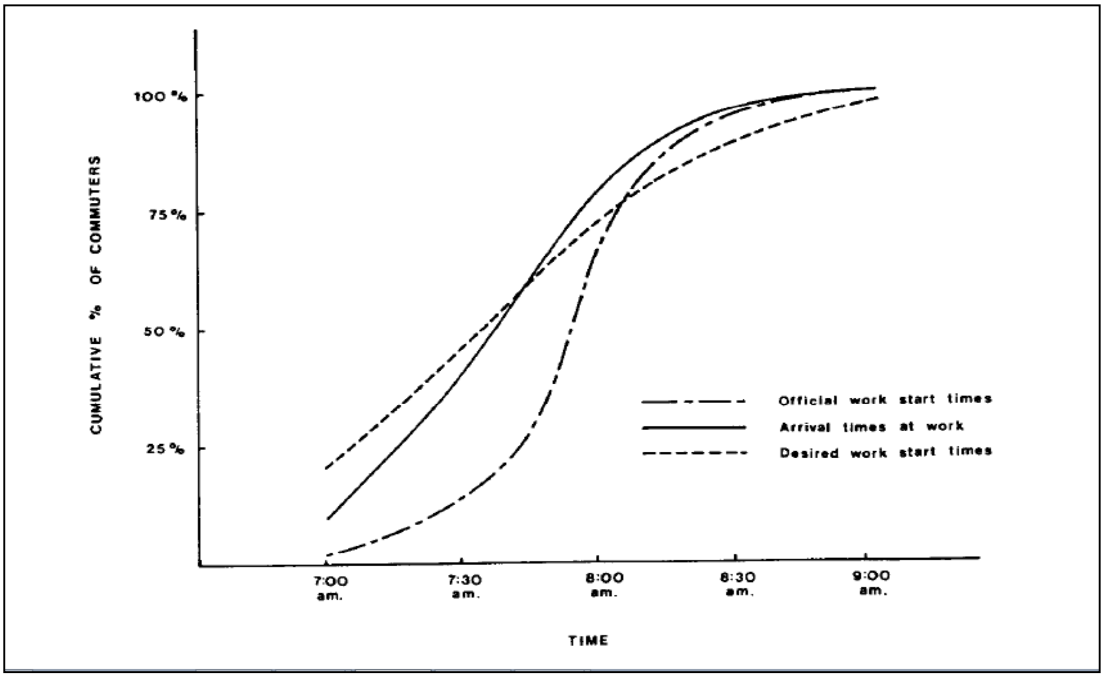

Figure 8. Arrival Times and Official Start Times for Work
(Source: *Hendrickson, 1984*)

Based on his survey study and multinomial logit model, the author proposes an equation to define the personal utility or preferences for a given set of departure times for work trip in a particular transport mode. The logit model includes 4 mode choices (drive-alone, shared ride, transit with walk and transit with auto) along with 7 departure time intervals of 10 minutes each. The proposed function as shown below is based on a number of factors that influence the preference for an individual. Based on the survey results, the coefficients in the equation are estimated and are shown in Table 1. As it is evident from the data in the table that most of the factors in the equation have a significant effect as they have a high significance value while some of the factors such as free flow travel time are not significant and have a very low t-statistic value which implies that departure time and mode choice does not depend on the in-vehicle travel time as it almost remains same for a given time interval. It is also worth noting that the coefficient for the shared ride indicates that this mode is highly sensitive to the other factors presented in the function. The individual utility or satisfaction function is then converted in terms of probability to determine the maximization of the utility of a specific person for a particular departure time with a particular mode.

$$V_{ijt} = a_0 + a_1FFTT_{ij} + a_2CONG_{ijt} + a_3\ (COST/\ INCOME)_{ijt} + a_4ACC_{ijt} + a_5WAIT_{ijt} + a_6LATE_{ijt} + a7(LATE_{ijt})^2 + a_8EARLY_{ijt} + a_9(EARLY_{ijt})^2 \quad (13)$$

$$P_{ijt} = \exp\ (V_{ijt})\ /\ \sum_k \sum_n \exp\ (V_{ikn}) \quad (14)$$

Where:

- V_{ijt} = Utility/ Preference function for an agent *i* for a particular time t in time window with mode j
- P_{ijt} = Probability to select a specific departure time t with mode j;
- FFTT= Free flow Travel Time in the vehicle (minutes);
- COST/Income = Ratio of annual travel cost to income level per annum;
- WAIT = Waiting time in minutes to depart for the trip
- ACC = Access time (e.g. for a carpool driver; time to walk from parking to destination);
- LATE = Minutes of late arrival at work associated with the departure time *t*;
- EARLY = Minutes of early arrival at work associated with the departure time *t*.

Variable Estimated	**Coefficient**	**t-statistic**
Drive Alone Constant	-1.47	3.5
Shared Ride Constant (Carpool)	-2.09	8.8
Transit Auto Constant	-1.26	6.3
Free Flow Vehicle Travel Time	-0.008	0.3
Congestion Time	-0.021	0.7
Annual Cost/ Income	-0.699	2.0
$(\text{Early Time})^2$	-0.00042	5.3
Late Time	-0.148	6.4
$(\text{Late Time})^2$	0.0014	2.3
Access Time	-0.095	5.0
Wait Time	-0.088	3.2

Table 1. Estimated model coefficients
(Source: *Hendrickson, 1984*)

As the table (1) indicates negative coefficient values for the factors illustrating the early and late arrivals at work, this suggests that these factors minimize the utility or satisfaction of an individual or in other words, these factors tend to increase the disutility curve. However, the value of the quadratic late factor as shown in the table is positive. This is contradictory to the other linear factors of late and early arrival which have a negative value. Hence, it can be concluded from the model that once an individual gets quite late at work, then it comes to a stage where additional late time does not affect the person anymore as shown in the curve below where the late curve tends to become constant at higher late arrival times.

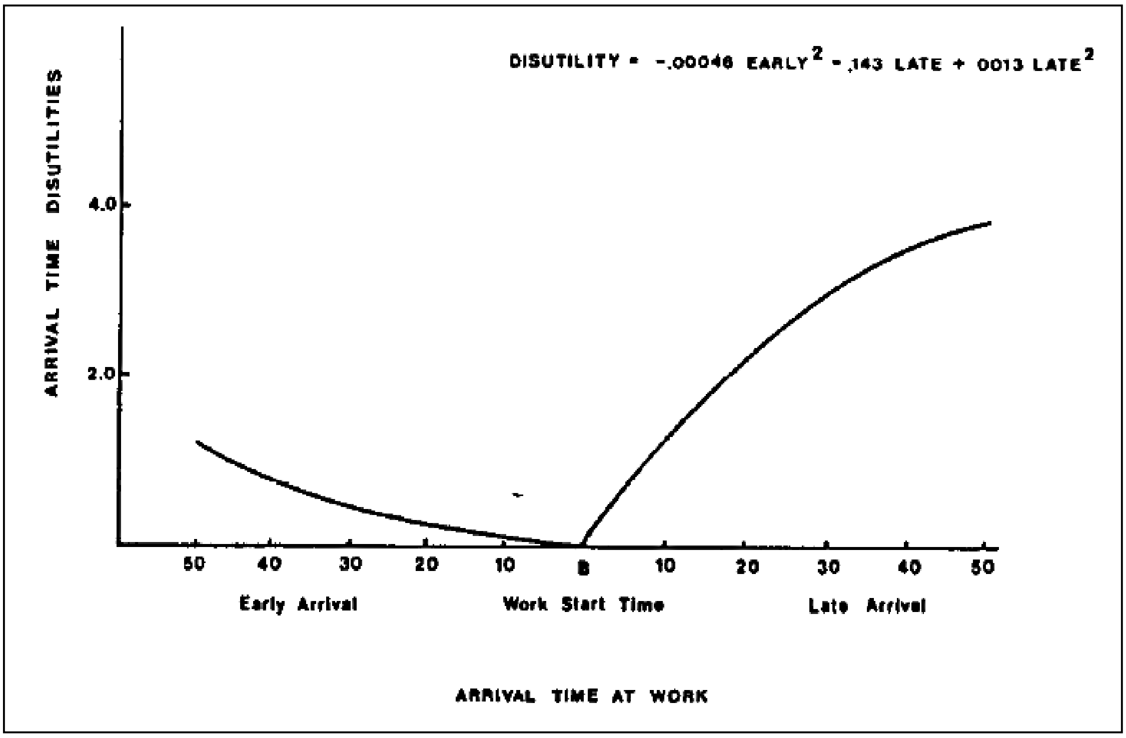

Figure 9. Dis-Utility Curve Based on Different Arrival Times

(Source: *Hendrickson, 1984*)

Another study to figure out the departure time patterns for daily commuters was carried out in Brussels, Belgium in the 1990s. *(De Palma et al, 1997)* explore the factors that have a significant influence on the departure time decisions taken by the daily commuters of the city. For this purpose, the authors conduct a detailed survey to collect the stated as well as reported behaviour data. Based on the collected data, the authors make a number of important conclusions in context of the departure time behavioural patterns of the daily commuters in Brussels region. These conclusions that will be discussed in the current section can lead to a better understanding of the psychology and mind-set of the workers who travel daily between two specific zones i.e. home zone and work zone location.

The authors identify that the accuracy of transportation network simulation models is highly dependent on the actual behavioural patterns and the incorporation of the realistic behavioural data is the most important step towards the creation of a precise and accurate simulation model. Therefore, they precisely define the aim of their study i.e. to obtain a real-world data regarding daily commuters' behaviour and preferential patterns, while establishing a particular focus on a medium sized city of Brussels that approximately had 1 million residents at the time the survey was conducted i.e. in 1996-97.

A considerable amount of respondents were identified to participate in the survey. The questionnaire was distributed at different work locations all over the city and eventually a sample of 1,218 commuters was obtained by the authors to proceed with their study. The respondents were asked to report their regular travel patterns along with personal and household attributes. They were also asked about the type of work timings they have i.e. whether they are on a flex-time working schedule or on a fix time schedule.

The questionnaire used by the authors consisted of two sections i.e. reported preference section and stated preference section. In reported preference section, the respondents were asked about the last time they actually made departure time changes and the consequent effects on the arrival times. While on the other hand, the questions that were posed to the respondents in the stated preference section were aimed at determining the willingness of people to change their departure times in order to shorten a certain length of travel time.

Basically, the authors' main purpose was to determine the trade-off values for travel time and schedule delay incurred for both morning and evening trips of the daily commuters. The authors, majorly influenced by *(Small, 1979)*, broadly split the generalized travel cost C(t) into two components i.e. travel time and schedule delay parameters as shown below in equation (15). The travel time depends upon different travelling factors such as free flow travel time, congestion delay time etc. while schedule delay costs vary according to the arrival time of the worker. The early and late schedule delay cost parameters are zero if the worker arrives within a tolerable time interval. As all the departure time studies including *(Small,1979)*, *(Hendrickson, 1984)* etc. affirm that the early and late schedule delay parameters nearly always vary from each other especially for morning commutes where late schedule delay is more onerous than both the early schedule delay and the travel time parameters. The ultimate goal of a traveller is to minimize this cost function, eventually maximizing its utility.

$$C(t) = \omega\,(\text{travel time} + \xi/\omega\ \text{early schedule delay} + \psi/\omega\ \text{late schedule delay}) \qquad (15)$$

Where:

ω= Unit Cost

Ψ= Late Schedule Delay Unit Cost

ξ= Early Schedule Delay Unit Cost

As discussed above as well, the main objective of the study was to determine the actual departure time changes made by the commuters as well as to know their willingness to change their departure times in order to save travel times. Therefore, authors conclude the results of the study in two parts i.e. the reported preference section and the stated preference section.

For morning commute i.e. from Home to Work location, the authors analyse the collected reported preference data and on the basis of that, they infer that the mean usual start time for workers in Brussels is 8:14 A.M with a flexible time interval of around 16 minutes in average. The flexible time interval is the grace time period during which the no fines or penalties are evoked on the workers.

The table (2) below illustrates the results of the reported preference data collected from the respondents. The respondents reported the last departure time change they made whether late or early with respect to their normal or preffered departure time. As shown in the table, the mean early home departure and the mean late departure for the sample is found out to be same for both cases i.e. approximately 17 minutes. It can be observed that the fix time workers have less changes in their departure time which depicts the time pressure in their schedule. Also it can be observed that the type of mode (auto or transit) and the type of work schedule (flex or fix-time work schedule) are the most influential factors behind a particular departure time decision.

	Early Home Departure (min)			Late Home Departure (min)			Early Work Arrival (min)			Late Work Arrival (min)		
	(N)	μ	σ	(N)	μ	σ	(N)	μ	σ	(N)	μ	σ
Flex-Auto	(141)	20.9	19.5	(153)	19.1	15.2	(135)	19.7	23.9	(152)	22.5	19.1
Fix-Auto	(141)	13.3	10.8 a	(144)	12.2	13.1 a	(137)	12.1	10.6 a	(144)	15.6	17.7 a
Flex-Transit	(107)	21.3	20.6	(111)	21.9	24.5	(97)	20.7	18.3	(114)	28.2	30.5
Fix-Transit	(87)	12.4	10.9 b	(81)	12.9	13.0 b	(84)	11.6	13.2 b	(81)	14.7	14.9 b
Sample	(476)	17.1	16.7	(489)	16.6	17.3	(453)	16.1	17.9	(491)	20.5	21.9

Notes:
a: Means for Flex-Auto and Fix-Auto significantly different at 95% significance level
b: Means for Flex-Transit and Fix-Transit significantly different at 95% significance level

Table 2. Departure Time Changes in Morning Commute: Reported Preference Data
(Source: *De Palma et al., 1997*)

Another interesting point worth mentioning here is that there were no significant travel time savings made as a result of departure time changes in the morning commutes. This indicates that in real life, the travel time-schedule delay trade-off may not be the governing factor behind the departure time changes. According to the the reported preference data collected by the authors, 25 percent of the respondents saved a certain amount of travel time by changing their departure times from home. The analysis of the collected data indicates that people who departed earlier as compared to the usual time managed to save 0.38 mintues of travel time on average while the commuters who decided to delay their departure managed to save a mean of 1.03 minutes of travel time.

Similarly, the authors also conclude the results of the conducted survey study for the evening travel i.e. from work location to home location by analyzing a number of factors that influence the evening departure decisions of the daily commuters. The analysis of different influencing factors reveals that the mean work departure time for different commuters in Brussels region is 4:48 p.m. Along with this, the study also states that the workers also have a grace time period of 14 minutes in average i.e. they can leave 14 minutes early from work without any penalty or fines being imposed on them.

The table (3) shows the statistical results obtained from the reported preference data. As the table clearly suggests that the flex-time commuters make more departure time changes as compared to the fixed-time commuters. The mean early work departure for the sample is found out to be approximately 27 minutes whereas the mean late work departure time is found out to be around 37 minutes. Consequently, the mean early home arrival is approximately 22 minutes while the mean value for the late home arrival for the reported preference study sample is found out to be around 40 minutes. However, similar to the morning commutes, it can be observed that the type of mode (auto or transit) and the type of work schedule (flex or fix-time work schedule) are the governing factors behind a particular departure time decision.

	Early Work Departure (min)			Late Work Departure (min)			Early Home Arrival (min)			Late Home Arrival (min)		
	(N)	μ	σ	(N)	μ	σ	(N)	μ	σ	(N)	μ	σ
Flex-Auto	(94)	33.5	32.6	(191)	44.1	42.6	(129)	21.7	28.2	(158)	42.7	46.9
Fix-Auto	(75)	24.6	36.3	(194)	30.9	29.6 a	(78)	20.4	33.8	(182)	28.9	26.5 a
Flex-Transit	(102)	29.8	22.1	(127)	41.4	47.3	(93)	29.4	25.1	(127)	48.6	50.8
Fix-Transit	(59)	14.6	21.3 b	(114)	29.8	34.2 b	(64)	15.8	22.0 b	(111)	35.8	35.2 b
Sample	(332)	26.8	29.5	(630)	36.8	38.9	(366)	22.3	28.0	(583)	38.2	40.8

Notes:
a: Means for Flex-Auto and Fix-Auto significantly different at 95% or higher probability
b: Means for Flex-Transit and Fix-Transit significantly different at 95% or higher probability

Table 3. Departure Time Changes in Evening Commute: Reported Preference Data
(Source: *De Palma et al., 1997*)

The analysis of the reported preference data reveals that people who decided to depart early from work managed to save 0.42 minutes of travel time while on the other hand, those who left late from work saved 0.92 minutes of travel time on average. This results in the conclusion that the trade-off between travel time savings and the schedule delay were not significantly different for the evening trips as compared to the morning trips.

As mentioned above as well, the survey conducted in Brussels also contained a section having stated preference questions. The respondents were asked how much are they willing to change their departure time whether early or late in order to save 10 minutes of travel time. The results of the stated preferences data obtained from the Brussel's commuters for morning trip reveal that 63 percent of the respondents were willing to make a trade-off between early schedule delay and travel time while 37 percent were not willing at all to shift their departure times to even a few minutes earlier in order to save 10 minutes of travel time. The sample data was used by the authors to state that people who were willing to leave earlier from home in order to save travel time were able to save 0.41 minute of travel time for every 1 minute of early schedule delay. Similarly for late schedule delay, the commuters managed to save 1.23 minutes of travel time for every 1 minute of late schedule delay. However, the late schedule delay is generally more difficult to adopt as compared to early schedule delay. Therefore, more people were ready to leave home earlier (63 percent) as compared to later (49 percent).

Similarly, for the evening work-home trip the stated preference data indicates that a signifciant number of respondents were not willing to leave later than usual from office. However, those who were willing to leave 30 minutes later from their work location were able to save 1 mnute of travel time. Also more transit users were willing to leave later than usual in order to save travel time. This reflects the effect of mode choice on departure time decision.

The trade-off values stated in the above paragraphs clearly indicate that there is no significant difference between early and late schedule delays for both the home and work departure times.

CHAPTER 3: Research Formulation

The traditional activity-based models consider the personal schedules or daily agenda of the individuals to be independent with no interaction within the social network. However, this assumption cannot be true in the context of joint carpool trips. Therefore, in order to model carpool mechanism efficiently, an interaction and negotiation methodology has to be incorporated. For this purpose, agent based models are employed that are state-of-the-art models simulating the effects and behaviour of different entities termed as agents (individuals, companies, governments etc. in the transportation scenario). The model can illustrate both the effects of the agents on the system as a whole or the interaction among different agents. This can be of particular interest especially in cases where each individual agent has its own interests and preferences. However, the construction of behaviourally accurate agent based models require an extensive and detailed database in order to simulate the actual mechanism. Many authors have attempted to formulate individual utility functions but due to lack of tangible data, none of them can be said to fully represent the real-life behavioural mechanism, as (Wooldridge, 2009) also suggests that utility functions are difficult to develop and tend to oversimplify the real-world processes.

After thorough literature review and going through various proposed transportation negotiation and cooperation models, it can be clearly concluded that the existing agent based negotiation outcome estimation models regarding the execution of joint social activities and trips lack in replicating or simulating the real-life human behavioural characteristics. This leads to the need of introducing an individual preference function for each agent regarding the selection of suitable trip departure time keeping in perspective the limitations and restrictions of the daily activities that have to be performed at fixed timings, referred to as constraining activities in the text. The proposed preference function based on a number of different types of factors is described in detail in the following section. However, first the detailed literature review is narrowed-down and the two most critical aspects involved in carpool trip negotiation, namely: (i) Departure time preferences and (ii) Constraining activities have been focused upon. These two aspects have not been dealt-with in the existing agent based models and there is a serious need to incorporate them into the existing models in order to make these models more realistic and close to human behavioural traits. A brief introduction along with the significance of the two objectives of the study, linking them with the literature review is mentioned in the following sub-sections:

3.1 <u>Departure Time Preferences:</u>

As discussed in detail in the literature review, the research carried out till date regarding simulation of carpool behaviours and activities through agent based models has heavy relied on assumptions and simplifications due to the lack of available data. This has resulted in a lot of basic level models with very simple negotiation mechanisms being employed in them. The previously proposed models have been too simplistic in their approach specifically regarding the selection of actual trip start times for a particular carpool group. Those models didn't represent the actual human behavioral preferences as they considered a uniform and maximum probability/preference i.e. 1 as a function of time for trip execution during the entire departure time interval. However, in reality this is not the case as each and every individual has its own personalized utility or preference function for each moment in time based on the individual behavioral habits and daily schedules. Therefore, in order to develop an accurate agent based model that simulates the close-to-reality carpool behavior and real life negotiation mechanism, a personalized trip departure preference function for each individual/agent has to be assigned.

3.2 Constraining Activities:

Schedule adaptation or a certain level of flexibility in the individuals' daily agenda is necessary in order to commute via a carpool. Rescheduling or schedule adaptation is vital for carpooling and is a part of the negotiation process. The schedule adaptation depends on the knowledge of travel times and departure times for a certain activity, which generally depend on the time of day and duration of the activity. The carpooling candidates reach an agreement after a rigorous negotiation procedure in which the individuals share their preferences and in the end accommodate for carpooling by making some adaptations to their daily agenda or schedules. However, the presence of certain fixed activities in the schedule that cannot be altered or delayed give rise to a huge limitation in making the negotiation and the execution of a carpooling activity successful.

The biggest hindering factor in the execution of carpool trips as discussed in the previous chapters as well is the lack of flexibility in people's daily schedule and tightness of the time intervals between certain fixed activities. The rigidity in the available time windows of commuters termed as time pressure can be due to a number of fixed and rigid daily activities termed as constraining activities with a short gap between them. The common examples of such phenomena are the fixed activities scheduled immediately before work such as a pick/drop activity (e.g. children to school) in the morning and after work such as shopping or other social commitments in the evening. Such activities limit the available departure time window for the individuals, consequently decreasing the chances of successful negotiation drastically. The probability to carpool decreases with the increase in cut-off time for the individual due to the presence of fixed constraining activities in the daily agenda. In this case, that particular individual has a very brief time window available to negotiate with carpooling candidates. Hence, the chances for a person to accommodate a carpooling activity into his schedule are very slim. The agent based negotiation models have to consider the time pressure and constraining activities factor in order to simulate the real life environment. For this purpose, a method has been proposed and integrated into the existing agent based carpool negotiation outcome estimation model as discussed deeply in the following chapters.

CHAPTER 4: Time Preference Function

Based on the Hendrickson's approach (discussed in detail in the literature review), a methodology to introduce a specified and personalized preference function for each agent in an agent based model, has been proposed. The proposed model is used for simulating the interactions of autonomous agents with their agenda in a more realistic manner. As it is well-known that the schedule adaptation depends on the preferences among feasible schedules of the individuals and it generally depends on both the time of day and on the duration of the participation. Therefore, our model aims to extend the previous models by incorporating a more realistic departure time preference function for each agent.

For the purpose of making the agent based simulation of carpooling activity more real and behaviorally accurate, an equation or a utility function as shown below has been extracted from Hendrickson's multinomial logit departure time choice model for work trips. As explained in the literature review as well, 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.

As people do not have a constant preference for departure as a function of time during their entire feasible time interval due to many factors such as time pressure, the following equations help to determine the actual probability of a particular agent to depart at a specific time in its available time window. The equation (16) is used to determine the actual utility or satisfaction value of a particular agent to depart at a specific time in its available time window. The coefficients are taken from Hendrickson's study for the specific mode (shared transport). 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 time T. The utility or preference $V_{a_i t_j}$ is specified to be;

$$\boldsymbol{V_{a_i t_j} = -2.09 - 0.008(FFTT_{a_i}) - 0.021\left(CONG_{t_j}\right) - 0.699\left(\frac{COST}{INCOME}\right)_{a_i t_j} - 0.095\left(ACC_{a_i t_j}\right) - 0.088\left(WAIT_{a_i t_j}\right) - 0.148\left(LATE_{a_i t_j}\right) + 0.0014\left(LATE_{a_i t_j}\right)^2 - 0.01\left(EARLY_{a_i t_j}\right) - 0.00042\left(EARLY_{a_i t_j}\right)^2} \quad (16)$$

Where:

Coefficients Of Equation (16) Taken from Departure Time MNL (Hendrickson, 1984)

- $\boldsymbol{V_{a_i t_j}}$ = Utility/ Preference function for an agent for a particular time in time window
- $\boldsymbol{P_{a_i t_j}}$ = Probability to select a specific departure time;
- $\boldsymbol{FFTT_{a_i}}$ = Free flow Travel Time in carpool vehicle (minutes);

- $\boldsymbol{CONG}_{t_j}$= Portion of travel time associated with congestion (minutes);
- $\left(\frac{\boldsymbol{COST}}{\boldsymbol{INCOME}}\right)_{a_i t_j}$= Ratio of annual cost of carpooling to income level per annum;
- $\boldsymbol{WAIT}_{a_i t_j}$= Waiting time with respect to individual's most preferred time to depart
- $\boldsymbol{ACC}_{a_i t_j}$ = Access time (for carpool driver e.g. time to walk from parking to destination);
- $\boldsymbol{LATE}_{a_i t_j}$ = Minutes of late arrival at work associated with the departure time *t*;
- $\boldsymbol{EARLY}_{a_i t_j}$ = Minutes of early arrival at work associated with the departure time *t*.

Several factors affect the preference function for the trip departure time of an agent. The equation(i) proposed above in order to define the preference function for each agent's departure time can be broadly classified into three different types of factors namely; (i) Travelling factors, (ii) Socio-Economic characteristics (SEC) and (iii) Time pressure factors. The travelling factors involved during the actual carpool trip execution are; (i) free flow travel time, (ii) expected congestion, (iii) waiting time and (iv) access time. The socio-economic factors (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. While the time pressure factors include 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. Following is a detailed description of the factors involved in the proposed preference function along with some examples:

i) <u>Traveling factors:</u> This includes the factors involved during the actual carpool trip execution such as free flow travel time, congestion time, waiting time and access time. Free flow vehicle travel time is the actual amount of time spent by a carpool group in the vehicle to travel towards the destination without any congestion or interruptions such as time wasted in picking or dropping someone. While congestion time is the amount of time spent in congested traffic conditions. Access time in the context of carpooling is the amount of time that a carpool driver has to reserve for walking from the parking to the destination whereas waiting time is the amount of time in minutes that an individual has to tolerate with respect to the most preferred departure time in order to accommodate for the carpool trip e.g. a person who initially wants to depart at 07:45 but in order to accommodate for carpooling, the mutual departure time for the group is decided to be 07:50, then that person would have a waiting time of 5 minutes.

ii) <u>Socio-economic factors:</u> The equation also contains a socio-economic factor i.e. the ratio of travelling cost to annual income. This factor helps to quantify the concept of value of time for departing at a particular time in the given time interval. A person having low income would show a higher flexibility in the selection of departure times, hence increasing the probability to carpool. On the other hand, a person having a higher income level would have a relatively less probability to participate in a carpool group in order to reach to his destination and his schedule and departure time would also be more rigid.

iii) <u>Time pressure factors:</u> The individual tolerance level for arriving late or early for a specific activity is termed as the time pressure factors. This indicates the level of rigidity in the starting times of different activities and also the time window available in between two specific fixed activities e.g. a certain fixed pick and drop activity in the morning before going for work activity limits and squeezes the time window available between the two activities. This shrinks the chances for a person to accommodate for a carpooling activity as the schedule becomes quite stiff. Apart from it, the nature of work timings also contributes towards the time pressure. If a person has fixed work timings, the time pressure is significant as he cannot afford to arrive late at work as it would incur deductions from salary or other consequences. Therefore, these factors are quite critical while defining the personal preference functions for different individuals.

The departure time choices are treated as a simultaneous interactive decision based upon maximization of individual traveller's utility or satisfaction with each departure time combination. The probability of an individual a_i selecting departure time alternative t_j of the carpool is as given in equation (17);

$$P_{a_i t_j} = \frac{\exp(V_{a_i t_j})}{\sum_{\mathrm{T}} \exp(V_{a_i \mathrm{T}})} \qquad (17)$$

As discussed above as well, the Hendrickson's base model includes seven different departure time intervals of 10 minute each. This results in discrete preference values for different departure times. However, to make the curve continuous, departure time intervals of one minute instead of 10 minute have been used in the simulation as will be discussed in detail in the following chapters. The results have been used to construct the continuous preference function shown in figure (10) and figure (11). This is done because, for the simulation, we need to calculate the individual preference value for each possible trip start time in the candidate specific time window (e.g. the time window $\pm\Delta t$ =30 minutes).

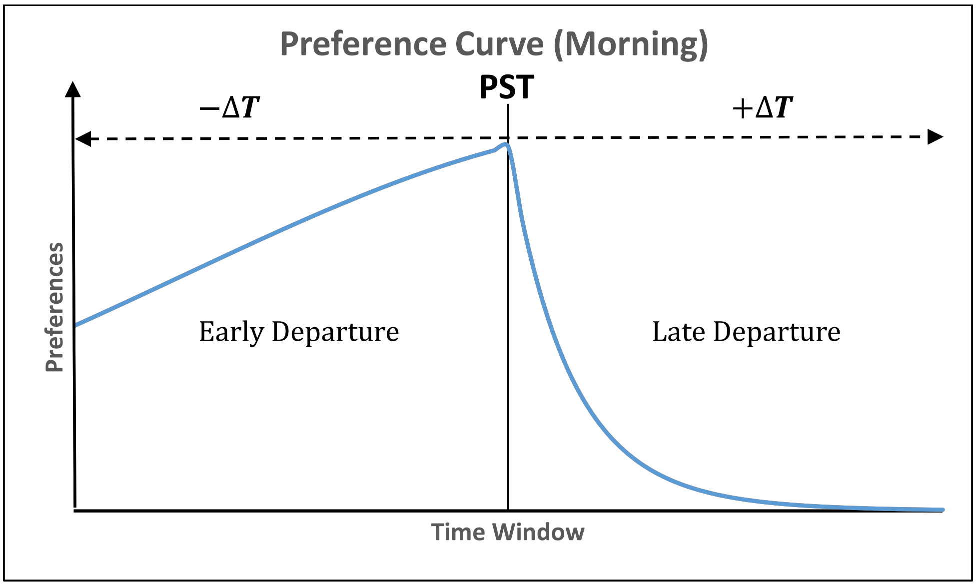

Figure 10. Continuous Preference Curve for Morning (HW) Trip

Similarly for the evening (*WH*) trip; the same function and the probabilities for the departure time alternatives as for the morning (HW) commute have been used, but mirrored in time to adjust for the evening trip behavioural characteristics as shown in the figure (11) below:

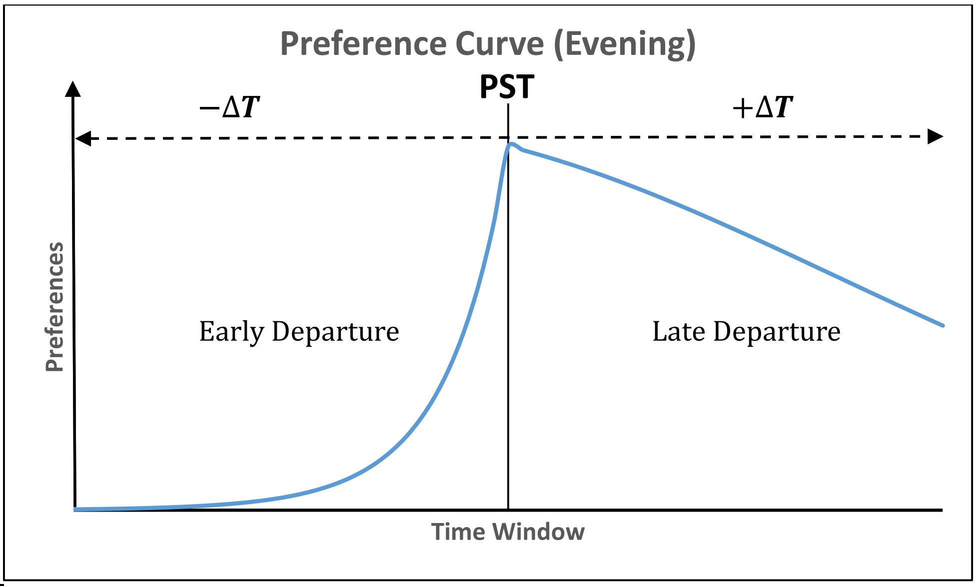

Figure 11. Continuous Preference Curve for Evening (WH) Trip

CHAPTER 5: Proposed Negotiation Mechanism

5.1 Conceptual Description:

The equations (16) and (17) based on the factors discussed above, at the end yield a positive number between 0 and 1 indicating the probability or preference of an individual to depart at a specific time in their available time window. The proposed preference function can be employed to make the existing agent based carpool negotiation model more accurate and realistic in nature. Each agent in the simulation is assigned an individual preference function that is based on a number of different types of factors that vary according to the personal and socio-demographic characteristics of an individual. After defining the preference functions, a suitable method to estimate the outcome of the negotiation process is proposed.

The proposed method suggests the most suitable time for the carpool trip departure keeping in consideration the driver characteristics, vehicle characteristics and the constraining activities that induce time pressure factor on the individuals. The proposed negotiation outcome estimation mechanism initially checks for the overlapping or intersecting time intervals from the preferred time intervals of the interested individuals. This is used to determine the fate of the negotiation process and eventually to find out the suitable and acceptable departure time to execute the carpool trip. Apart from the selection of trip departure time, the driver for the carpool trip is also selected by extracting driving license and vehicle ownership data from FEATHERS which is an activity-based model developed for Flanders region by IMOB.

The figure (12) below illustrates the proposed negotiation mechanism in a simple block diagram and helps in better understanding of the methodology. The diagram represents the architecture of an agent that is comprised of the personal preferences for the maximization of the utility along with the interaction or negotiation protocol that an agent goes through in order to effectively respond to the collaboration proposal. The personal preferences as discuss above are based upon multiple factors including departure time characteristics i.e. travelling, socio-economic and time pressure factors. This also includes the vehicle and license ownership characteristics that play an important role in deciding the fate of the negotiation process. The personal preferences block is used as a base for the negotiation or interaction block. When an agent receives an invitation from another agent, the negotiation process begins. First of all the respective preferred departure times are matched. If there is no overlap present between the individual preferred departure time intervals, the agent turns down the invitation. However, if there is an overlapping time period present in the respective preferred departure time periods of the agents, the probability to carpool is calculated and checked against the pre-defined threshold negotiation success criteria (probability of success). If the probability to carpool at the intersected time period comes out to be greater than the threshold point, then a specific trip departure time is determined as explained in the following sub-section with the help of a series of equations.

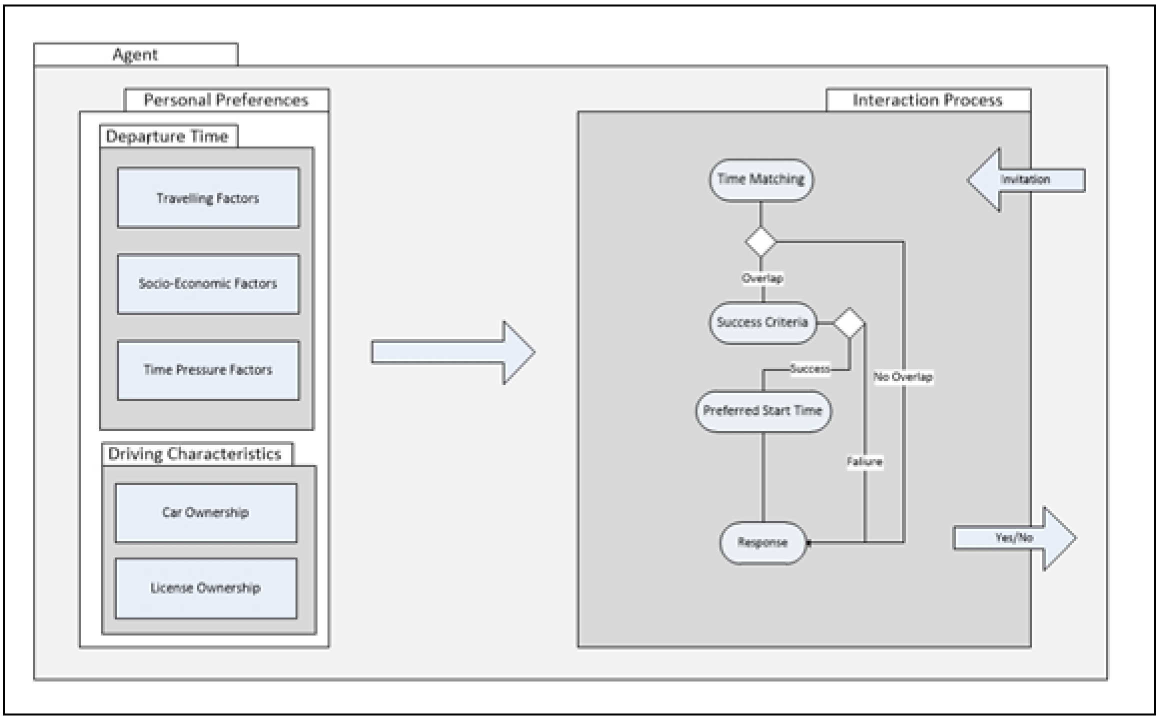

Figure 12. Architecture of an Agent and the Negotiation Outcome Estimation Mechanism

5.2 Equations for Proposed Negotiation Mechanism:

The proposed negotiation mechanism as explained above with the help of figure (12) is employed after the assignment of an individual preference function based on the factors elaborated above for each agent in order to determine the carpool trip departure time. This section contains a detailed step by step description of the proposed negotiation mechanism in the form of equations. However, first of all, the terminologies that have been used in the negotiation mechanism are summarised in the table (4) below as:

a_i	An agent or Individual, $a_i \in N$
TW	Time Window
$TW_{HWLower,a_i}$	Lower Bound of Time Window of Agent a_i for Home-Work Trip
$TW_{HWUpper,a_i}$	Upper Bound of Time Window of Agent a_i for Home-Work Trip
$TW_{WHLower,a_i}$	Lower Bound of Time Window of Agent a_i for Work-Home Trip
$TW_{WHUpper,a_i}$	Upper Bound of Time Window of Agent a_i for Work-Home Trip
PST_{HWTrip,a_i}	Preferred Trip Start Time of agent a_i for Home-Work Trip
PST_{WHTrip,a_i}	Preferred Trip Start Time of agent a_i for Work-Home Trip
$AST_{Constraining,a_i}$	Constraining Activity Start Time

$AFT_{Constraining,a_i}$	Constraining Activity Finish Time
$\pm\Delta T$	Symmetric Time Deviation w.r.t PST (For Non-Constraining Case)
$\pm\,\overline{\Delta T}$	Time deviation w.r.t PST (For Constraining Activities Case)
$\Delta T_{HW,Intersection}$	Length of Intersecting Time Interval For Home-Work Trip
$\Delta T_{WH,Intersection}$	Length of Intersecting Time Interval For Work-Home Trip
$TW_{L,carpool}$	Lower Bound of Time Window Available for Carpool
$TW_{U,carpool}$	Upper Bound of Time Window Available for Carpool
$P_{carpool}$	Probability to Carpool
$probOfSuccess$	Probability of Negotiation to Succeed (Threshold Value)
$V\ _{a_i t_j}$	Preference of an agent a_i for a given time of departure t_j
$P_{a_i t_j}$	Probability of an agent a_i to depart at a certain time t_j
$V_{carpool,t_j}$	Combined Preference for All Carpoolers for a given time of departure t_j
$TST_{carpool}$	Carpool Trip Start Time

Table 4. Terminologies Used In Proposed Negotiation Outcome Prediction Mechanism

In the simplest case i.e. Case I, the individual has a time window $\pm\Delta T$ w.r.t. the preferred trip start time. This implies that the agent has no constraining or restricting activities present in his daily schedule. However in general, this is not necessarily true since preceding or succeeding activities can induce timing constraints and can affect the available time windows for the departure as discussed in Case II.

<u>For Morning Home-Work Trip:</u>

Case I: Schedule with No Constraining Activities

The possible lower and upper bounds of the departure time window for the trip of an agent a_i are given by the equation (18a):

$$\begin{aligned} TW_{HWLower,a_i} &= PST_{HWTrip,a_i} - \Delta T \\ TW_{HWUpper,a_i} &= PST_{HWTrip,a_i} + \Delta T \end{aligned} \qquad (18a)$$

Case II: Schedule with Constraining Activities

The equation (18b) helps to determine the lower and upper limits of the departure time window for the trip of an agent a_i who has certain fixed constraining activities present in his schedule before the morning home-work commute.

$$\overline{\Delta T} = PST_{HWTrip,a_i} - AFT_{Constraining,a_i}$$

$$\begin{aligned} TW_{HWLower,a_i} &= PST_{Trip,a_i} - \overline{\Delta T} \\ TW_{HWUpper,a_i} &= PST_{Trip,a_i} + \Delta T \end{aligned} \qquad (18b)$$

<u>For Evening Work-Home Trip</u>:

Case I: Schedule with No Constraining Activities

Similarly, for evening work-home commute, the possible lower and upper bounds for the trip of a_i are given as:

$$\begin{aligned} TW_{WHLower,a_i} &= PST_{WHTrip,a_i} - \Delta T \\ TW_{WHUpper,a_i} &= PST_{WHTrip,a_i} + \Delta T \end{aligned} \qquad (19a)$$

Case II: Schedule with Constraining Activities

When there are some constraining activities scheduled just after work, then the time window especially the upper bound for an agent a_i has to be re-adjusted as in equation (19b):

$$\overline{\Delta T} = AST_{Constraining,a_i} - PST_{WHTrip,a_i}$$

$$\begin{aligned} TW_{WHLower,a_i} &= PST_{WHTrip,a_i} - \Delta T \\ TW_{WHUpper,a_i} &= PST_{WHTrip,a_i} + \overline{\Delta T} \end{aligned} \qquad (19b)$$

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 trip of the carpool for both the morning home-work as well as evening work-home trips; the indices used for the *max()* function range over the set of candidate participants.

$$\begin{aligned} TW_{HWLower,carpool} &= \max_{j=1\ldots N} (TW_{HWLower,j}) \\ TW_{HWUpper,carpool} &= \min_{j=1\ldots N} (TW_{HWUpper,j}) \end{aligned} \qquad (20a)$$

$$\begin{aligned} TW_{WHLower,carpool} &= \max_{j=1\ldots N} (TW_{WHLower,j}) \\ TW_{WHUpper,carpool} &= \min_{j=1\ldots N} (TW_{WHUpper,j}) \end{aligned} \qquad (20b)$$

The length of the intersecting time intervals can be determined as follows:

$$\Delta T_{HW,Intersection} = \min_{j=1\ldots N}\left(TW_{HWUpper,j}\right) - \max_{j=1\ldots N}(TW_{HWLower,j})$$
$$\Delta T_{WH,Intersection} = \min_{j=1\ldots N}\left(TW_{WHUpper,j}\right) - \max_{j=1\ldots N}(TW_{WHLower,j}) \quad (21)$$

The product of the sum of the probabilities of the departure time alternatives of the carpool participants for the intersection time intervals is used as an indicator to determine the chances of successful negotiation among different agents;

$$P_{carpool} = \prod_{i=0}^{n} \sum_{j=TW_{L,carpool}}^{TW_{U,carpool}} \left(P_{a_i t_j}\right) \quad (22)$$

The negotiation succeeds if and only if;

$$P_{carpool} > probOfSuccess \quad (23)$$

The probability of success is the threshold probability value that is used to determine the fate of the negotiation process. This value highly affects the number of successful carpool trip executions as will be discussed in detail in the results' chapter.

Now, for every agent, the preference for a given time of departure is assumed to be proportional to the probability that the person will select that time.

$$V_{a_i t_j} = k(P_{a_i t_j}) \quad (24)$$

Where k is an arbitrary proportionality constant.

The combined preference for all carpoolers is assumed to be the product of the preference values as:

$$V_{carpool,t_j} = \prod_{i \in carpool} k(V_{a_i t_j}) \quad (25)$$

Where K is

The effective trip start time $TST_{carpool}$ of the carpool is given by;

$$TST_{carpool} = \underset{j=TW_{L,carpool\ to\ TW_{U,carpool}}}{\arg\max} (V_{carpool,t_j}) \quad (26)$$

The same mechanism is followed for morning (HW) trips as well as for the evening (*WH*) trips; for evening trips, the probabilities of the departure time alternatives of the morning trip (*HW*) are used but mirrored in time as indicated in the graphs in the figures (10) and (11) in the previous chapter.

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

$$\prod_{i=0}^{n} \sum_{j=TW_{HWLower,carpool}}^{TW_{HWUpper,carpool}} (P_{a_i t_j}) \quad \text{AND} \quad \prod_{i=0}^{n} \sum_{j=TW_{WHLower,carpool}}^{TW_{WHUpper,carpool}} (P_{a_i t_j}) > probOfSuccess \qquad (27)$$

The effective trip start times of the carpooling trips (*HW* and *WH*) are given by the equation (28);

$$\underset{j=TW_{HWL,carpool\ to\ TW_{HWU,carpool}}}{\arg\max} (V_{carpool,t_j}) \quad \text{AND} \quad \underset{j=TW_{WHL,carpool\ to\ TW_{WHU,carpool}}}{\arg\max} (V_{carpool,t_j}) \qquad (28)$$

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

The following figure (13) illustrates the proposed negotiation mechanism between two individuals for the selection of most preferred trip start time with no constraining activities (Case I) for both the morning (HW) as well as evening (WH) trips. The figure shows the individual preference curves and using the individual trip start time preference data, it indicates the most suitable time intervals as black-dotted hatched area for the execution of a carpool trip.

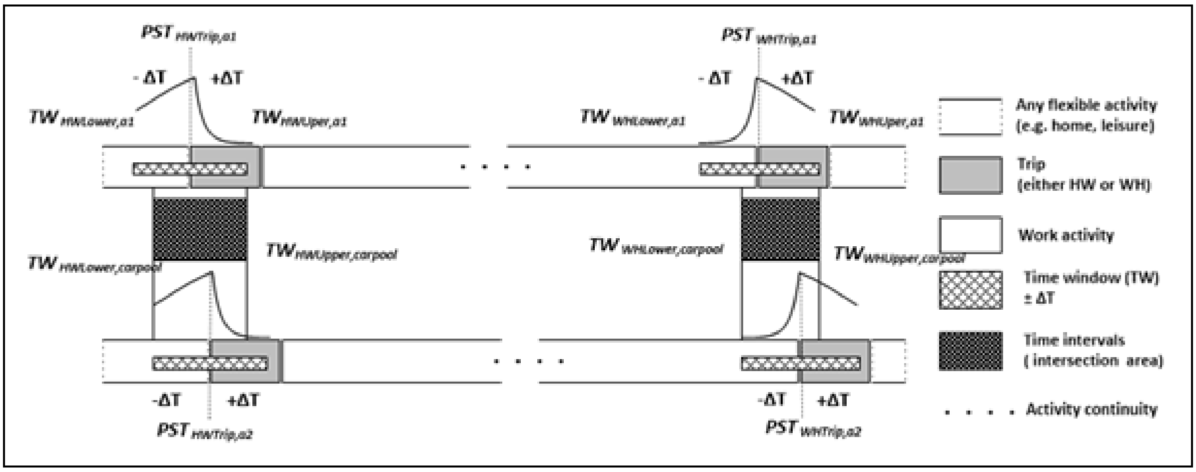

Figure 13. Negotiation on Trip (*HW* and *WH*) Departure Times between Two Agents without Constraining Activities

Similarly, the following figure (14) shows the proposed negotiation mechanism in case of constraining activities present in the schedule of the participants for morning as well as for evening commuter trips. It is clearly evident that the fixed constraining activities restrict the available departure time window for the individual, hence decreasing the overall intersecting time interval and consequently reducing the chances of successful negotiation.

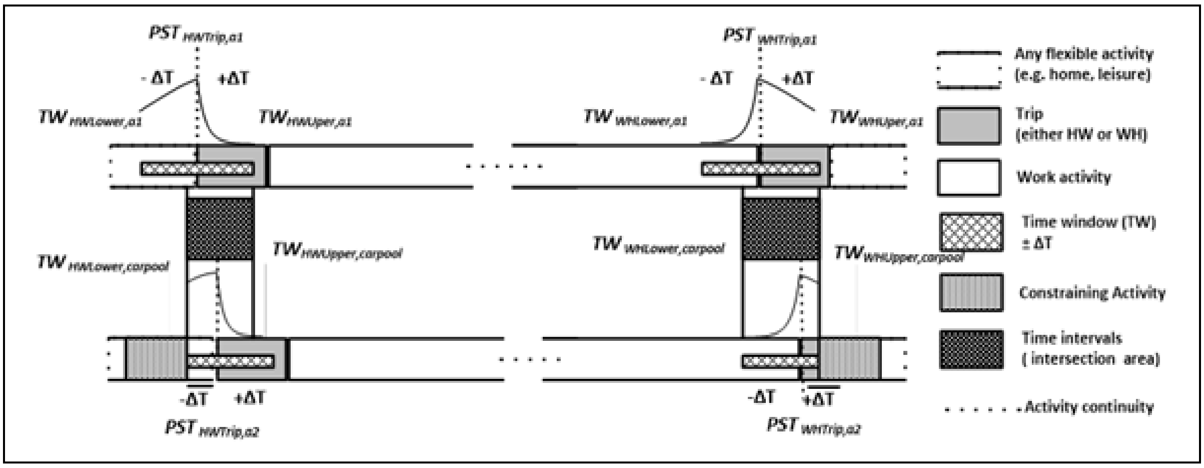

Figure 14. Negotiation on Trip (*HW* and *WH*) Departure Times between Two Agents with Constraining Activities

The proposed mechanism integrated into the agent based carpool model has been discussed conceptually in detail in the following chapters along with the detailed simulation and experimental results.

CHAPTER 6: Analysis & Simulation

The behaviorally sound negotiation outcome prediction method based on the personalized preference functions for each agent in a carpool agent- based model as proposed in the above chapters, had to be initially analyzed and tested and then demonstrated in the form of graphical outputs in order to verify its validity and soundness. For this purpose, the proposed methodology was tested with the available real FEATHERS data collected in Flanders, Belgium. FEATHERS is an activity based travel demand model developed by IMOB-Hasselt University Belgium and is currently operational for the region of Flanders, Belgium.

The output of FEATHERS i.e. the daily agenda or schedule for different individuals, filtered to refine the data relevant only for carpooling scenario was used to analyze the soundness of the proposed negotiation methodology regarding trip departure times. The initial or preliminary analysis of the proposed negotiation methodology during the initial part of the Master Thesis was executed manually in Microsoft Excel. However, during the Part 2 of the Master Thesis, the proposed preference function and the negotiation mechanism was simulated in Java Environment (with the help of the Master Thesis Supervisor) in order to verify the logical and technical aspects of the proposed methodology.

The analysis process has been discussed in detail with the help of examples in the current chapter. Separate cases have been discussed for schedules with and without the presence of constraining activities. After the preliminary analysis in Microsoft Excel, the simulation or implementation of the proposed preference function and the negotiation mechanism in Java environment has been discussed. The proposed methodology was coded in Java with the help of thesis supervisor and integrated into the already existing agent-based carpool model (as explained in detail in the following chapter) developed at IMOB-Hasselt University, Belgium.

6.1 Preliminary Analysis:

The preliminary analysis of the proposed negotiation methodology was conducted in Microsoft Excel in order to determine the soundness of the mechanism. For this purpose, a filtered output of FEATHERS data was used as a base.

The individuals having similar home and work locations along with similar work start times were randomly selected from the Feathers filtered output data. This was done only to check the validity of the suggested mechanism. The following figure highlights the feathers data of the two matching individuals who were selected as a sample to determine the results:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	houseHoldId	personId	homeLocId	tHW_workLocId	tHW_predAct	tHW_predActDur	tHW_startTime	tHW_tripDur	tHW_mode	tWH_workLocId	tWH_succAct	tWH_succAc	tWH_startTime	tWH_tripDur	tWH_mode
514	166752	262257	149	1	0	244	650	31	4	1	0	664	925	31	4
515	166996	262714	152	1	0	553	379	22	4	1	0	100	954	22	4
516	167130	262953	152	1	0	525	442	10	1	1	0	635	977	8	1
517	167302	263268	153	1	0	722	556	6	1	1	0	330	1284	6	1
518	167333	263327	152	1	0	494	463	10	1	1	0	645	967	8	1
519	167439	263523	153	1	0	170	622	6	1	557	0	67	985	23	1
520	167565	263750	152	1	0	534	449	10	1	1	0	619	993	8	1
521	167574	263768	152	1	0	582	514	5	1	1	0	514	1101	5	1
522	167712	264020	153	1	0	674	369	7	1	1	7	260	1050	6	1
523	167824	264222	153	1	0	263	425	6	1	1	0	18	694	6	1
524	168013	264563	153	1	0	498	715	6	1	1	0	395	1219	6	1
525	168019	264575	153	1	0	9	467	15	3	1	1	522	491	15	3
526	168749	265798	155	1	0	17	478	23	4	575	0	520	975	125	4
527	169481	267067	154	1	0	541	455	16	3	1	0	15	1012	16	3
528	169504	267105	154	1	0	545	502	6	1	1	0	13	1053	6	1
529	169680	267417	155	1	0	614	520	7	1	1	0	472	1141	7	1

Table 5. Processed FEATHERS Output Data

Case I: No Constraining Activities

The simplest case with presence of no constraining activities in the daily schedule of the individuals involved in the negotiation process, is discussed first. In this case, the participants have a time window ($\pm \Delta T$) of predefined duration available on either side of the most preferred departure time for both the morning as well as evening commuter trips.

The table (6) below represents and explains the attributes from the FEATHERS data considered to scrutinize the two individuals that have a likely chance to co-travel for their work activities as a carpool group. As it is clearly evident that the two shortlisted candidates travel from zone 152 to zone 1 in their private cars for their work activities in a similar time period and same is the case for their return trip. The table (7) above shows the preference values of individuals (A) and (B) for the morning HW trip. The preference values have been calculated on the basis of the proposed preference equation with 7 different departure time options of 10 minutes interval each, derived partly from *(Hendrikson,1984)* as explained in detail in the previous chapters.

Person ID	Home Location (Zone #)	Work Location (Zone #)	HW Trip Start Location	HW Trip Start Time	HW Trip Duration	HW Mode	WH Destination	WH Trip Start Time	WH Trip Duration	WH Mode
262953 (A)	152	1	Home	08:45	10	Car	Home	16:17	8	Car
263750 (B)	152	1	Home	08:54	10	Car	Home	16:33	8	Car

Table 6. Work Trip Details for Person (A) and (B)

The table (7) above shows the preference values of individuals (A) and (B) for the morning HW trip. The preference values have been calculated on the basis of the proposed preference equation with 7 different departure time options of 10 minutes interval each, derived partly from *(Hendrikson,1984)* as explained in detail in the previous chapters.

	Individual A		Individual B	
	Departure Time	Preferences	Departure Time	Preferences
Early	08:15	0.1896045	08:24	0.1898733
Early	08:25	0.2339109	08:34	0.2342425
Early	08:35	0.265321	08:44	0.2656971
Most Preferred	08:45	0.2767018	08:54	0.277094
Late	08:55	0.0294287	09:04	0.02826
Late	09:05	0.004229	09:14	0.0040611
Late	09:15	0.0008041	09:24	0.0007722
Sum		1		1

Table 7. Time Window Data for Person (A) and (B)

A series of graphs below show the graphical form of the utility or preference function proposed in the previous chapters. Figure(15) below shows different preferences of individual A to depart to his work location at a specific time in his preferred time window. The most prefered time (maximum probability) in the departure time window denoted as 0 in the graph is the arrival at the work location at the exact time with no late or early arrival. While the negative time values show the number of minutes, an indiviual is prepared to leave earlier than his preferred time and would eventually reach earlier at his destination. Similarly, the values on the right side of 0 indicate the number of minutes and the corresponding probabilities if the individual leaves late for his work.

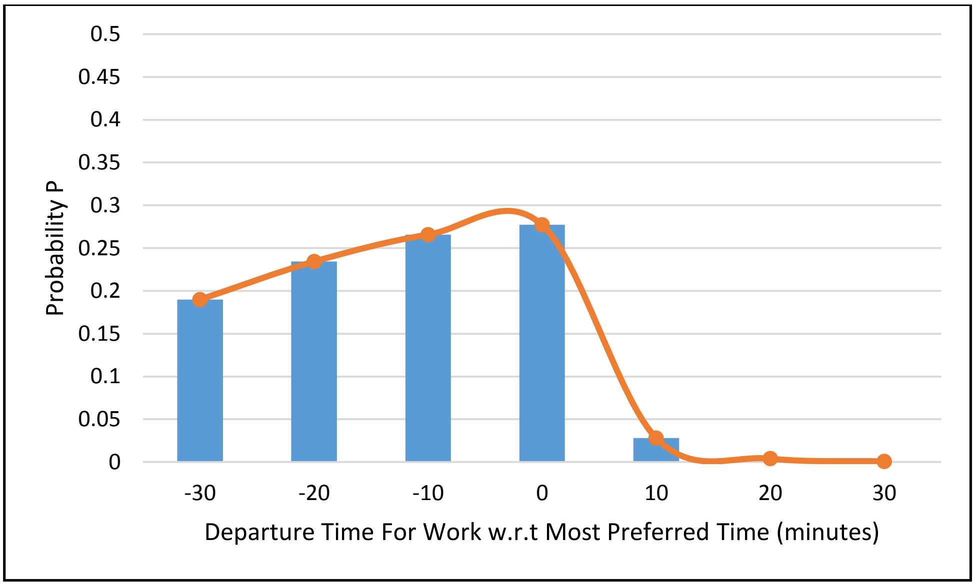

Figure 15. Preference Function for Person (A)'s Trip Departure Times

It is clear from the graph above that an individual A is prepared to leave earlier for his work but in no case, he wants to arrive late at his work location. This shows the preference of the individual that he cannot afford to be late to his work as it would implicate negative consequences for him. The pie chart in the figure (16) below shows the probabilities of the individual A of departing early, on-time and late for his work and it is quite evident that he would almost never want to reach late to his work, in that sense he has a pretty rigid stance and would never compromise on it. This introduces the concept of time pressure into his schedule. Interestingly, this behaviour is consistent not only for fixed-time users but also for flex-time users as they tend to settle down into their habitual fixed routine.

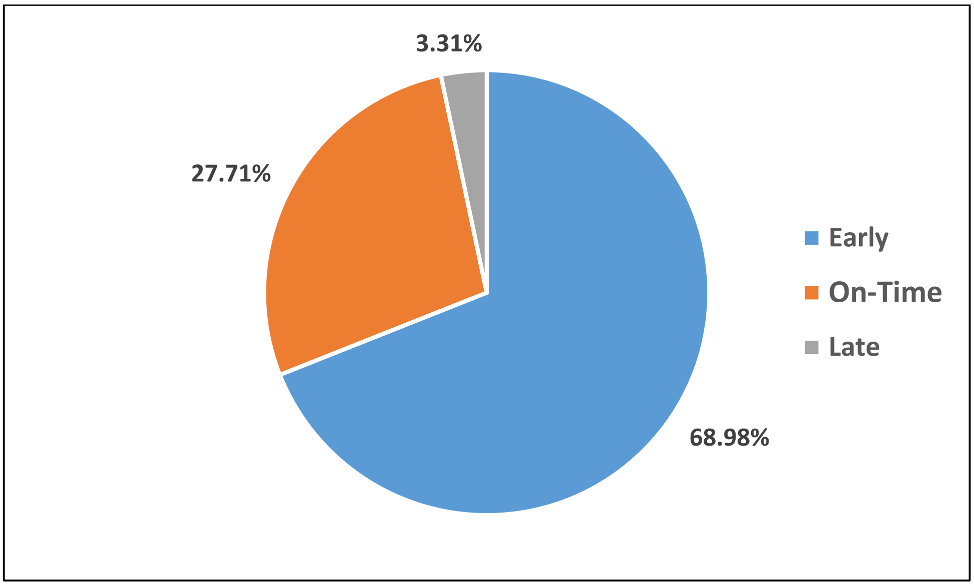

Figure 16. Person A's Probabilities of Departing Early, On-Time and Late

Similarly, the other individual i.e. the individual B who also travels from zone 152 to zone 1 for work purposes has the most preferred departure time at 08:54 as compared to 08:45 for individual A. The following graph in figure (17) shows the probabilities calculated from the proposed preference function for the available time window with 0 as the most preferred departure time taken as reference.

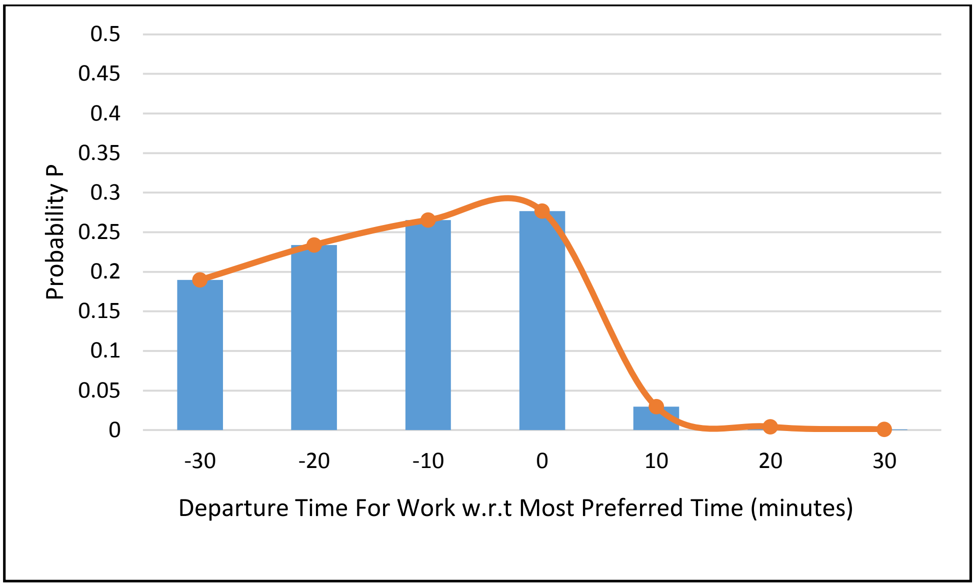

Figure 17. Preference Function for Person (B)'s Trip Departure Times

The pie chart in the figure (18) below shows the acceptance level of departing early, being on-time or being late for work as a percentage of the probabilities calculated above from the proposes preference equation. This indicates that individual B also like individual A cannot afford to be late in departing for his work activity.

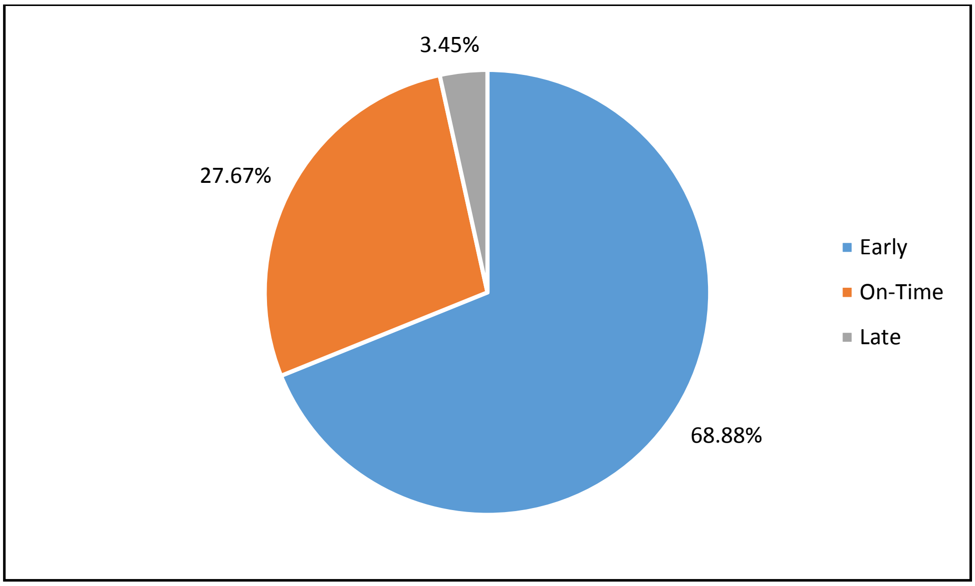

Figure 18. Person B's Probabilities of Departing Early, On-Time and Late

After determining the individual preferences for particular trip departure times for the two individuals A and B under consideration, the next step was to combine the two individual preference functions according to the negotiation mechanism explained in the previous chapter.

According to the negotiation equations presented above, the first step is to determine the overlapping time interval from the individuals' preferences in absolute times. In case of the example being discussed, the available time window for the execution of a carpool trip comes out to be from 08:24 to 09:15. Now, as per proposed equation (23), the negotiation between concerned individuals only succeeds when the probability to carpool is greater than the predefined threshold i.e. probability of success. This success criteria depends on the length of the intersected time interval and is determined by multiplying the sum of the probabilities of the carpool candidates' to depart at specific times in the available time window. For our example, the individual A's sum of probabilities (in case the person would drive alone) comes out to be 0.81 whereas for individual B, the value is 0.99. The product of the two values i.e. 0.81 comes out to be greater than the predefined threshold value of 0.5, so the negotiation is termed as successful.

After the determination of the feasibility of the negotiation process for the execution of the carpooling activity, the next step is to find out the most preferred trip start time. For this purpose, the probabilities of the individuals during the combined available time window are multiplied one-on-one and the time with maximum product value is then selected as the most preferred carpool trip departure time. Therefore, for the example under consideration, the most preferred trip departure time is determined to be around 08:45.

The table below summarises the example of the negotiation mechanism explained above. The cells highlighted in green show the intersected time interval of the individuals while the orange cells show the proposed negotiation outcome method followed by the final result in the yellow coloured cells.

Individual A		Individual B		
Departure Time	Preferences	Departure Time	Preferences	Product of Intersecting Preferences
08:15	0.1896045			
08:25	0.2339109	08:24	0.1898733	0.081869
08:35	0.265321	08:34	0.2342425	0.094705
08:45	0.2767018	**08:44**	0.2656971	**0.100689 Max Product**
08:55	0.0294287	08:54	0.277094	0.010913
09:05	0.004229	09:04	0.02826	0.001598
09:15	0.0008041	09:14	0.0040611	0.000309
		09:24	0.0007722	
Sum of Intersection	**0.81**		**0.99**	
Product of Sum	**0.81 x 0.99 = 0.8019**			
Threshold Probability	**0.5**			
Result	**Success (As 0.8019>0.5)** **Trip Start Time: 08:45 (Max Product)**			

Table 8. Analysis of the Proposed Mechanism for Person (A) and (B)

The method to determine the optimal time for their trip departure is illustrated graphically as in figure (19). The product of the two individual preference functions is calculated and is shown as a grey line in the graph below. This results in a curve indicating the combined preferences to depart at particular times to execute a trip as a carpool group. The hatched area shows the probable combined time window for the trip departure while the black dotted line shows the point where the product of the preference values of the participants is maximum and is termed as the most suitable or most preferred trip departure time i.e. at 08:45.

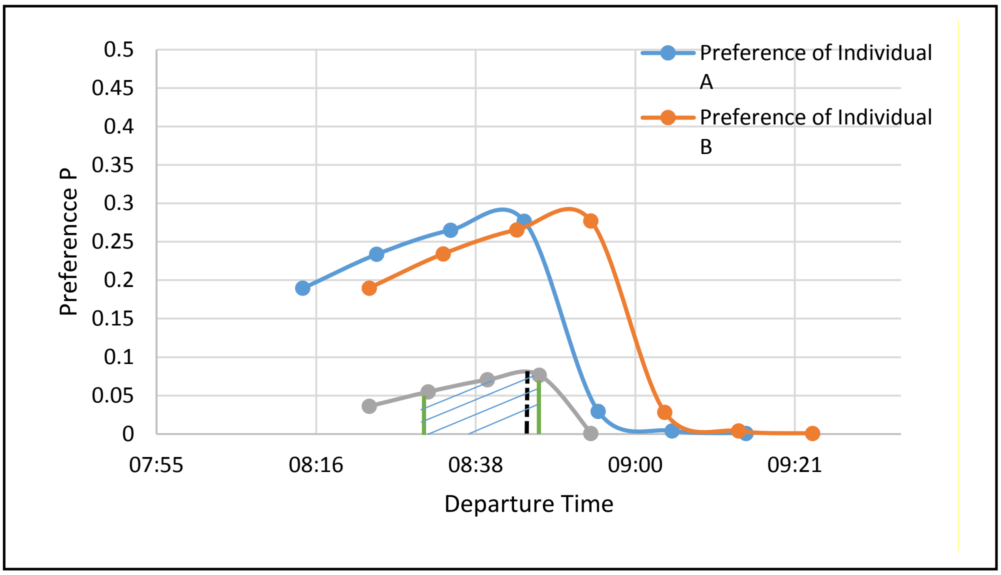

Figure 19. Combined Preference Functions for Trip Departure Times

Case II: Constraining Activities

This case is more complex than the first discussed case with no restricting activities present in the daily agenda. The presence of constraining activities and the resulting time pressure factor in the daily schedules of the people involved in the negotiation process for the execution of a combined carpool trip, requires a special consideration given to the scenario. The time windows for the individuals can no longer be considered as symmetrical or uniform on either side of the most preferred departure time.

The effects of constraining activities on the proposed negotiation mechanism as mentioned in the equational form in section 5.2, is illustrated in graphical format with the help of an example. The constraining activities such as pick/drop, shopping or any other social commitment induce time pressure on the individuals, which consequently forces them to alter their schedule by departing earlier or later for the destination or by shortening or cutting down the duration of certain activities. In the following paragraphs, the negotiation process in case of constraining activities is elaborated with the help of examples.

The negotiation mechanism for constraining activities differs from the non-constraining in such a way that the individuals no longer have a symmetrical and maximum time window available for the execution of a combined trip. The reduced time window consequently effects the negotiation process and the chances of the execution of a carpool trip are significantly narrowed down.

As the figure (20) shown below illustrates the example of a person's schedule with the presence of constraining activities in morning e.g. a fixed pick/drop activity to be conducted before leaving for work. This implies time pressure on the individual, hence the available time window for the departure to work location is restricted and reduced. The orange line in the graph represents the time window for the simplest case with no constraining activity- schedule. The other two lines represent the constraining activity case. These lines show the time window for a person who has a cut-off point in his available time window due to the presence of some fixed constraining activities in his schedule. The green line has a 10 minute cut-off with respect to the full non-constraining available time window whereas the blue line represents a 20-minute cut-off.

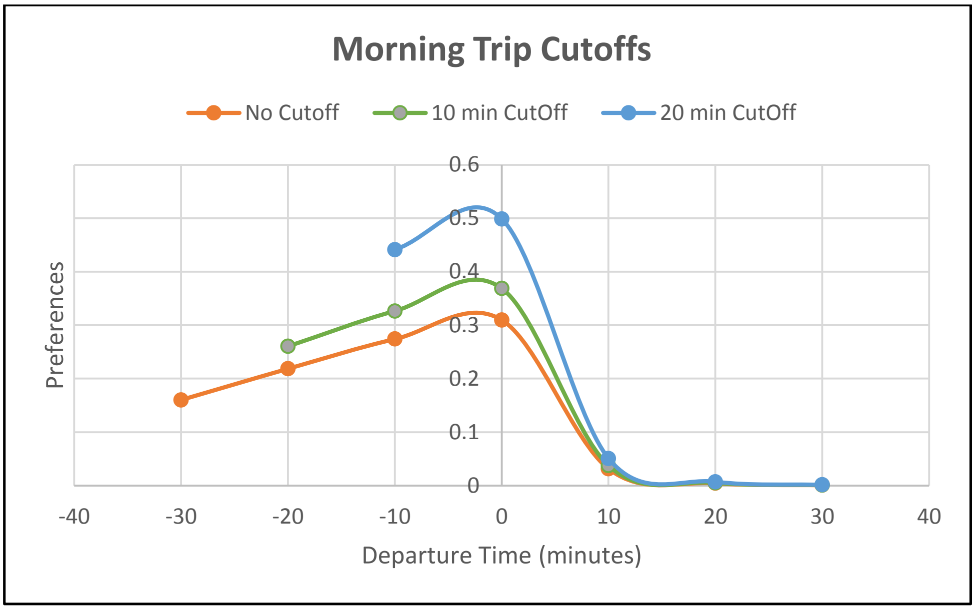

Figure 20. Preference Curves for Constraining Activities: Morning Trips

As it is evident from the graph above that due to the presence of constraining activities, the length of time window available for departure is cut and consequently affects the chances of successful negotiation for the execution of a carpool trip. Another interesting point to observe here is that as the intensity level of the effect of constraining activities increase, there is a significant increase in the probability of departing late for work. This is because we assume that the probability to select a given start time is proportional to the preference; after cutting the infeasible part, the curve is re-normalized so that the integral equals one. The green and blue lines in the graph representing 10 and 20 minute cut-offs respectively, show a rise in the probability to depart at the later times, hence compromising on the maximization of the utility. This shows that the induction of time pressure in a person's schedule forces a behavioural and habitual change which leads him/her to delay the departure time. Though, this effect might implicate negative consequences on a fixed-time worker in the form of fines or salary cuts being imposed. However, according to the Brussels departure time study discussed in the literature review, the workers in Brussels have an average 16 minute flexible or grace period available to them in the morning during which no fines or penalties are imposed on them, *(De Palma et al., 1997)*.

Similarly, the fixed activities scheduled just after work such as pick/drop, shopping or any other social commitment can be termed as constraining activities for the evening work to home trip. This also implies a time pressure on the individual, hence reducing the time window available drastically for the departure and consequently minimizing the chances for the negotiation process to succeed. The figure (21) below shows different available time windows effected by constraining activities. The orange line is the normal time window with no constraining activities while the other two lines represent the restricted versions of the available departure time window in the presence of certain constraining activities. The green curve shows the available departure time window with a 10 minute cut-off with respect to the full 60 minute time window while the blue curve depicts the 20 minute cut-off version of the available time window.

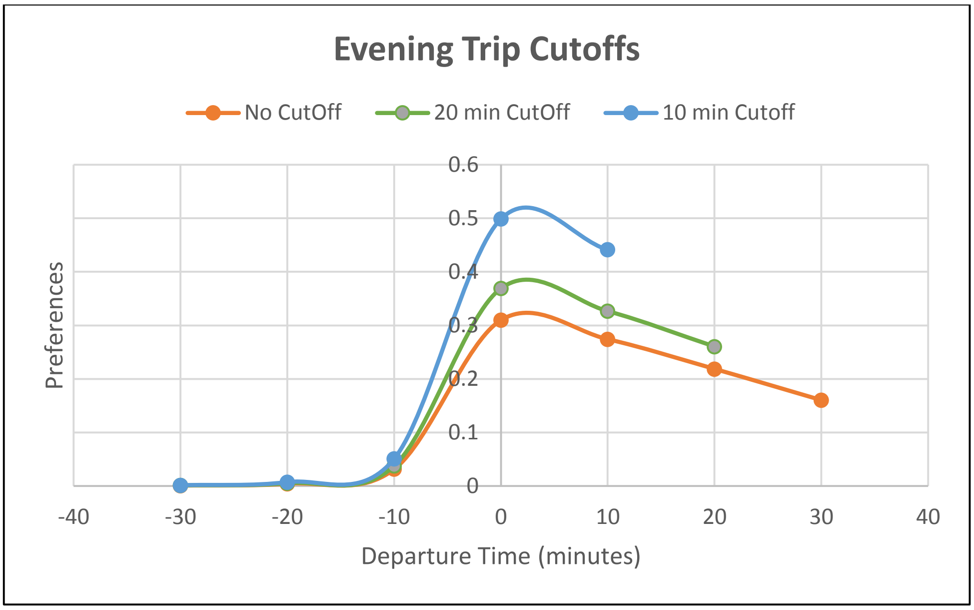

Figure 21. Preference Curves for Constraining Activities: Evening Trips

A similar phenomenon can be seen for the evening trips graph as was the case with the morning trips. The constraining activities induce a factor of time pressure on the individuals, hence forcing them to make changes to their schedule. As can be seen in the graph, people having restricted departure time window tend to leave earlier from the work which might implicate negative consequences on them in the shape of fines or penalties. However, (de Palma et al., 1997) concludes from his departure time study in Brussels that the workers usually have a 14 minute flexible period in evening which allows them to leave without any action taken against them.

After defining the preference function for the special cases with the presence of constraining activities, the negotiation mechanism remains the same as with the other cases. The only difference lies in the length of the available departure time window as explained above.

6.2 Simulation in JAVA:

After the preliminary analysis of the proposed negotiation methodology in Microsoft Excel, the next step was to implement and simulate the mechanism in an automated environment like JAVA in order to proceed with the development of an accurate and behaviourally sound agent based negotiation model.

First of all, a standalone version of the proposed preference function and the corresponding negotiation mechanism was coded in JAVA and further it was integrated into the existing agent based carpool negotiation model developed at IMOB (explained in detail in the following chapter). The purpose of the standalone version was to check the integrity and soundness of the proposed mechanism. The following figure shows the screenshot of the JAVA environment with code, whereas detailed code can be seen at Annex 3.

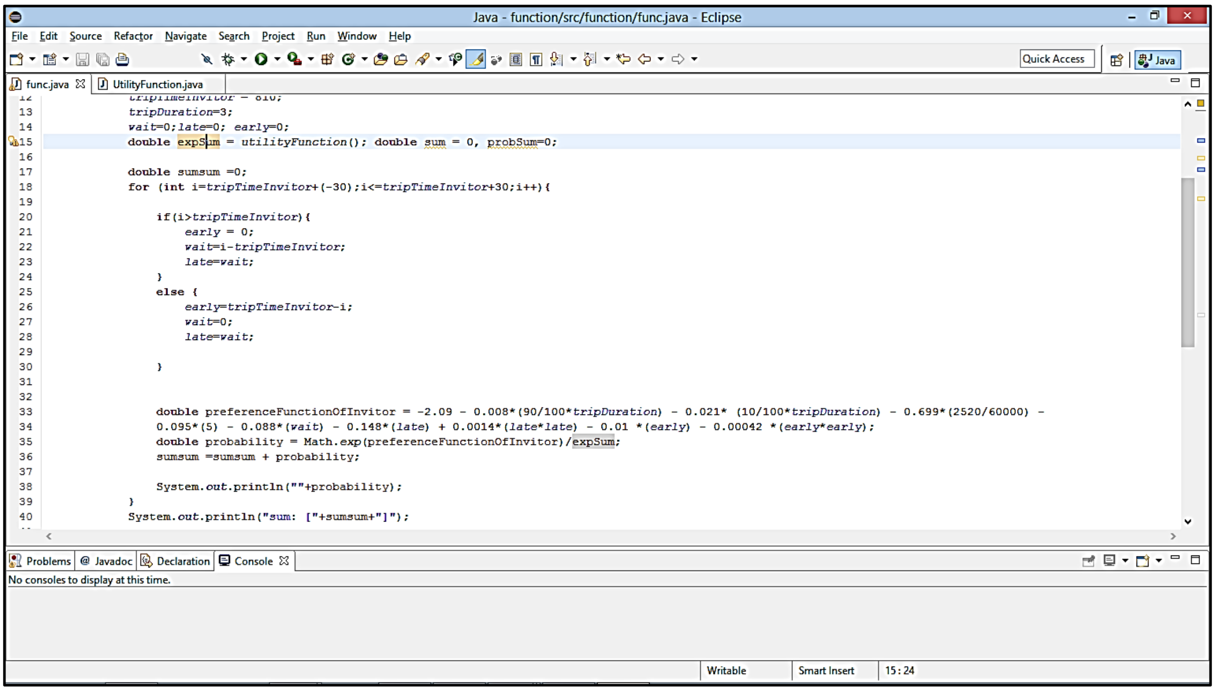

Figure 22. Screenshot of the Preference Function Coded in JAVA

An important point to mention here is regarding the discrete nature of the proposed preference curve and how it has been dealt with particularly in the simulation. As discussed above as well that the proposed preference function for the selection of trip departure times is partly derived from the Hendrickson's departure time model. As the Hendrickson's base model included seven different departure time intervals of 10 minute each, therefore the proposed preference curve resulted in preference values for specific discrete departure times. However, to make the curve continuous, departure time intervals of one min instead of 10 min have been used in the simulation. This is done because, for the simulation, we need to calculate the individual preference value for each possible trip start time in the candidate specific time window (e.g. the time window $\pm\Delta t$ =30 minutes). This enables the simulation to define the preference of a person at any given point in time in the available time window and then consequently use those preference values for the negotiation process.

The following figure (23a) and (23b) illustrate the discrete and continuous preference curves respectively. It can be seen that for discrete function, probability at only certain points can be defined whereas when the function is considered to be continuous, preference values at any point can be determined throughout the available time window. This is critical for the performance of the simulation as in reality different people have different time preferences in their available time window, therefore to make the function more accurate and practical, the proposed preference function has to be continuous.

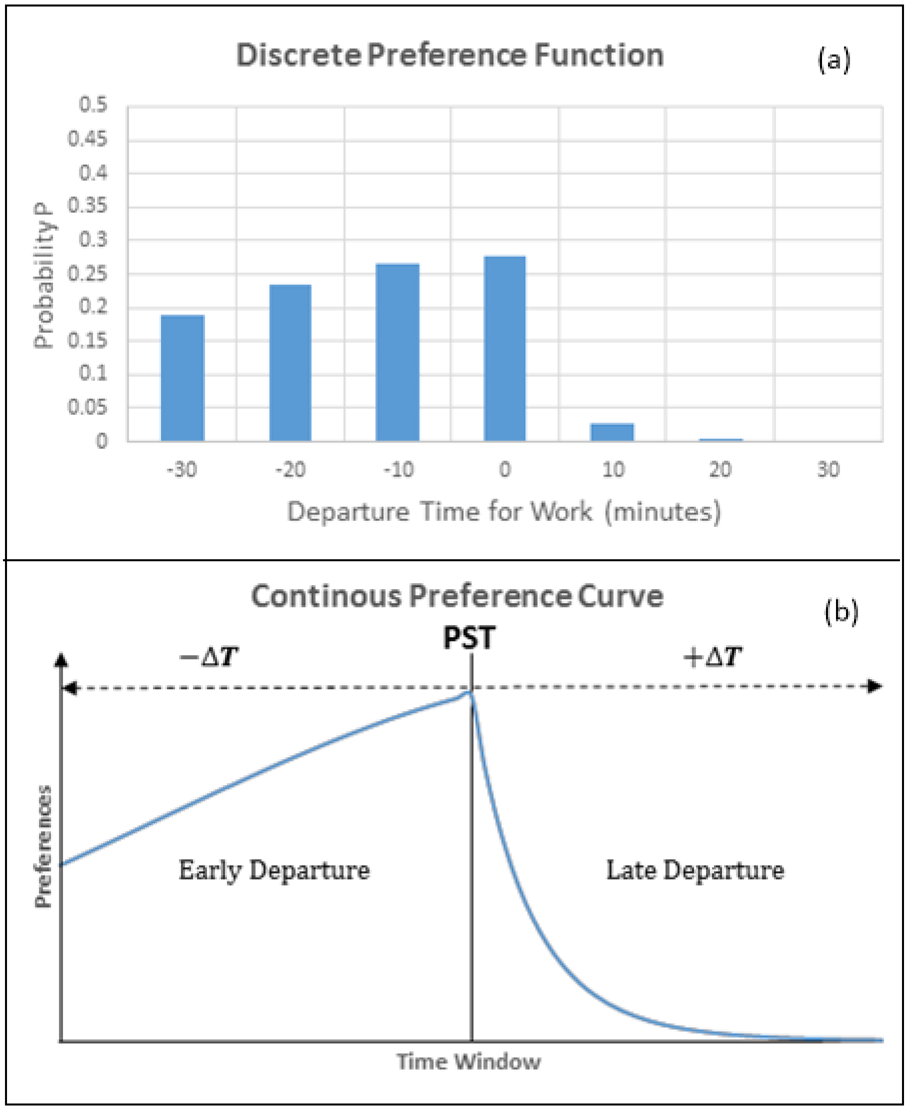

Figure 23. Comparison of Discrete and Continuous Preference Functions

The simulation of the proposed preference and the negotiation methodology in Java provided an automated environment for the application of the function. For this purpose, the FEATHERS data was employed along with a number of assumptions that were made regarding the factors involved in the proposed function in order to make the simulation operational. The assumptions were based on the traffic behaviour characteristics along with the employment of socio-economic characteristic data for some factors.

The following table explains the logic behind the values of the factors used in the simulation and also enlists some assumptions made regarding the preference function factors for the simulation:

$\boldsymbol{FFTT}_{\boldsymbol{a_i}}$: Free flow Travel Time in carpool vehicle	Peak Time: 75% of Total Travel Time Off-Peak Time: 90% of Total Travel Time
$\boldsymbol{CONG}_{\boldsymbol{t_j}}$: Portion of travel time associated with congestion	Peak Time: 25% of Total Travel Time Off-Peak: Time: 10% of Total Travel Time
$(\frac{\boldsymbol{COST}}{\boldsymbol{INCOME}})_{\boldsymbol{a_i t_j}}$: Ratio of annual cost of carpooling to income level per annum	Income: Linked to FEATHERS Socio-Economic data Costs: depends on the time-of-day because toll and parking charges are included (assumed to be 10€/day)
$\boldsymbol{ACC}_{\boldsymbol{a_i t_j}}$: Access time	For drivers: time required to pick/drop passengers (assumed to be 5 minutes)
$\boldsymbol{WAIT}_{\boldsymbol{a_i t_j}}$: Waiting time w.r.t. individual's most preferred time to depart.	Linked with the late departure
$\boldsymbol{LATE}_{\boldsymbol{a_i t_j}}$: Late arrival at work associated with the departure time.	Based on FEATHERS data
$\boldsymbol{EARLY}_{\boldsymbol{a_i t_j}}$: Early arrival at work associated with the departure time.	Based on FEATHERS data The co-efficient of $EARLY_{a_i t_j}$: not given in Hendrickson's model (assumed to be 0.01) smaller magnitude than that of $LATE_{a_i t_j}$; this is because late arrival at work is felt to be more onerous than early arrival.

Table 9. Specifications Used for Preference Function Factors in the Simulation

CHAPTER 7: Agent-Based Carpool Negotiation Model

The ultimate aim of proposing a trip negotiation outcome estimation mechanism as elaborated in above sections was to make the existing agent based carpool negotiation model for the selection of suitable trip start time more behaviourally and technically sound. This was done by introducing an individualized preference function based on various real life factors. After detailed analysis and stand-alone simulation of the proposed methodology in Java environment, the next step was to integrate the negotiation mechanism into the agent based carpool model. This section based on our published paper *(Hussain, Knapen & Khan, 2015)* provides an extensive and technical description of the improved and behaviourally sound agent based negotiation model is given.

First of all, certain assumptions of the agent based carpool negotiation model are discussed. 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. The carpool candidates can explore for partners whenever needed.

The agent-based negotiation model for the long term carpooling is simulated to account for individual specific behaviour during the carpooling process. The goal is to simulate the interactions of autonomous agents, to enable communication to trigger the negotiation process by incorporating a personalized preference function. The purpose is to introduce a behaviourally sound negotiation mechanism that determines the extent to which people need to adapt their daily schedule to enable cooperation and accommodate for a carpooling activity. 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 as discussed in detail in the literature review can be broadly classified into three stages namely; (i) exploration and communication, (ii) negotiation, and (iii) carpooling (long-term trip execution). In this chapter, however, we focus on the proposed negotiation mechanism that efficiently represents the actual human preferential behaviour based on a number of influencing factors. The proposed preference function for 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.

The agent based negotiation model's purpose is to simulate the real life trip negotiation mechanism. The most important element of this decision mechanism is the selection of the most preferred trip departure time. As explained in previous chapters as well, a preference function was derived from Hendrickson's multinomial logit model for the work trips. 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 minutes each. However, in the proposed preference function as described in the previous chapters, only the coefficients of the shared-ride mode (including carpool, vanpool etc.) presented in the Hendrickson's multinomial logit model have been used. Also the departure time intervals of 10 minutes each as presented by Hendrickson result in a discrete function, therefore in order to make the function continuous, departure time intervals of one minute instead of 10 minutes have been considered in the simulation. Apart from these departure time influencing factors, the driver and vehicle selection is based on the inspection of the individual's profiles (car and driving-license ownership).

In the simulation model, a "negotiation mechanism" is used to adapt the trip start times of an individual. The commuting trips in daily schedules (home-to-work *HW* and work-to-home *WH*) were considered. Home and work locations, trip start times (*HW* and *WH*) and their durations, and activity duration, the SEC attributes, including vehicle and driving-license ownership were used as input.

As mentioned in the previous Analysis chapter, the operational activity-based model for the region of Flanders (Belgium), FEATHERS was used to generate a planned schedule for each member of the synthetic population. In FEATHERS, mutually independent individuals using a transportation network free from unexpected congestion, 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 three stages of the negotiation and trip execution in the carpooling process are described in more detail in the following subsections.

7.1 Exploration and Communication:

Each agent looks for other individuals to cooperate while executing its periodic trip by exploring the carpooling social network. People decide to select carpool partners from the group of individuals who share respectively 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) as opposed to specific street addresses.

The agents belonging to the same groups may communicate with each other by sending and receiving text messages. Through communication, the agents may negotiate on start time of the trips (*HW* and *WH*), on the vehicle to use and hence on the selection of the driver. 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 same group, as shown in the fig. 1. Following messages are used: *CarpoolRequestMessage*, *AcceptMessage* and *RejectMessage*.

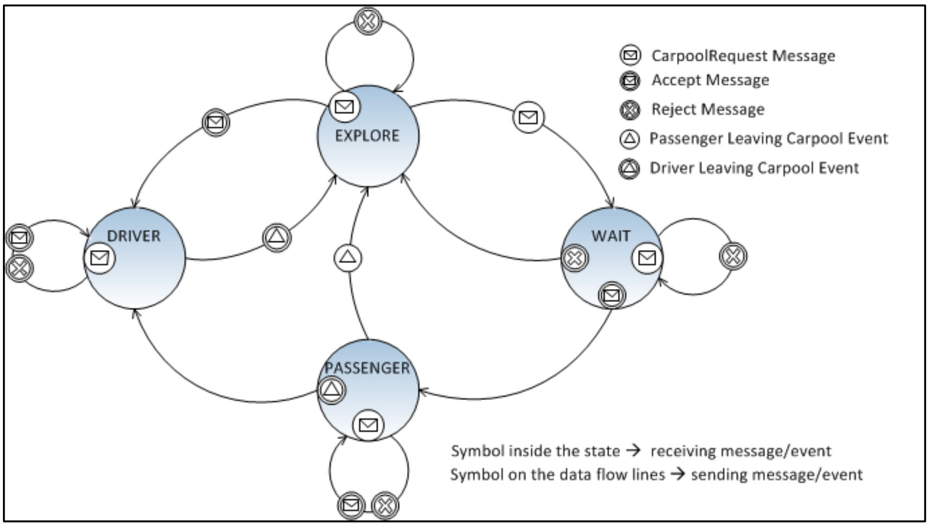

Figure 24. State-Transition diagram of an Agent $\boldsymbol{a_i}$

An agent performs the following activities in different states:

1. In the EXPLORE state, each agent (*sender*) may search for a partner (*receiver*) 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 receiver's response. In the EXPLORE state, an agent can receive carpool invitations from other agents as well.
2. In the WAIT state, if the receiver's response is an *AcceptMessage* then the sender tries to join the *CarPoolGroup* the receiver belongs to and the sender 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 a *CarPoolGroup*, can receive carpool invitation and replies with either *AcceptMessage* or *RejectMessage* depending on the sender's departure time requirements and on the remaining car capacity. If the carpool 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 carpool period expires. While being a passenger, the agent handles carpool invitations in the same way as a driver.

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

7.2 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 for both the trips (*HW* and *WH*) are mutually compatible within the carpool.

7.3 Carpooling (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. The carpool candidates can explore for partners whenever needed.

CHAPTER 8: Results

The proposed preference function and the corresponding negotiation mechanism as discussed in detail in the above sections was integrated into the existing agent based carpool model developed at IMOB as explained in Chapter 7. The results discussed in the section can be used to figure out the human behavioural and habitual characteristics for the commuting trip over a number of working days. It also enables to determine the pattern for travelling via carpool after negotiating with other individuals while managing other fixed constraining activities as well.

The proposed model was simulated in Janus Multi-agent platform. The model was simulated for data created by the FEATHERS activity-based model for the Flanders region. For the experiments, data for 20,000 individuals from a set of selected zones was 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). The following table summarises the general specifications and certain assumptions used for the simulation of the proposed model:

No. of Individuals	20,000 agents form a set of selected zones
No. of Simulation Days	150
No. of Carpooling Days	Randomly Selected: 30 to 60 days
Probability to Invite	If 100%: Must send carpooling requests Otherwise: Not necessary to send request
No. of Explorations	Maximum 5/day
Carpool Size	4 people at most (including driver)

Table 10. General Specifications of the Simulation

In the following sections, the results of different simulation runs have been presented followed by a detailed discussion.

8.1 Simulation for Different Threshold Values:

This section discusses the results for a simulation for the number of active carpool groups and active carpoolers i.e. people involved in carpooling respectively during the simulation period of 150 days for different threshold values of probability i.e. 0.9, 0.8, 0.7, 0.6, 0.5, 0.4 and 0.3. The value of the probability to succeed determines the level of flexibility in adapting to the trip start time. These probabilities can be termed as threshold points and serve as the success criteria that determine the fate of the negotiation process.

The table (11) shows the summary of the specifications used for the particular simulation run. The graph in figure (26) shows the number of active carpool groups over 150 simulated working days for different threshold probability values. The horizontal axis shows the number of working days whereas the vertical axis represents the number of active carpool groups for each day. Similarly, the graph in figure (27) shows the number of active carpoolers throughout the simulation period.

It can be observed clearly in the figures (26) and (27) that a lower threshold value enables more carpool groups to be created as the combined probability of the concerned individuals to depart in a specific time interval is more than the threshold value. Similarly if the threshold value is set higher such as for the case of 0.9, the criteria becomes very strict, hence reducing the number of carpool groups and the carpoolers significantly. The following figure (25) helps to understand the effect of threshold probability of success on the number of carpools and carpoolers.

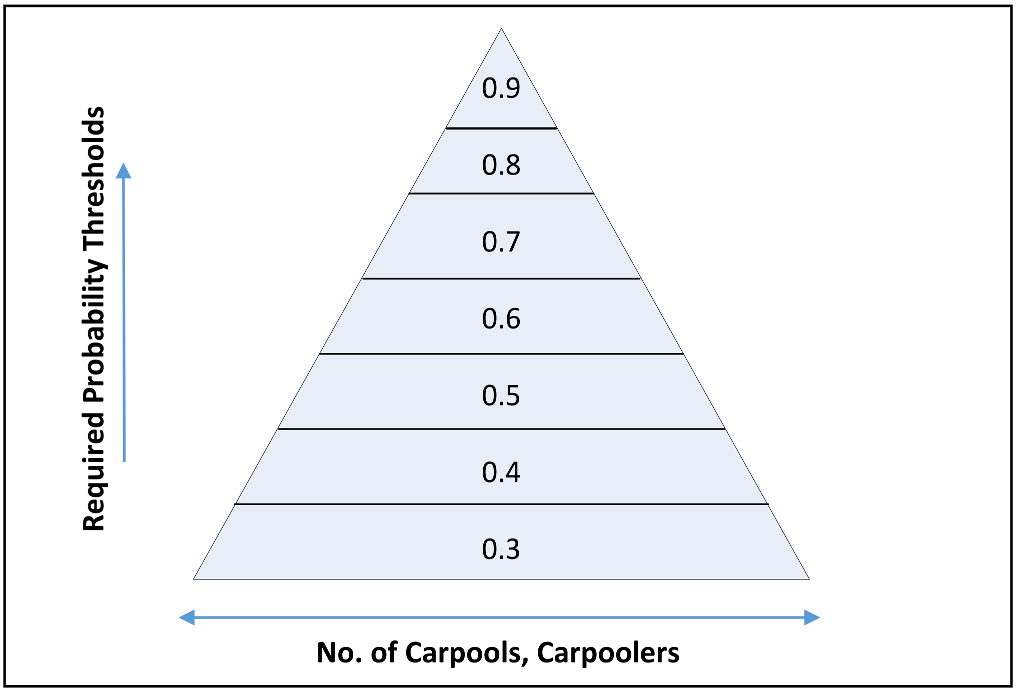

Figure 25. The Effect of Different Threshold Probabilities

In the figures (26) and (27) below, it can be observed that for each threshold value, the number of carpool groups as well as the number of carpoolers increase rapidly at the start of the simulation up to about 30 days since the shortest possible carpooling period lasts for 30 days. However, the curves show a decrease after 30 days because new carpoolers due to their varying preferences and strict time windows find it difficult to immediately join or create new carpool groups, consequently reducing the number of carpoolers and carpool groups. The model does not consider the carpool that was left as the preferred candidate to be joined again. Nevertheless, after 45 days, the number of carpoolers curve stays stable i.e. low increase rate till the end of the simulation. This indicates that the people start finding their suitable partners and they cooperate with each other by either joining an existing group or by creating a new one. The possibility to join existing carpool group is same as the creation of the new carpool groups as the curve remains consistent indicating an equilibrium state.

It can also be figured out from figure (27) that the maximum participation is for the most flexible case of 0.3 threshold probability. In this case, a maximum of approximately 4.5% of the population engages in a carpooling activity.

No. of Individuals	20,000 agents
No. of Working Days	150
Model	With Preference Function
Time Window	Without Constraining Activities $\underline{+}\Delta T$= 30 minutes
Success Probability Threshold	0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9
Carpool Size	4 people at most (including driver)

Table 11. Specifications of the Particular Simulation Results

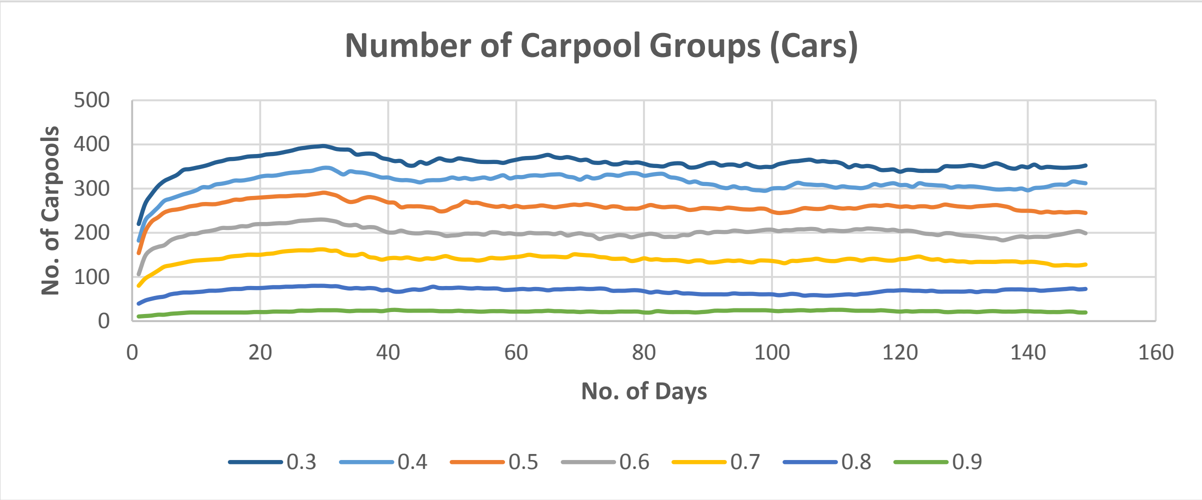

Figure 26. Simulation Results of the Number of Active Carpool Groups for Different Threshold Values

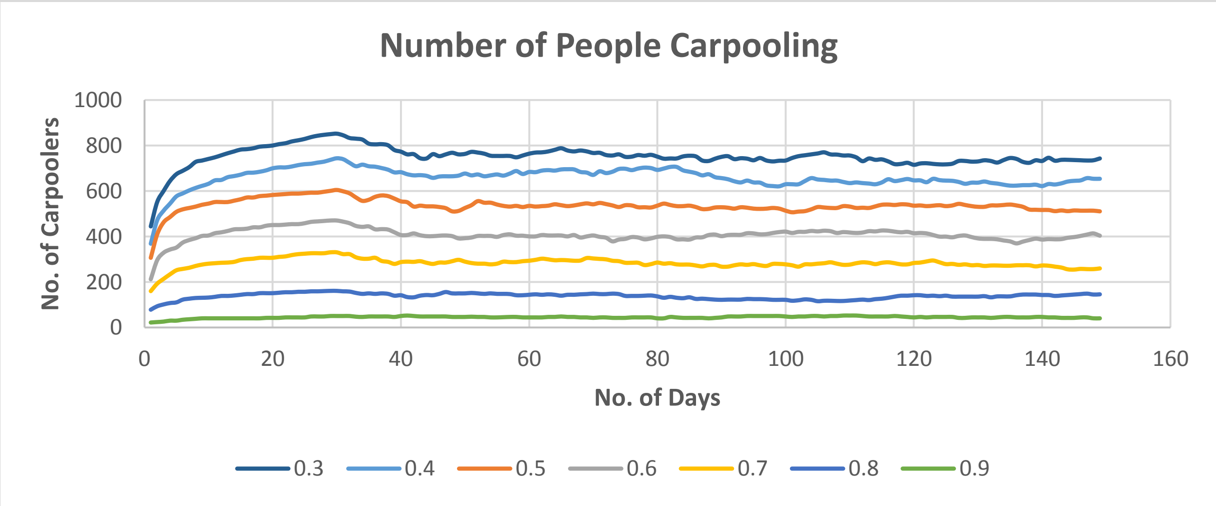

Figure 27. Simulation Results of the Number of Active Carpoolers for Different Threshold Values

8.2 Comparison of Simulations with and without Preference Function:

The effect of introducing a preference function in the agent-based carpool negotiation model has been discussed in this section. The following figure (28) shows the basic difference in the models. The constant preference model has a uniform preference for trip execution throughout the available time window whereas the other model is based on the proposed preference function in which the departure preferences of the individuals vary throughout the feasible time window.

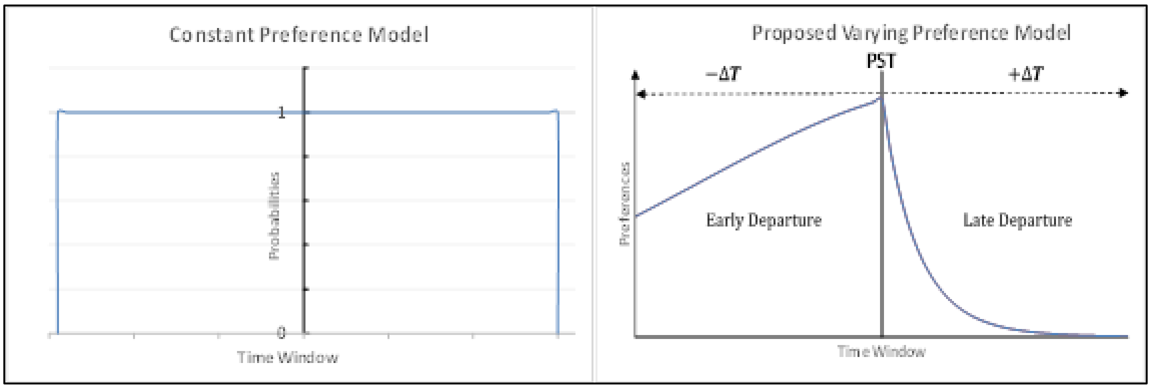

Figure 28. Comparison of Constant and Varying Preference Functions

The graphs in figures (29) and (30) show the simulation results for both the model with proposed preference function at a threshold value of 0.3 as well as for the old model that assumed constant preference for the whole time window. The simulation has been run for 150 working days. The horizontal axis shows the number of working days whereas the vertical axis represents the number of active carpool groups and carpoolers respectively for each day. The table (12) shows the summary of the specifications used for the particular simulation run.

The graphs help in understanding the behaviour of the model. It is evident that the number of carpoolers as well as the number of carpools significantly reduce because of the strict and varying time window preferences for the individuals. The simulation curve without preference functions exhibits that a maximum of nearly 12.5% of the total agents engage in carpooling on a specific day whereas the model with the proposed preference function shows that a maximum of approximately 4.5% of the people out of 20,000 agents travel via a carpool on a specific day. This is because of the fact that the available time window in the case of proposed preference function gets reduced effectively as the preference of the people to depart late is almost negligible for the morning trip and vice versa for the evening trip.

No. of Individuals	20,000 agents
No. of Working Days	150
Model	With and Without Preference Function
Time Window	Without Constraining Activities $\pm\Delta T$= 30 minutes
Success Probability Threshold	0.3
Carpool Size	4 people at most (including driver)

Table 12. Specifications of the Particular Simulation Results

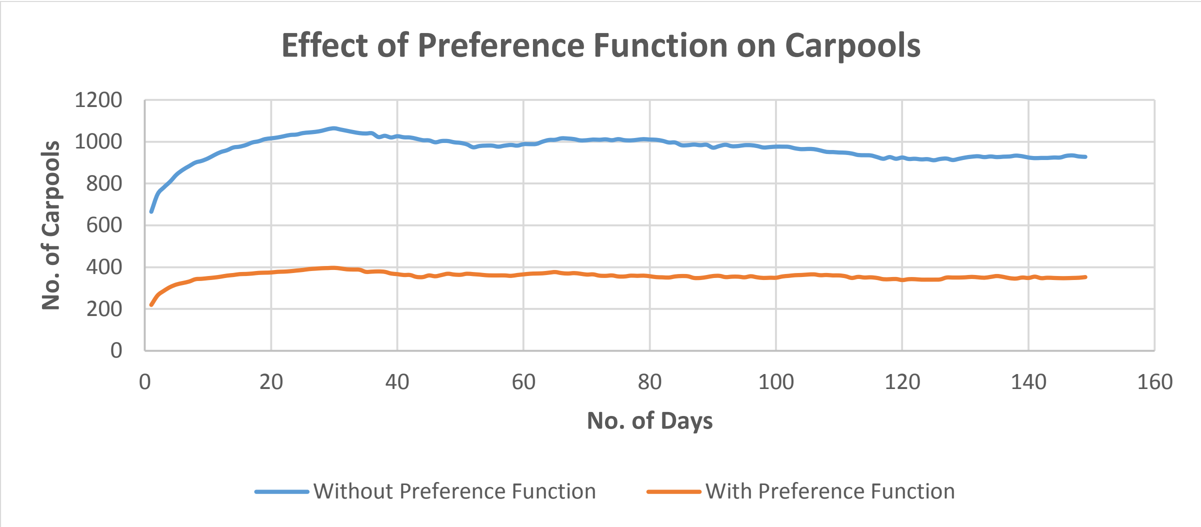

Figure 29. Comparison of Simulation Results for Carpool Groups with/without Preference Function

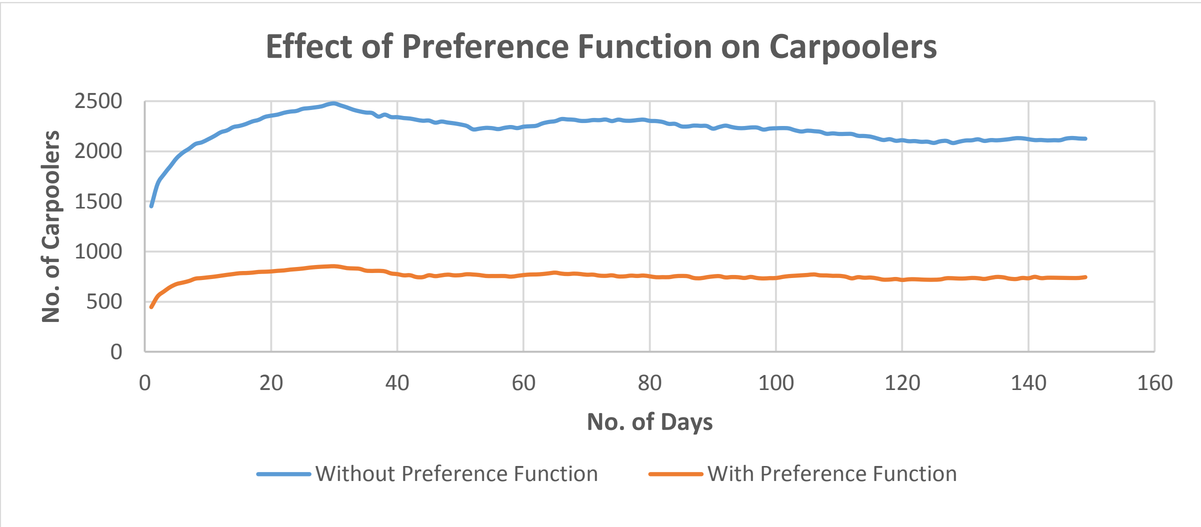

Figure 30. Comparison of Simulation Results for the Carpoolers with/without Preference Function

8.3 Comparison of Simulations with and without Constraining Activities:

In this section, the effects of different types of constraining activities on the carpooling behaviour are analysed. The simulation has been run for 150 working days along with some other specifications as summarized in table (13). The model has been simulated after incorporating different constraining activities such as pick and drop activity and shopping activity in both the morning as well as evening trips.

The graphs in figures (31) and (32) show the comparison of the simulation results of the model with and without constraining activities. The orange line shows the no constraining activity curve while the grey and blue lines represent the pick drop activity and the combined constraining activity i.e. shopping and pick drop respectively. It can be figured out that the number of carpools and carpoolers decrease due to the presence of fixed constraining activities. This is because of the time pressure and strict time window constraints. Both the curves for the constraining activities including the pick/drop activity only and the combined constraining activity i.e. shopping and pick drop activity show almost a similar behaviour. The small difference is due to the stochastic variability. Initially, both the curves increase until 30th day but then they start decreasing as the simulation days pass by. The analysis of the curves with and without constraining activities indicates a reduction of almost 1.5% of the carpoolers in the presence of constraining activities as compared to the non-constraining case. This shows that the existence of constraining activities in the schedule is a big hindrance and a lot of people are not able to participate in a carpooling activity due to such constraining activities.

No. of Individuals	20,000 agents
No. of Working Days	150
Model	With Preference Function
Time Window	With Constraining Activities: Pick/Drop Activity, Combined (Shopping+ Pick/Drop) Activity Without Constraining Activities: $\underline{+}\Delta T$= 30 minutes
Success Probability Threshold	0.3

Table 13. Specifications of the Particular Simulation Results

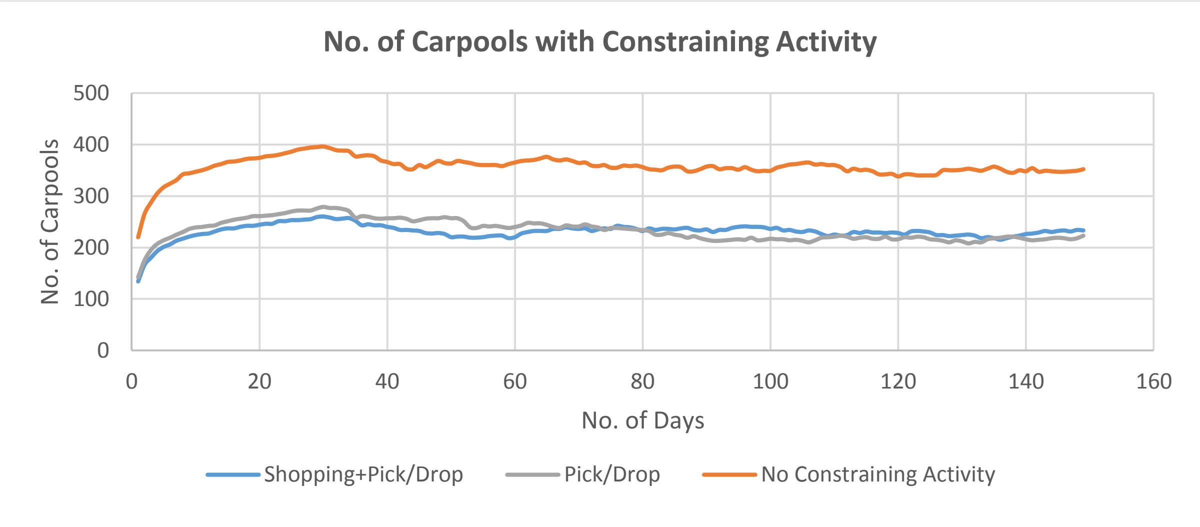

Figure 31. Comparison of Simulation Results for the Carpool Groups with/without Constraints

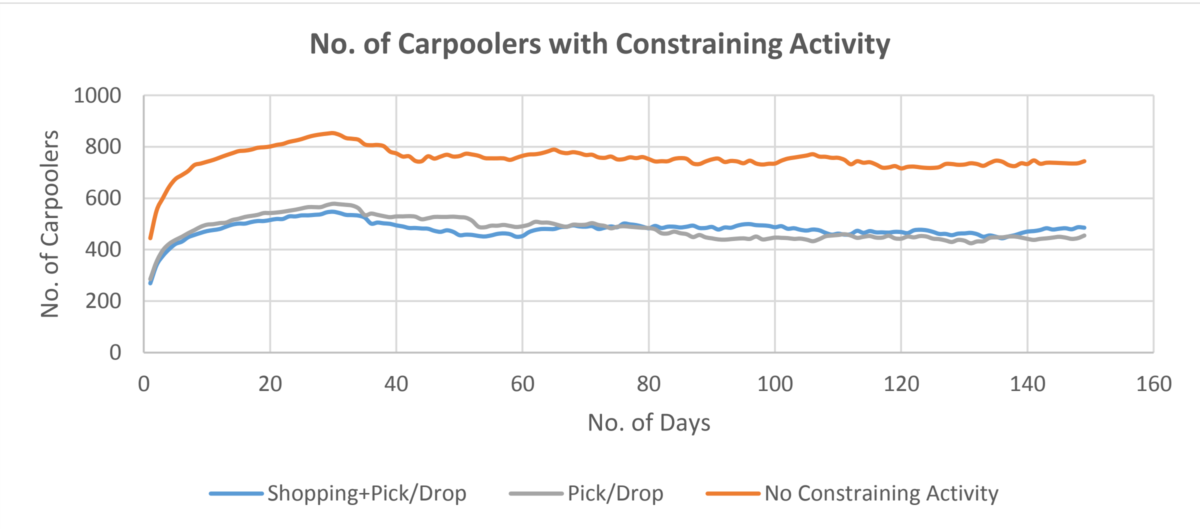

Figure 32. Comparison of Simulation Results for the Carpoolers with/without Constraints

CHAPTER 9: Discussion

The research method and the corresponding results as discussed in detail in the above chapters can contribute quite significantly towards the development of a behaviourally sound negotiation outcome prediction mechanism incorporated in an agent based carpool simulation model. As people have varying departure time preferences throughout their available time window, they have to negotiate on the basis of their preferences in order to cooperate for carpooling. They also have to consider other constraining activities present in the schedule to accommodate for a carpool trip. The model proposed in this thesis helps to simulate the actual departure time preferences of the individuals. This can ultimately be helpful in determining the factors and pointing out the general reasons behind the low participation level of the people in carpooling especially for long term.

It is evident from the simulation results that the incorporation of a preference function in an agent based carpool model represents the actual behaviour of the people. The model without preference function indicates a maximum of 12.5% participation level for each day in 150 days simulation period whereas the model without preference function results in the participation of maximum 4.5% population in a carpooling activity. This shows that the negotiation criteria in the model without preference function is very flexible whereas the model with preference function represents more accurately the real life phenomena in which people generally have strict time windows and tight schedules. The presence of rigid time windows makes the negotiation process more hectic and strict, ultimately limiting the number of carpoolers significantly.

The results of the simulation also show that when the threshold value is lower, the chances for negotiation success are greater. As the threshold value goes higher, the negotiation success criteria gets more and more strict resulting in a significant reduction in the number of carpools and carpoolers. Also, the results show that the presence of constraining activities such as pick drop and shopping activities in the schedule significantly decrease the probability of the execution of a carpool trip. This shows that the presence of constraining activities such as shopping or pick drop activity influence the choice of carpool as a travel mode as the time windows and the preferences of the individuals become even more rigid.

Although, there might be some concerns regarding the validity of the model coefficients of the proposed preference function for European region as originally it was designed on the basis of a survey conducted in an American State. However, the selected approach towards the construction of a close-to-reality individualized preference function for each agent in the population can eventually turn out to be helpful for future studies and only a few adjustments to the coefficients of the multinomial logit model will lead to a model that will be accurately representative of the actual negotiation mechanism specifically for Flanders, Belgium.

CHAPTER 10: Conclusion & Future Research

The activity based travel demand models (e.g. FEATHERS) generate individual and independent schedules for a population. However, these independent schedules have to be interacted in order to simulate the effects of various social and joint activities such as carpooling. For this purpose, agent based models ae used that enable the modellers to simulate the interaction and negotiation among the concerned individuals. The advantage of using an agent-based simulation model is the flexibility in the individual settings and the inherent sociality *(Ronald, 2012)*.

The study of the existing scientific literature and the proposed negotiation models especially relating to carpool scenario revealed that most of the models till date lack in a behaviourally sound negotiation mechanism in order to accurately simulate the real interaction among the interested individuals. To fill this gap, a negotiation outcome estimation model to determine the trip start times has been proposed that is then integrated into the existing agent based carpool model. The proposed mechanism aims to simulate the outcome of the real negotiation procedure by defining the preference functions for each individual involved in the negotiation process.

The proposed negotiation outcome estimation mechanism is based on the assignment of personalized preference functions for each agent that is based on a number of factors namely; (i) travelling factors, (ii) socio-economic factors and (iii) Time pressure factors. Apart from it, special consideration is also given to the presence of fixed constraining activities in the daily schedules of the people involved in the negotiation process. The proposed mechanism after detailed analysis in Microsoft Excel and in JAVA environment, has been integrated into the existing agent based carpool model developed at IMOB. The data used for simulation has been created by the FEATHERS activity-based model for the Flanders region.

The improved agent based carpool negotiation model evaluates the evolution of a carpooling society under several conditions with the aim of analysing various effects of agent interactions and behaviour adaptation. The agents negotiate on trip (morning and evening) departure times and on the driver assignment for the long term carpooling involving multiple trips. During the negotiation process the agents may adapt their daily schedules to enable cooperation. As people do not have constant preferences for trip execution during the entire departure time interval, therefore the proposed model with preference function represents the real life mechanism more accurately as compared to the model having uniform preferences. The simulation results of the proposed model show that a maximum of approximately 4.5% of the population engages in a carpooling activity for each day. This number seems to be closer to the value found by OVG i.e. 5 to 7% of the active workforce carpool at least once a week (OVG, 2000). Apart from it, the results of the simulation also demonstrate that when the threshold value is lower, the chances for negotiation success are greater. Also, it can be concluded that the presence of constraining activities further reduce the number of participants in a carpooling activity, eventually also decreasing the number of carpool groups.

The preference function and the model proposed in this thesis is an initial step towards the simulation of the real life trip negotiation mechanism. The research carried out in this thesis can be further expanded in different directions. The proposed model can be refined by improving and even adding various factors in the proposed time preference function. Also, data can be collected through different survey studies to determine the actual human behavioural preferences in any particular region regarding carpooling and trip start times. The model can also be extended to simulate the negotiation process for different social activities at weekends when there are no hard constraints of work activities.

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APPENDICES

ANNEX 1: Abstract of the Published Paper (WIT Conference, Valencia, Spain, 2015)

Agent-based Negotiation Model for Long-term Carpooling: A Flexible Mechanism for Trip Departure Times

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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, individuals (agents) can reach complex agreements in an iterative. The success of negotiation highly depends on the lifestyle factors that influence the departure time decision of the individuals. This paper presents a conceptual design of an agent-based model of a set of candidate carpoolers that serves as a proof of concept and is an extension of a simple negotiation model for carpooling. The proposed model extends the previous one by incorporating a more realistic departure time preference function for each agent by taking; (i) traveling, (ii) socio-economic characteristics, and (iii) time pressure factors into account for a specific activity. From the simulation's discussions, it is possible to portray the real picture of people's preferences for selecting the optimal departure time. The Janus (multi-agent) platform is used for simulating the interactions of autonomous agents with their agenda. The future research will mainly focus on incorporating different daily activities in addition to work and home activities.

Keywords: Negotiation, departure time, carpooling, commuting, Agent technology, Janus platform.

ANNEX 2: Simulation Results Data for Different Threshold Values

Threshold (0.3)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	220	225	445	75	355	396	751
2	265	287	552	76	355	397	752
3	287	314	601	77	359	400	759
4	305	340	645	78	358	398	756
5	317	358	675	79	359	401	760
6	324	366	690	80	356	396	752
7	331	375	706	81	352	391	743
8	342	387	729	82	351	393	744
9	344	391	735	83	350	394	744
10	347	395	742	84	355	398	753
11	350	399	749	85	357	399	756
12	354	404	758	86	356	397	753
13	359	408	767	87	348	387	735
14	362	413	775	88	348	385	733
15	366	417	783	89	352	391	743
16	367	418	785	90	357	394	751
17	369	420	789	91	358	396	754
18	372	424	796	92	352	389	741
19	373	425	798	93	354	391	745
20	374	427	801	94	354	389	743
21	377	430	807	95	351	385	736
22	378	433	811	96	356	390	746
23	380	439	819	97	351	384	735
24	383	441	824	98	348	383	731
25	386	444	830	99	349	385	734
26	390	448	838	100	349	386	735
27	392	452	844	101	355	391	746
28	394	454	848	102	358	396	754
29	395	456	851	103	361	397	758
30	396	457	853	104	362	400	762
31	393	453	846	105	364	402	766
32	389	445	834	106	365	406	771
33	388	443	831	107	361	401	762
34	387	440	827	108	362	399	761
35	377	432	809	109	360	397	757
36	378	428	806	110	360	397	757
37	379	428	807	111	356	393	749
38	377	425	802	112	348	384	732
39	369	412	781	113	353	391	744
40	366	408	774	114	350	388	738
41	362	400	762	115	351	389	740
42	362	401	763	116	348	383	731

43	353	392	745	117	342	377	719
44	352	392	744	118	342	378	720
45	360	403	763	119	343	382	725
46	356	398	754	120	338	378	716
47	362	400	762	121	342	380	722
48	368	401	769	122	342	381	723
49	364	398	762	123	340	380	720
50	363	401	764	124	340	378	718
51	368	405	773	125	340	378	718
52	366	404	770	126	341	380	721
53	364	401	765	127	350	383	733
54	361	395	756	128	350	383	733
55	360	395	755	129	350	380	730
56	360	395	755	130	351	380	731
57	360	395	755	131	353	383	736
58	358	391	749	132	351	382	733
59	362	395	757	133	349	377	726
60	365	400	765	134	353	384	737
61	368	402	770	135	357	389	746
62	369	402	771	136	353	389	742
63	370	405	775	137	347	382	729
64	373	409	782	138	345	380	725
65	376	413	789	139	350	386	736
66	371	408	779	140	348	385	733
67	369	406	775	141	354	393	747
68	371	408	779	142	347	387	734
69	368	407	775	143	349	389	738
70	364	404	768	144	348	390	738
71	365	404	769	145	347	390	737
72	359	400	759	146	347	389	736
73	358	399	757	147	348	387	735
74	360	402	762	148	349	387	736
				149	352	392	744
Threshold (0.4)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	182	187	369	77	333	366	699
2	227	245	472	78	335	368	703
3	243	271	514	79	334	367	701
4	257	288	545	80	329	364	693
5	272	305	577	81	331	368	699
6	277	313	590	82	333	373	706
7	282	321	603	83	333	373	706
8	287	327	614	84	326	365	691
9	291	332	623	85	324	361	685
10	296	336	632	86	320	359	679
11	303	344	647	87	314	355	669

12	303	346	649	88	316	358	674
13	309	352	661	89	311	350	661
14	311	355	666	90	310	347	657
15	314	358	672	91	308	344	652
16	318	362	680	92	303	340	643
17	318	363	681	93	301	337	638
18	320	365	685	94	305	341	646
19	323	368	691	95	301	337	638
20	327	373	700	96	301	336	637
21	329	375	704	97	297	328	625
22	329	375	704	98	296	326	622
23	331	377	708	99	295	326	621
24	334	380	714	100	300	330	630
25	336	382	718	101	301	329	630
26	337	383	720	102	301	329	630
27	339	386	725	103	307	337	644
28	340	389	729	104	313	344	657
29	344	393	737	105	310	341	651
30	347	397	744	106	309	340	649
31	346	394	740	107	308	338	646
32	339	385	724	108	308	338	646
33	332	377	709	109	305	335	640
34	339	377	716	110	302	333	635
35	337	372	709	111	305	333	638
36	336	371	707	112	303	332	635
37	333	368	701	113	302	331	633
38	329	365	694	114	301	329	630
39	325	357	682	115	304	334	638
40	325	358	683	116	310	342	652
41	321	353	674	117	307	337	644
42	319	350	669	118	310	338	648
43	319	351	670	119	312	341	653
44	317	350	667	120	308	339	647
45	314	344	658	121	308	339	647
46	318	346	664	122	304	335	639
47	319	346	665	123	312	342	654
48	319	346	665	124	309	339	648
49	321	347	668	125	308	338	646
50	325	352	677	126	307	338	645
51	322	347	669	127	306	334	640
52	324	349	673	128	302	330	632
53	321	344	665	129	305	332	637
54	323	346	669	130	304	333	637
55	325	348	673	131	305	337	642
56	322	346	668	132	304	332	636
57	326	351	677	133	302	331	633

58	330	358	688	134	300	328	628
59	323	352	675	135	298	326	624
60	326	358	684	136	298	326	624
61	326	357	683	137	299	327	626
62	329	361	690	138	298	328	626
63	330	362	692	139	300	328	628
64	329	361	690	140	296	326	622
65	331	364	695	141	301	330	631
66	332	364	696	142	302	327	629
67	332	363	695	143	304	330	634
68	327	357	684	144	308	334	642
69	325	356	681	145	309	336	645
70	320	351	671	146	309	338	647
71	327	360	687	147	316	341	657
72	323	356	679	148	314	340	654
73	325	360	685	149	312	342	654
74	331	366	697				
75	331	367	698				
76	329	363	692				
Threshold (0.5)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	154	153	307	75	260	278	538
2	202	208	410	76	259	278	537
3	225	238	463	77	255	274	529
4	235	251	486	78	255	274	529
5	246	263	509	79	255	273	528
6	251	269	520	80	259	277	536
7	253	273	526	81	263	282	545
8	256	276	532	82	260	279	539
9	260	280	540	83	258	276	534
10	262	283	545	84	259	275	534
11	265	287	552	85	259	277	536
12	265	287	552	86	256	274	530
13	265	287	552	87	252	269	521
14	268	290	558	88	253	269	522
15	271	293	564	89	256	272	528
16	275	297	572	90	256	273	529
17	275	297	572	91	255	272	527
18	278	300	578	92	254	269	523
19	279	301	580	93	257	272	529
20	280	303	583	94	256	271	527
21	281	304	585	95	254	269	523
22	282	305	587	96	253	269	522
23	283	306	589	97	253	270	523
24	283	306	589	98	255	271	526
25	284	307	591	99	254	269	523

26	285	308	593	100	248	266	514
27	285	308	593	101	245	262	507
28	287	310	597	102	246	264	510
29	289	312	601	103	248	264	512
30	291	314	605	104	252	268	520
31	288	311	599	105	256	274	530
32	284	306	590	106	255	273	528
33	276	296	572	107	254	272	526
34	270	287	557	108	255	271	526
35	272	290	562	109	259	275	534
36	278	297	575	110	257	275	532
37	281	300	581	111	255	271	526
38	279	299	578	112	256	271	527
39	274	293	567	113	255	271	526
40	269	286	555	114	258	275	533
41	268	283	551	115	261	279	540
42	258	274	532	116	262	279	541
43	260	276	536	117	261	278	539
44	260	273	533	118	263	279	542
45	260	273	533	119	261	280	541
46	258	272	530	120	259	277	536
47	256	269	525	121	260	277	537
48	249	262	511	122	258	276	534
49	250	263	513	123	260	276	536
50	257	269	526	124	260	278	538
51	262	276	538	125	258	276	534
52	271	285	556	126	260	277	537
53	268	281	549	127	264	280	544
54	268	281	549	128	262	277	539
55	264	277	541	129	260	274	534
56	261	274	535	130	259	272	531
57	259	273	532	131	258	273	531
58	261	274	535	132	260	277	537
59	258	272	530	133	261	276	537
60	261	274	535	134	262	277	539
61	258	274	532	135	263	278	541
62	259	275	534	136	261	276	537
63	260	276	536	137	258	273	531
64	262	280	542	138	252	267	519
65	260	278	538	139	250	268	518
66	258	276	534	140	250	267	517
67	260	277	537	141	249	268	517
68	262	280	542	142	246	266	512
69	264	282	546	143	248	267	515
70	263	279	542	144	246	266	512
71	265	283	548	145	247	268	515

72	263	280	543	146	246	268	514
73	260	277	537	147	247	267	514
74	257	273	530	148	247	267	514
				149	245	266	511
Threshold (0.6)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	106	106	212	77	194	202	396
2	147	149	296	78	190	198	388
3	162	167	329	79	193	199	392
4	168	175	343	80	196	203	399
5	172	180	352	81	198	203	401
6	183	191	374	82	196	202	398
7	189	196	385	83	191	197	388
8	192	201	393	84	191	197	388
9	197	206	403	85	191	196	387
10	198	207	405	86	195	201	396
11	202	213	415	87	195	202	397
12	204	215	419	88	201	206	407
13	207	218	425	89	202	207	409
14	211	221	432	90	199	203	402
15	211	222	433	91	202	205	407
16	212	223	435	92	202	206	408
17	215	226	441	93	202	206	408
18	215	226	441	94	205	210	415
19	219	229	448	95	204	210	414
20	220	231	451	96	202	208	410
21	220	231	451	97	203	208	411
22	221	232	453	98	205	211	416
23	222	233	455	99	207	213	420
24	222	233	455	100	207	215	422
25	224	235	459	101	204	212	416
26	227	238	465	102	206	215	421
27	228	239	467	103	206	215	421
28	229	240	469	104	208	217	425
29	230	241	471	105	208	215	423
30	230	241	471	106	209	217	426
31	228	238	466	107	208	216	424
32	225	234	459	108	204	212	416
33	219	228	447	109	206	214	420
34	217	226	443	110	205	213	418
35	218	227	445	111	204	212	416
36	212	220	432	112	205	213	418
37	213	220	433	113	208	216	424
38	212	219	431	114	208	215	423
39	206	213	419	115	210	217	427
40	201	206	407	116	209	217	426

41	201	206	407	117	208	214	422
42	205	209	414	118	206	213	419
43	201	205	406	119	207	214	421
44	199	203	402	120	204	211	415
45	199	203	402	121	205	211	416
46	201	203	404	122	204	210	414
47	200	205	405	123	201	206	407
48	198	204	402	124	198	202	400
49	193	199	392	125	197	203	400
50	194	199	393	126	195	202	397
51	195	201	396	127	199	204	403
52	198	205	403	128	199	206	405
53	198	205	403	129	196	202	398
54	198	205	403	130	194	198	392
55	196	203	399	131	193	197	390
56	201	206	407	132	192	198	390
57	201	209	410	133	190	198	388
58	198	206	404	134	188	195	383
59	199	205	404	135	187	192	379
60	197	204	401	136	183	187	370
61	197	204	401	137	186	192	378
62	200	207	407	138	190	195	385
63	199	206	405	139	192	199	391
64	199	206	405	140	190	197	387
65	199	206	405	141	191	198	389
66	197	204	401	142	191	197	388
67	200	207	407	143	191	198	389
68	194	202	396	144	194	201	395
69	197	204	401	145	196	202	398
70	199	206	405	146	199	204	403
71	196	203	399	147	202	207	409
72	194	201	395	148	204	210	414
73	186	193	379	149	199	205	404
74	190	197	387				
75	192	198	390				
76	195	203	398				
Threshold (0.7)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	80	80	160	75	141	144	285
2	96	97	193	76	141	144	285
3	105	109	214	77	141	144	285
4	114	120	234	78	136	139	275
5	123	129	252	79	138	141	279
6	126	132	258	80	142	144	286
7	129	134	263	81	139	142	281
8	132	139	271	82	140	143	283

9	135	142	277	83	138	140	278
10	137	144	281	84	138	139	277
11	138	145	283	85	138	139	277
12	139	146	285	86	136	137	273
13	140	146	286	87	134	135	269
14	141	148	289	88	137	138	275
15	145	152	297	89	137	139	276
16	147	154	301	90	133	135	268
17	148	155	303	91	133	135	268
18	150	157	307	92	135	139	274
19	150	157	307	93	137	141	278
20	150	157	307	94	136	140	276
21	152	159	311	95	137	142	279
22	153	160	313	96	134	140	274
23	156	163	319	97	133	138	271
24	158	165	323	98	137	143	280
25	159	166	325	99	137	143	280
26	160	167	327	100	136	142	278
27	160	167	327	101	134	140	274
28	160	167	327	102	131	137	268
29	162	169	331	103	136	142	278
30	162	169	331	104	136	142	278
31	159	164	323	105	138	143	281
32	159	164	323	106	139	144	283
33	152	157	309	107	141	146	287
34	149	154	303	108	138	143	281
35	149	154	303	109	136	140	276
36	152	155	307	110	136	141	277
37	145	148	293	111	139	144	283
38	143	146	289	112	141	146	287
39	139	141	280	113	140	145	285
40	142	146	288	114	137	142	279
41	143	147	290	115	140	145	285
42	142	147	289	116	141	146	287
43	144	148	292	117	139	144	283
44	141	144	285	118	137	141	278
45	139	141	280	119	137	141	278
46	142	144	286	120	140	144	284
47	141	145	286	121	141	145	286
48	144	148	292	122	144	147	291
49	147	151	298	123	146	149	295
50	143	147	290	124	142	145	287
51	140	144	284	125	139	140	279
52	139	142	281	126	140	140	280
53	139	142	281	127	136	140	276
54	137	141	278	128	137	141	278

55	139	142	281	129	135	139	274
56	143	147	290	130	135	140	275
57	142	146	288	131	133	138	271
58	142	146	288	132	134	139	273
59	144	148	292	133	134	139	273
60	145	149	294	134	134	138	272
61	147	151	298	135	134	138	272
62	150	153	303	136	135	139	274
63	148	152	300	137	135	139	274
64	146	150	296	138	135	139	274
65	146	151	297	139	133	136	269
66	146	150	296	140	134	139	273
67	145	149	294	141	134	138	272
68	145	150	295	142	132	136	268
69	151	155	306	143	130	134	264
70	150	154	304	144	126	130	256
71	149	153	302	145	126	129	255
72	148	152	300	146	127	131	258
73	145	149	294	147	126	131	257
74	144	148	292	148	126	131	257
				149	128	132	260
Threshold (0.8)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	40	39	79	77	69	70	139
2	47	47	94	78	70	70	140
3	51	51	102	79	70	71	141
4	54	54	108	80	68	69	137
5	56	55	111	81	65	66	131
6	61	62	123	82	67	68	135
7	63	64	127	83	65	66	131
8	65	65	130	84	64	65	129
9	65	66	131	85	66	67	133
10	66	66	132	86	63	63	126
11	67	68	135	87	63	64	127
12	69	70	139	88	62	63	125
13	69	70	139	89	61	62	123
14	70	71	141	90	61	61	122
15	72	72	144	91	61	62	123
16	73	74	147	92	61	62	123
17	73	74	147	93	61	62	123
18	75	76	151	94	63	63	126
19	75	76	151	95	62	63	125
20	75	76	151	96	62	63	125
21	76	77	153	97	62	62	124
22	77	78	155	98	61	61	122
23	77	78	155	99	61	61	122

24	78	79	157	100	61	61	122
25	78	79	157	101	59	59	118
26	79	80	159	102	60	60	120
27	79	80	159	103	62	62	124
28	80	80	160	104	61	61	122
29	80	81	161	105	58	58	116
30	80	81	161	106	59	59	118
31	79	80	159	107	59	59	118
32	79	79	158	108	58	59	117
33	76	76	152	109	58	59	117
34	74	74	148	110	59	60	119
35	75	75	150	111	60	61	121
36	74	74	148	112	61	62	123
37	75	75	150	113	60	61	121
38	74	74	148	114	62	63	125
39	70	70	140	115	63	64	127
40	71	71	142	116	65	66	131
41	67	67	134	117	67	69	136
42	67	66	133	118	69	71	140
43	70	70	140	119	69	71	140
44	72	71	143	120	70	72	142
45	71	71	142	121	70	72	142
46	74	74	148	122	69	70	139
47	78	78	156	123	69	71	140
48	75	75	150	124	68	70	138
49	75	75	150	125	69	71	140
50	75	75	150	126	67	69	136
51	76	76	152	127	67	69	136
52	75	75	150	128	67	69	136
53	74	74	148	129	67	69	136
54	75	75	150	130	67	69	136
55	74	74	148	131	68	70	138
56	74	74	148	132	66	67	133
57	74	73	147	133	68	69	137
58	71	71	142	134	68	69	137
59	71	71	142	135	68	69	137
60	72	72	144	136	71	71	142
61	73	73	146	137	72	73	145
62	72	72	144	138	72	73	145
63	73	73	146	139	72	73	145
64	72	72	144	140	71	72	143
65	70	70	140	141	71	72	143
66	72	72	144	142	69	70	139
67	72	72	144	143	70	71	141
68	73	73	146	144	71	72	143
69	73	74	147	145	72	73	145

70	74	75	149	146	73	74	147
71	73	74	147	147	74	75	149
72	73	74	147	148	72	73	145
73	74	75	149	149	73	73	146
74	73	74	147				
75	69	70	139				
76	69	70	139				
Threshold (0.9)							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	11	11	22	75	21	21	42
2	12	12	24	76	22	22	44
3	13	13	26	77	22	22	44
4	15	15	30	78	22	22	44
5	15	15	30	79	22	22	44
6	17	17	34	80	20	20	40
7	18	18	36	81	20	20	40
8	19	19	38	82	23	23	46
9	20	20	40	83	22	22	44
10	20	20	40	84	21	21	42
11	20	20	40	85	21	21	42
12	20	20	40	86	21	21	42
13	20	20	40	87	21	21	42
14	20	20	40	88	20	20	40
15	20	20	40	89	21	21	42
16	20	20	40	90	22	22	44
17	20	20	40	91	24	24	48
18	20	20	40	92	24	24	48
19	21	21	42	93	24	24	48
20	21	21	42	94	25	25	50
21	21	21	42	95	25	25	50
22	22	22	44	96	25	25	50
23	22	22	44	97	25	25	50
24	22	22	44	98	25	25	50
25	22	22	44	99	25	25	50
26	24	24	48	100	24	24	48
27	24	24	48	101	23	23	46
28	24	24	48	102	24	24	48
29	25	25	50	103	24	24	48
30	25	25	50	104	25	25	50
31	25	25	50	105	25	25	50
32	25	25	50	106	24	24	48
33	24	23	47	107	25	25	50
34	23	23	46	108	25	25	50
35	24	24	48	109	26	26	52
36	24	24	48	110	26	26	52
37	24	24	48	111	26	26	52

38	24	24	48	112	25	25	50
39	23	23	46	113	24	24	48
40	25	25	50	114	24	24	48
41	26	26	52	115	24	24	48
42	25	25	50	116	24	24	48
43	24	24	48	117	25	25	50
44	24	24	48	118	24	24	48
45	24	24	48	119	23	23	46
46	24	24	48	120	22	22	44
47	24	24	48	121	23	23	46
48	23	23	46	122	22	22	44
49	23	23	46	123	23	23	46
50	23	23	46	124	23	23	46
51	24	23	47	125	23	23	46
52	23	23	46	126	23	23	46
53	23	23	46	127	21	21	42
54	22	22	44	128	21	21	42
55	22	22	44	129	22	22	44
56	23	22	45	130	22	22	44
57	23	23	46	131	22	22	44
58	23	23	46	132	21	21	42
59	22	22	44	133	22	22	44
60	22	22	44	134	23	23	46
61	22	22	44	135	23	23	46
62	22	22	44	136	22	22	44
63	23	23	46	137	22	22	44
64	23	23	46	138	22	22	44
65	24	24	48	139	23	23	46
66	23	23	46	140	23	23	46
67	23	23	46	141	22	22	44
68	22	22	44	142	22	22	44
69	22	22	44	143	21	21	42
70	21	21	42	144	21	21	42
71	22	22	44	145	21	21	42
72	22	22	44	146	22	22	44
73	21	21	42	147	22	22	44
74	21	21	42	148	20	20	40
				149	20	20	40

ANNEX 3: Simulation Results Data for Constraining Activities

Shopping + Pick/Drop							
Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	134	135	269	77	240	258	498
2	166	174	340	78	239	256	495
3	180	196	376	79	236	253	489
4	193	209	402	80	232	251	483
5	201	221	422	81	237	255	492
6	206	225	431	82	234	250	484
7	213	235	448	83	236	253	489
8	217	240	457	84	236	253	489
9	221	244	465	85	235	251	486
10	224	248	472	86	237	252	489
11	226	250	476	87	238	255	493
12	227	253	480	88	234	250	484
13	231	258	489	89	233	251	484
14	235	262	497	90	235	253	488
15	237	264	501	91	230	248	478
16	237	264	501	92	234	252	486
17	240	267	507	93	234	251	485
18	242	269	511	94	238	255	493
19	242	269	511	95	240	258	498
20	244	271	515	96	241	258	499
21	246	273	519	97	240	255	495
22	246	273	519	98	240	254	494
23	251	278	529	99	239	253	492
24	251	278	529	100	236	251	487
25	253	280	533	101	238	253	491
26	253	280	533	102	233	248	481
27	254	281	535	103	234	249	483
28	255	282	537	104	231	246	477
29	259	286	545	105	230	244	474
30	260	287	547	106	233	245	478
31	258	284	542	107	231	244	475
32	255	280	535	108	226	239	465
33	256	278	534	109	222	236	458
34	257	275	532	110	225	237	462
35	252	272	524	111	223	235	458
36	243	258	501	112	224	236	460
37	245	260	505	113	230	243	473
38	243	259	502	114	228	237	465
39	243	257	500	115	231	241	472
40	240	254	494	116	229	238	467
41	238	252	490	117	229	238	467
42	234	250	484	118	228	238	466

43	234	250	484	119	229	240	469
44	233	249	482	120	228	240	468
45	232	249	481	121	225	239	464
46	228	245	473	122	231	244	475
47	227	242	469	123	232	245	477
48	228	247	475	124	231	244	475
49	226	243	469	125	229	240	469
50	220	236	456	126	224	237	461
51	221	237	458	127	224	237	461
52	221	236	457	128	222	234	456
53	219	234	453	129	223	239	462
54	219	232	451	130	224	239	463
55	220	235	455	131	225	240	465
56	222	239	461	132	223	237	460
57	223	240	463	133	218	232	450
58	223	237	460	134	220	235	455
59	218	232	450	135	218	232	450
60	220	233	453	136	215	229	444
61	227	241	468	137	218	233	451
62	230	246	476	138	221	235	456
63	232	248	480	139	223	241	464
64	232	248	480	140	226	244	470
65	232	248	480	141	227	245	472
66	236	251	487	142	229	247	476
67	236	253	489	143	232	251	483
68	239	255	494	144	230	248	478
69	237	253	490	145	232	249	481
70	236	253	489	146	233	250	483
71	237	254	491	147	231	248	479
72	232	248	480	148	234	253	487
73	235	250	485	149	233	252	485
74	237	253	490				
75	236	251	487				
76	242	259	501				

Pick/Drop

Day	Drivers(Cars)	Passengers	Carpoolers	Day	Drivers(Cars)	Passengers	Carpoolers
1	142	144	286	77	237	252	489
2	175	179	354	78	236	251	487
3	195	203	398	79	235	250	485
4	207	216	423	80	234	250	484
5	214	224	438	81	232	247	479
6	219	231	450	82	225	239	464
7	225	239	464	83	225	238	463
8	230	246	476	84	228	242	470
9	236	253	489	85	225	239	464
10	239	258	497	86	223	237	460

11	240	259	499	87	219	230	449
12	242	261	503	88	222	235	457
13	243	262	505	89	218	230	448
14	248	267	515	90	215	229	444
15	251	269	520	91	213	227	440
16	254	273	527	92	213	226	439
17	256	275	531	93	214	227	441
18	258	277	535	94	215	228	443
19	261	281	542	95	216	228	444
20	261	281	542	96	215	227	442
21	262	282	544	97	219	232	451
22	263	284	547	98	214	226	440
23	265	286	551	99	215	228	443
24	267	288	555	100	217	230	447
25	270	290	560	101	216	230	446
26	272	293	565	102	216	229	445
27	272	293	565	103	214	228	442
28	272	293	565	104	215	228	443
29	276	297	573	105	213	226	439
30	279	299	578	106	210	223	433
31	277	299	576	107	214	227	441
32	277	297	574	108	219	233	452
33	275	296	571	109	220	235	455
34	271	289	560	110	221	236	457
35	258	276	534	111	223	237	460
36	261	279	540	112	221	234	455
37	260	275	535	113	217	229	446
38	257	273	530	114	219	231	450
39	256	270	526	115	220	233	453
40	257	272	529	116	217	230	447
41	257	272	529	117	217	230	447
42	258	272	530	118	221	233	454
43	256	272	528	119	216	228	444
44	251	267	518	120	216	227	443
45	253	269	522	121	220	231	451
46	256	271	527	122	219	229	448
47	257	270	527	123	221	232	453
48	257	270	527	124	220	231	451
49	259	269	528	125	216	227	443
50	257	269	526	126	215	226	441
51	257	267	524	127	213	223	436
52	251	261	512	128	210	220	430
53	239	250	489	129	214	224	438
54	238	249	487	130	212	223	435
55	242	251	493	131	208	217	425
56	241	252	493	132	211	221	432

57	242	254	496	133	210	223	433
58	240	252	492	134	216	230	446
59	238	250	488	135	218	230	448
60	240	251	491	136	219	229	448
61	243	254	497	137	221	230	451
62	248	260	508	138	221	230	451
63	247	258	505	139	219	228	447
64	247	258	505	140	216	226	442
65	244	256	500	141	214	224	438
66	240	253	493	142	215	227	442
67	238	251	489	143	216	228	444
68	243	254	497	144	218	229	447
69	241	255	496	145	219	231	450
70	241	256	497	146	218	229	447
71	245	258	503	147	216	226	442
72	241	255	496	148	218	227	445
73	239	253	492	149	223	232	455
74	234	249	483				
75	238	251	489				
76	238	253	491				

ANNEX 4: JAVA Coding of the Proposed Preference Function

```
package function;
public class func {

		public func() {
			// TODO Auto-generated constructor stub
		}
		private static int tripTimeInvitor = 0, tripDuration=0, wait=0,late=0, early=0;
		private static double maxPF = 0;
		public static void main(String[] args) {
			// TODO Auto-generated method stub
			tripTimeInvitor = 810;
			tripDuration=3;
			wait=0;late=0; early=0;
			double expSum = utilityFunction(); double sum = 0, probSum=0;

			double sumsum =0;
			for (int i=tripTimeInvitor+(-30);i<=tripTimeInvitor+30;i++){

				if(i>tripTimeInvitor){
					early = 0;
					wait=i-tripTimeInvitor;
					late=wait;
				}
				else {
					early=tripTimeInvitor-i;
					wait=0;
					late=wait;

				}



				double preferenceFunctionOfInvitor = -2.09 - 0.008*(90/100*tripDuration) -
0.021* (10/100*tripDuration) - 0.699*(2520/60000) -
				0.095*(5) - 0.088*(wait) - 0.148*(late) + 0.0014*(late*late) - 0.01 *(early) -
0.00042 *(early*early);
				double probability = Math.exp(preferenceFunctionOfInvitor)/expSum;
				sumsum =sumsum + probability;

				System.out.println(""+probability);
			}
			System.out.println("sum: ["+sumsum+"]");

		}
		private static double utilityFunction(){
			double sum = 0;
			for (int i=tripTimeInvitor+(-30);i<=tripTimeInvitor+30;i++){

				if(i>tripTimeInvitor){
```

```
						early = 0;
						wait=i-tripTimeInvitor;
						late=wait;
					}
					else {
						early=tripTimeInvitor-i;
						wait=0;
						late=wait;

					}


					double preferenceFunctionOfInvitor = -2.09 - 0.008*(90/100*tripDuration) -
0.021* (10/100*tripDuration) - 0.699*(2520/60000) -
								0.095*(5) - 0.088*(wait) - 0.148*(late) + 0.0014*(late*late)
- 0.01 *(early) - 0.00042 *(early*early);
					sum = sum + Math.exp(preferenceFunctionOfInvitor);

				}
				return sum;
			}

		}
```

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Activity-based models: agent negotiation to cooperate for carpooling

Richting: **Master of Transportation Sciences-Mobility Management**
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Khan, Muhammad Arsalan

Datum: **2/06/2015**