An Agent-based model to assess the impacts of introducing a shared-taxi system in Lisbon (Portugal)

Luis M. Martinez
Instituto Superior Técnico
Phone: (+351) 21 841 84 25
E-mail: martinez@civil.ist.utl.pt

Gonçalo Correia
University of Coimbra
Phone: (+351) 239 79 71 05
E-mail: gcorreia@dec.uc.pt

José M. Viegas
Instituto Superior Técnico
Phone: (+351) 21 841 84 13
E-mail: viegas@civil.ist.utl.pt

ABSTRACT

This paper presents a simulation procedure to assess the market potential for the implementation of a new shared taxi service in Lisbon (Portugal). The proposed shared taxi service has a new organisational design and pricing scheme which aims to use the capacity in traditional taxi services in a more efficient way. In this system a taxi acting in "sharing" mode offers lower prices to its clients, in exchange for them to accept sharing the vehicle with other persons who have compatible trips, (time and space) while also increasing the revenue for the operator.

The paper proposes and tests an agent based simulation model in which a set of rules for space and time matching between the shared taxis and passengers is identified considering a maximum deviation from the original route and then presents an algorithm that considers the following different objectives: minimum cost per passenger.km, maximum revenue per vehicle.km, minimum passenger in-vehicle time, minimum vehicle idle time.

An experiment for the city of Lisbon is presented with the objective of testing the proposed simulation conceptual model and to show the potential of sharing taxis for improving mobility management in urban areas.

General Terms: Algorithms; Design; Performance

Keywords: Agent-based models; shared taxi systems; ride matching

1. INTRODUCTION

The rising of automobile usage deriving from urban sprawl and car ownership growth is making traffic congestion more frequent and harder in urban areas. Moreover the majority of the trips are single occupant vehicle trips (SOV) resulting in more automobiles for the same persons. In 1990 approximately 90% of the work trips and 58% of the other trips in the United States were done in SOV [1]. Numbers of 1997 show that the occupation rate of the automobiles in commuting trips for the 15 Countries of the European Union was, at that time, in the interval between 1.1 and 1.2 persons per vehicle [2]. This results in air pollution, energy waste and unproductive and inefficient consumption of the time that persons have, and this does not show a tendency to slow down. In fact, traffic congestion and the corresponding environmental damage present a tendency to be aggravated.

This brings direct disadvantages for the users but also for the general economy and society at large. In 2001, the White Book on Transport Policy in the European Union stated that "if nothing is done, the cost of congestion will, on its own, account for 1 % of the EU's gross domestic product in 2010" [3], with a significant part of these costs respecting to urban transportation: traffic congestion associated to the automobile commuter trips. This is happening even in countries with high fuel prices, good Public Transport (PT) systems and dense land occupation [1].

PT cannot be the only alternative because providing transport capacity for peak periods would result in too many vehicles staying idle in non-peak periods, and too many people would be served with two or more transfers. Thus, there is the need to consider other alternatives, outside the classical transport modes. This is actually not a new idea. In the seventies, with the Arab Oil Crises, scientific interest arose for new transport alternatives, mainly in the United States. In fact it was in this decade that the first extensive research on this subject was published. In 1974 Ron Kirby and Kisten Bhat of the Urban Institute in Washington, U.S., released their report named: "Para-transit: Neglected Options for Urban Mobility" [4], this term, "Para-transit" was used as a general term to describe the various forms of flexible transportation that do not follow fixed routes or schedules such as shared taxis or carpooling.

Each one of these new modes has been studied and developed in the last decades, with several research projects and experiments being run and tested all over the world but the most advanced mainly in the USA and in Europe. They have been generally studied as isolated measures for controlling traffic congestion or for improving mobility options and, in some cases, they were able to have some (albeit rather limited) impact in reaching these objectives.

The shared taxi alternative denotes the use of common taxi-cabs by more than one person (or small party) serving multiple trips in the same taxi route [5]. This allows increasing the taxi operator's profit because costs should not vary significantly while there is the possibility of collecting a price from each passenger, even implementing a lower fare which should attract more passengers to this mode. Being a PT option but at the same time a low capacity mode, it is ideal for serving as a feeder system for other heavy transportation modes such as suburban trains [6].

However, there are not only advantages in using this system. In order for it to work there has to be people willing to share the vehicle with unknown passengers. In this case this should be softened by the presence of the taxi driver when compared to carpooling. Regarding trip time there may also be some discomfort for the extra riding time resulting from detours, this may or may not be compensated by lower transport costs and shorter waiting time for an available taxi.

All these questions make this an interesting mode for policy consideration, and for being modelled through simulation, studying the effect of different operational parameters on the its market potential, mobility enhancement and transferring SOV trips to more efficient transport options.

In this paper we present such a simulation model developed under the principles of agent-based techniques. In the next section we review the existing shared taxi experiments followed by the system that we propose. The conceptual model is developed next presenting its main components, relationships and necessary input data and possible output indicators. In the following section an experiment is conducted using the conceptual model implemented in the simulation software AnyLogic (Xj Technologies). In this experiment we aim at proving the usefulness of the model by trying to answer the question as to how many less taxicab vehicles would be needed to attend current taxi demand if they were all functioning in shared mode. In the final section of the paper we end taking conclusions about the shared taxi mode and the simulation method.

2. THE SHARED TAXI EXPERIENCE

The idea of sharing taxis is not entirely new, both for economic reasons and for convenience there have been experiences in different countries of the world. However, the concept may vary greatly and is sometimes confused with other transportation alternatives as, for instance, vanpooling or mini-bus services. These are usually classified as paratransit transport services [7], a term which initially covered only unregulated services and is now extending to several offers being integrated in city transport networks.

These paratransit services usually operate under fixed routes, picking up passengers in pre-determined stops or at any point and leaving them in any place along a fixed route, charging a lower fare when compared to the regulated transport services. They found their share in places where supply was weaker. Not surprisingly it was in third world countries that these alternatives flourished, nourished by poor quality PT services and a great latent demand for travelling. For instance, while illegal, it is still normal in Korea to share a taxi with people having similar destinations [8].

Nevertheless these transport alternatives have also found their space in developed countries. One of the examples is carpooling, which has taken a very significant share of US commuters, is present even in Europe where PT systems are traditionally of a superior quality in service and comfort [9].

The most similar transport mode with the shared taxi systems has actually appeared very early in the 20th century in the USA and it had the curious designation of jitney. “During the economic downturn of 1914, some Los Angeles motorists down on their luck began giving rides at a nickel, or ‘jitney’, per trip and tended to shadow streetcar routes” [10].

The concept of collective taxi has been used for many years in Istanbul, Turkey, where it is a popular transportation alternative. There, it is called the dolmus which means to fill in Turkish. These cabs run a pre-determined route, with each passenger paying only a portion of the normal fare, making it a win-win situation where passengers pay less and drivers earn more money for the same distance. Passengers can get out anywhere along the route for a single set fare that is the same for all passengers no matter what their destination. Although their use is declining, dolmushes still operate within cities, and between cities and nearby towns and villages.

Despite the unregulated transport experiments with shared taxis or mini-bus and their progressively being included in the regulated services which always demands a certain level of standardisation of the operation, these systems objectives have not reduced their value along the years. There is still demand for intermediate modes between private transportation and high capacity PT vehicles such as buses and subway systems. That is why the shared taxi is being recovered as a modern transport option.

Advanced initiatives have been tested in order to take advantage of modern communication technology, namely cell phones, to help make viable the concept of shared taxi. A seed-stage company in the UK has developed a system that collates requests for point-to-point travel from a dispersed set of clients via SMS (they text-message by cell phone their destination postcode to the system), and then packages clients going in the same direction into one vehicle at a discounted fare. This is active now in four cities: London, Liverpool, Bournemouth and Isle of White. Passengers are instructed to go to pre-determined pickup points to meet the driver who will have received a text confirming each passenger’s booking reference [11].

In Brussels, Belgium, taxis are a regulated private sector undertaking, legally defined as door-to-door transport (strictly distinguished from limousine and car rental), with a proportional distance and time-based fare. Local authorities grant licenses, set price levels, supervise compliance with social legislation and define policy objectives. There is no possible confusion with the PT operators, whose core business is regular collective transport, based on fixed routes and timetables, integrated into bus, tramway and subway networks. Both are struggling against their polarised public images: whereas PT is upgrading to decrease its reputation as overcrowded, unreliable transit for the captive masses, taxis are striving to be seen as more than elite luxury transport [12]. In this city, authorities decided to implement a new night taxi service operated by a dispatcher and call-centre as a public service contract. The operator has been equipped with an optimisation system technology, and has upgraded the necessary number of cabs of affiliated taxi operators. No extra vehicles or drivers were put into circulation: ordinary taxis alternate between traditional taxi trips or shared taxi trips, as dispatched by the central. The operator provides a monthly listing of trips, their real cost (as registered by the taximeters) and fare revenue. The authorities then compensate for the difference, and the central distributes this sum among the taxi companies involved. For the taxi companies, each shared taxi trip is simply an extra trip, yielding full revenue.

From a modelling perspective, some incipient models have been recently developed to explore the shared taxi concept. Most of them use an optimisation [1316], simulation [17] or simulation-optimisation approach that support the ride matching algorithms, as well as a network operation model in dynamic models[1820]. Some of the simulation models have explored an Agent-based formulation [1720].

Overall it is noteworthy to verify that the previously referred studies have used simulation models and have pointed them as a good method to test the proposed dispatching strategies given the highly dynamic characteristics of the taxi services. Moreover, it is obviously impractical to deploy new taxi directives immediately in the real world without carefully studying them, which can be done through a realistic computer simulated environment.

3. A NEW SHARED TAXI SYSTEM

As we have seen, when taxi shared services are successful they are so for two main reasons: short supply of traditional taxi services and other PT modes and/or allowing saving money in travel expenses. It is not surprising that the night period has come up as the best period for operating such transportation option: supply of PT is rather low during this period of the day, moreover there are many young people going out who often do not have a driving license, or want to drink beyond the legal limit for driving and whose only option is the taxi, an option which is usually expensive and that could be reduced through sharing the vehicle.

The system that we propose should be more comprehensive and not just an alternative for a night out, it should be a real option for any kind of trip at any period of the day within the boundaries of an urban area. Nevertheless the price must also play a strong role for sharing the taxi in such a way.

One should be reminded that the taxi is one of the best transport options that a person can have when convenience, comfort and safety are considered. A person is driven in a private vehicle which picks him up at the origin's door and drops him off at a precise destination point, without worries about parking the vehicle, and carrying a load whenever needed. Travel time maybe affected by traffic congestion during peak periods of the day but in many cities (as in Lisbon) less so than for a private car, as taxis are allowed to use Bus lanes. Moreover, as they are making a point to point trip, they can take detours recommended by GPS-based navigation systems, whereas when using traditional PT options the route is fixed.

The only problem remains to be the price of riding a cab. This varies from country to country, however it is never as low as other PT modes, hence it makes it a transportation option for higher income people or for those who do not own a private vehicle [21]. Sharing the taxi allows dividing the cost of the ride as already mentioned. However, the key question is: how is it possible to maintain the advantages of the taxi while sharing the vehicles? We have seen that most taxi sharing schemes are supported by pre-defined routes and/or have pre-located stops where people have to go, thus in practice the door to door advantage is lost.

The system which we propose makes use of current communication technology and GPS in order to bring flexibility to the system, managing virtually any possible origin and destination in an urban area. Trip requests are sent through a cell phone stating current position (or wished boarding point) and asking for a ride for a specific destination point. A central dispatcher collects this request and must then find a taxi match (this process is explained in the next section).

Central dispatching is already used as part of regular taxi services in order to improve customer demand compliance by computing in real time the closest taxi available [22]. However, the task of matching passengers and vehicles is obviously not straightforward as some of the cabs will already be transporting one or more passengers who have to be adequately served and reach their destination in acceptable time. The detours for picking and dropping-off other passengers may hinder many matches to be formed. This is not the case with the majority of the examples of current shared taxi practice where taxis stay practically in pre determined routes constrained by the existing stops.

4. THE SIMULATION FRAMEWORK

Every simulation experiment should start by a conceptual model which determines the relationship between its main elements and aims capturing the way the real system will function once it is implemented.

Because this is a simulation model of a system which will work in real-time, the simulation is based in a typical working day. The environment where the simulation takes place is a Road Network of the city where shared-taxi vehicles circulate and trips should be created according to census data or trip generation indicators. A Dispatcher will manage a centralised operation assigning taxis to clients using as his main information sources: the location of shared taxi vehicles, their current occupancy rate and the location of clients (assuming for simplification purposes that all passengers will want to be picked up at their current coordinates).

The simulation model for shared taxi services which we present is developed through agent-based simulation which is a class of computational models for simulating the actions and interactions of autonomous agents (either individual or collective entities such as organisations or groups) with the objective of assessing their effects on the system as a whole.

The models simulate the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena. The process is one of emergence from the lower (micro) level of systems to a higher (macro) level. As such, a key notion is that simple behavioural rules generate complex behaviour.

This structure makes it clear how to program each element of the Agent-Based model for the shared taxi system and understand its possibilities. Using this classical structure one may begin by defining these elements for the two types of agent in the model: Taxis and Clients.

4.1 Client Agent

When a client decides to take a taxi, he first decides which type of service he will take: hail a taxi near their origin (where he may decide to go to a specific point of the network with greater probability of finding an available taxi); walk to a close taxi rank; or call a dispatching company. The selection of the action is randomly generated but with different probability profiles according to the city area and time of the day, trying to reproduce the knowledge that clients have. The possible states of this agent are then: searching for a taxi, waiting for an assigned taxi, or riding a taxi.

The general flowchart of the client agent is presented in Figure 1, where the different states, transitions and interaction are detailed. The decision process will be dependent of the type of taxi market selected by the client (e.g. hailing, taxi rank or phone request for a shared taxi service).

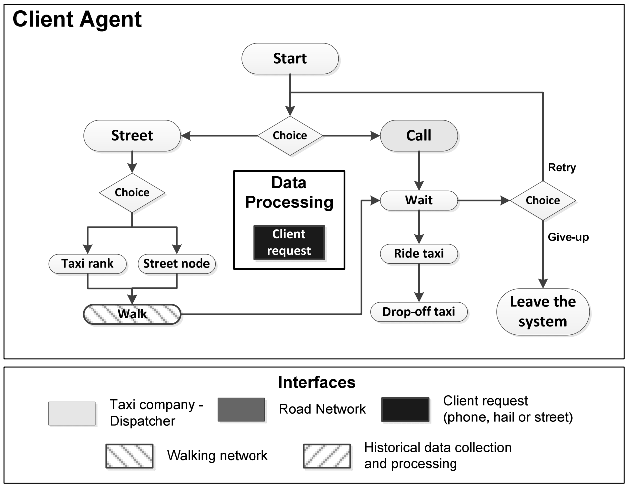

Figure 1. Simulation flowchart of the clients' agent

The rules for his behaviour are:

- Hail a taxi in the initial node or walk to a better hailing location;
- Walk to the "best" taxi rank within a walking threshold of his current location (using a trade-off function between the probability of finding a taxi and the willingness to walk);
- Dial to a dispatching service (randomly selected among the existing available options) to ask for a share taxi service;
- When the client goes to a road node or taxi rank, he waits for a taxi using a FIFO serving procedure;
  - If the client does not get a taxi after a threshold waiting time, he may re-evaluate (using a probabilistic approach) the decision of waiting or calling a dispatcher company to get a taxi;
  - After waiting up to a maximum of $\text{waiting}_{\text{max}}$, the client leaves the system.
- When the client calls for a taxi and one is assigned to him, he automatically accepts that assignment;
- If a taxi is not assigned to him immediately, he waits for a given period (e.g. 1 minute) and places another taxi order, being the waiting time accounted since the first call for a taxi. After a maximum of three trials, the client considers selecting another dispatcher;
- After waiting more than the limit threshold ($\text{waiting}_{\text{max}}$) without a taxi being assigned, he gives up from the service and goes out of the system.

4.2 Taxi Agent

A taxi can be connected to different taxi dispatching companies, being operated by a single driver (owner of the car) or belong to a taxi firm where several drivers work in shifts. The organisational model of supply is an input of the model. The possible states of this agent are then: being on route to pick-up a specific passenger (allocated by the Dispatcher); being on route; in service with passengers on board; being on route to a taxi rank; browsing the area for passengers; waiting at a taxi rank for an assignment; or being idle (taxi driver resting).

The general flowchart of the taxi agent is presented in Figure 2, where the different states, transitions and interaction are detailed.

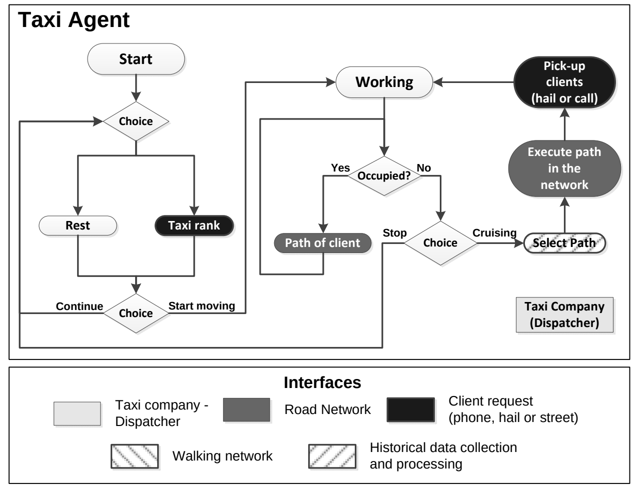

Figure 2. Simulation flowchart of the taxi agent

The main rules of behaviour are:

- The taxi is normally heading to a taxi rank to wait for the next service. This next service may be picking up a client at that taxi rank or, if in the meanwhile the central dispatch assigns him a passenger, he will deviate from the current destination. When the taxi decides to stop at a taxi rank, it uses a route passing through areas where the probability of finding a customer is higher;
- The taxi not connected to a central dispatch system also routes through the network covering mainly the areas which historically have had a higher demand for taxi trips;
- The taxis located at a taxi rank give up waiting for a passenger if the service time in the taxi queue leads to a waiting time greater than a threshold. In this situation, the taxis either search for another taxi rank or route through the network (Monte Carlo generated);
- Taxis have shifts thus they are not always active. These are city and country specific and must be set because it determines the percentage of active taxis. If the taxi is connected to a central dispatch system, the company office's location will be selected as stop location; otherwise, the taxi will select randomly a node of the network to become inactive.

4.3 Simulation Environment

The environment where the agent based simulation takes place is a road network where taxi vehicles circulate and trips are created according to mobility survey data of the city. The road network contains link attributes, resulting in different travel times for different periods of the day. In each period, the network should accurately translate the impedance of travelling from point to point in the simulated urban area, reproducing the measured average congestion of road sections for the different periods of the day. Yet, the model presents a static non-equilibrium based traffic assignment procedure for the taxis, in a fixed traffic state, depending on the hour of the day. This simplification reduces considerably the computational burden of the model because it avoids the inclusion of other modes using the same road infrastructure (i.e. private cars and PT vehicles).

The model assumes that taxi drivers are experienced and that they are able to choose the shortest path for their destination, thus we use the Dijkstra's Algorithm, which computes in real time the shortest (quickest) path between any given pair of nodes on the road network for a given time period during the day. We assume that the variation of the number of taxis in service in our simulation does not affect the predefined travelling speeds on the links of the network.

This changing environment is then used as interface for the different agents of the system, which interact through this platform and generate new data that changes its state variables. The different information linkages among agents and between agents and the environment can also be seen in Figure 1 and Figure 2.

The model presents five main types of interactions. A key element of interaction of the model is the taxi request, which can activate the three different types of taxi operational modes (rank, hail and call). Depending on the selected option by the user other types of interfaces are activated. If the clients chose to dial to a taxi company, a dispatcher service is activated to match the user and the active taxis. Otherwise, the client will connect to the taxi through the walking network: either by hailing a taxi or by walking to the most adequate taxi rank nearby. This demand data is then collected by the system to provide information to the taxi driver about the historical distribution, time and space dimensions, of the clients. This information is then used by taxi drivers to choose the most adequate taxi ranks to stop at different hours of the day. Furthermore, this information is also used to choose the most attractive routes for finding clients in the street. The last element of interaction between the agents and the environment is used in the hailing market, where the "vision" of the clients of a taxi that is approaching and of a taxi driver of a client request is modelled. This component considers the geometry of the road network (length of the road links and angles at intersections) assessing the maximum range of visibility at a certain location. Moreover, the probability of a taxi being able to stop and get the client is also a function of the estimated traffic flow of the street where the client is located. If arc is congested is more difficult for a taxi driver to switch to the right lane and stop for boarding. All these processes are parameterised in the model, considering fixed parameters for all clients and taxi instead of a statistical distribution with a specific value generated for each individual agent.

4.4 The Dispatcher

The Dispatcher was not conceived in the model as an Agent, but as an entity that defines a set of rules for matching together taxis and passengers, concentrating all real-time information required to produce and monitor these trips.

The choice of which taxis to match with each client follows a linear programming optimisation model. The problem was formulated with an objective function that aims to combine the minimisation of passenger travel time (the one(s) riding and the one requesting a taxi), while also considering the revenues of each individual taxi and the equity among them (always a strong concern in the real world).

There are several ride-matching optimisation algorithms formulated in the literature [23]. Yet, most of these models formulate a simultaneous matching between several drivers, going to their destinations, and several ride requests, aiming to achieve a system optimum considering all demand and supply gathered in a time interval. This is especially important when there is great density of clients and drivers, but in our case we believe that the simplicity of only considering one client at a time makes the simulation much faster and the solution will not be significantly far from the optimum due to the low density of requests in the city (distance between callers is too high for there to be any true competition for the same taxi).

We should note however that it would be easy to integrate in the simulation model any kind of algorithm to match passengers and clients, which is one of the advantages of simulation techniques.

The current formulation reduces significantly the complexity of this problem by evaluating the best ride matching alternative for a single client, following a request order. The smaller size of this problem allows searching exhaustively for an optimal solution within a small to medium size domain of solutions in a very short simulation time.

The strategy for selecting taxis is shown in Figure 3, in it we may see multiple taxis available within a coverage area centred in the client's coordinates. We also describe the coefficients used to build the constraints of the problem.

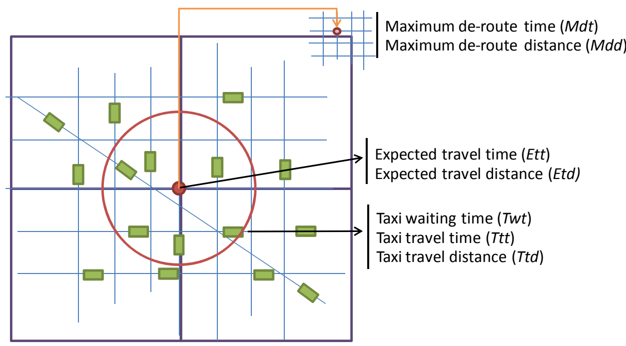

Figure 3. The taxi-client matching problem

In order to solve this combinatorial problem, we started by defining the maximum de-route time (*Mdt*) and de-route distance (*Mdd*) that the passenger is willing to accept for the current trip. These parameters of the simulation were initially set by the authors as percentage of *Ett* and *Etd* values respectively, function of travelled time and distance.

Then, for each client *i*, the dispatcher's computer specifies: The expected travel time (*Ett*) and travel distance (*Etd*) for the given origin and destination of the passenger, computed by the shortest path algorithm for the current time period of the day (Dijkstra's Algorithm included in the agent-based model).

It also computes for each taxi *j* and each client *i* at time instant *t*, the following variables: the waiting time for the taxi (*Twt*), the taxi travel time (*Ttt*) and travel distance (*Ttd*). This travel time takes into consideration the minimum sum of disturbance time for each passenger on board that would be introduced to the current riders and to the new client. This time is also computed using a combinatorial problem which can be expressed by:

$$Ttt_{Taxi\ P} = tt_{Taxi\ P} + min\left\{tt_{Pi} + \sum_{j=i,k=j+1}^{Clients} tt_{jk}\right\}$$

Where $Ttt_{Taxi\ P}$ is the travelling time between the current position of the taxi and pick-up point of client *P*, tt_{Pi} the travelling time between the pick-up point of client *P* and the drop-off point of client *i*, and tt_{jk} the travelling time between the drop-off point of client *j* and the drop-off point of client *k*.

The estimation of the taxi travel time (*Ttt*) is done using the procedure presented in Figure 4, where we may see the different approaches depending on the number of passengers already on-board of the taxi.

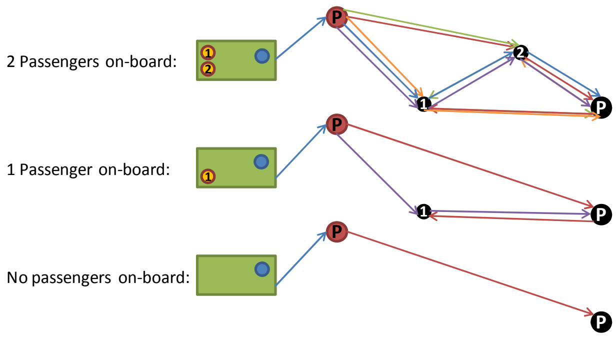

Figure 4. Example of the Taxi travel time (*Ttt*) estimation for different number of passengers on-board

The model contains the information on which road network arc the taxi and the passenger are currently positioned. It also collects the code of the zone in which the passenger is contained as well as the codes of neighbouring zones (vector *Nz*).

Then the problem is to select the taxis which are within a certain distance (e.g. 2 km) of the client's position scanning also their neighbouring zones (*Nz*) which comply with the client's constraints to travel time and distance acceptance (*Mdt* and *Mdd*). The mathematical formulation of the problem is the following:

$$\min_{i \in Taxis \subseteq Nz \subseteq R \subseteq 2km} \{Twt_{ij} + Ttt_{ij} + 1000 \cdot Empty_i - 2500 \cdot EB_i - 3000 \cdot 1Pass_i + 1500 \cdot 2Pass_i\}$$

Subject to:

$$\forall\, j \epsilon\, \mathrm{i} \therefore \mathrm{Ttt_j} \leq \mathrm{Ett_i} \cdot (1 + \mathrm{Mdt_j})$$

$$\forall\, j \epsilon\, \mathrm{i} \therefore \mathrm{Ttd_j} \leq \mathrm{Etd_i} \cdot (1 + \mathrm{Mdd_j})$$

Where Twt_{ij} is the waiting time of client *j* to be picked-up by taxi *i*; $Empty_i$ is a binary variable which takes the value 1 if taxi *i* is empty; EB_i is a binary variable which takes the value 1 if taxi *i* has been without passengers for the last 5 minutes; $1Pass_i$ is a binary variable that takes the value 1 if taxi *i* has one client already on-board; finally $2Pass_i$ is also a binary variable that takes value 1 if the taxi *i* has already two clients on-board.

The objective function, while minimising the client travel time, also assigns preferentially clients to taxis which have been empty during the last five minutes and also to taxis with two clients already on-board, presenting the same premium as the previous (weights in the objective function), and especially to taxis that have one client already on-board, which lead to greater taxi revenues and maximum discounts to the clients.

This optimisation procedure, while not corresponding to a NP-Complete problem, also presents increasing computing times with the problem dimension, which has been addressed in the simulation by reducing the subset of candidate taxis in each optimisation procedure. The considered subset includes 50% of the total taxi fleet contained by the relevant zones (vector *Nz*) or a minimum number of candidate 50 taxis.

This method allows a considerable reduction of computational time in large scale simulations (typically all the trips in an urban area), by reducing the number of times the shortest path algorithm has to be applied for the estimation of the objective function, especially during the peak hours when the average frequency of requests is considerably increased.

Another important algorithm which is used dynamically during the simulation is the estimation of taxi densities along the road network for the different zones, and the estimation of this indicator deviation relative to historical data. This information is used to determine the most suitable destinations in the network for each taxi that is going to route for passengers at a given simulation period *t*.

The Dispatcher gathers information about passenger requests from previous days at the same hour of the day and joins this information to the historical data in order to estimate the predicted concentration of taxi passengers during the next hours. At each time period, the Dispatcher measures the deviation of taxis available for clients calls (empty or with available capacity) in each zone of the city relative to its estimation of what would be required and distributes recommendations for direction of browsing based in the utilities of the different zones. Zone *i* utility function for time period *t* is given by:

$$ZU_{ti} = \frac{ED_{ti}}{\sum_{j=1}^{N} ED_{tj}}$$

$$ED_{ti} = 0.75 \cdot \sum_{k=1}^{N} D_{kti} + 0.25 \cdot SH \cdot \sum_{d=1}^{N} OD_{tid}$$

Where ED_{ti} is the estimated taxi demand of zone *i* for the time period *t* (an hour), D_{kti} are the collected taxi calls for zone *i* for the time period *t* in the *k* day, SH is the estimated taxi share for the study area, and OD_{tid} is the total number of trips in the study area for the period *t* that were originated in zone *i*.

The obtained utilities are then converted to probabilities of selecting each zone, and for each taxi order, the model generates a random number and assigns a destination zone. The final destination road network node is obtained by a random generation procedure among the nodes contained by the selected zone.

5. LISBON CASE-STUDY

The initial test bed of this new simulation procedure was the municipality of Lisbon, Portugal. Lisbon is the Capital city of Portugal and is the largest city of the country with approximately 565,000 inhabitants in an area of 84.6 km^2. Lisbon is situated on the Atlantic Ocean coast on the Tagus estuary, being the most western capital in mainland Europe. Lisbon is the centre of the Lisbon Metropolitan Area (LMA), which has approximately 2.8 million inhabitants, representing roughly 25% of Portugal population, with an area of 2,962.6 km^2, formed by other 18 municipalities.

The taxi market in Lisbon is formed by approximately 3,500 taxis, which have to apply and pay a municipal license. The number of available licenses is capped, and has not increased in recent years, which led to a significant enhancement of its (unofficial) value. Taxis have to apply and pay a municipal license [24]. The number of available licenses is capped, and has not increased in recent years, which led to a significant increase of its (unofficial) value. These licenses cannot be traded directly on the market, still companies are the owners of the licenses and companies are tradable which indirectly leads to a license market.

This license allows taxis to operate simultaneously in three market types regarding the way clients access the service: rank market, hail market and pre-booked market:

- Rank places are designated places where a taxi can wait for passengers and vice versa. Taxis and customers form queues regulated by a FIFO system. Disadvantages are that due to the FIFO policy established, price has no effect on customer choice of which taxi to take.
- In the hail market, clients hail a cruising taxi on the street. There is uncertainty about the waiting time and the quality of the service customers will find. The advantage here is that the customer does not have to walk to a taxi rank.
- In the pre-booked market, consumers telephone a dispatching centre asking for an immediate taxi service or for a later taxi service. Only in this kind of market consumers can choose between different service providers or companies. At the same time, companies can get clients' loyalty providing a good door to door service.

The three markets described are active in Lisbon and taxis may operate in them at the same time. Some taxi drivers are associated to a taxi phone dispatching company paying a fee to have access to that pool of clients. The client also has to pay the phone call when he wants to access that service. A recent study performed by Mobility and Transport Institute (IMT) showed that only approximately 48% of the taxis are associated with a dispatching company, being the other 52% restricted to the hailing and taxi rank market [24].

These three service configurations have different market expressions across the world, although they are almost all the times present in the taxi market at the same time. In New York, for instance, most of the passengers hail the taxi on the street (90%) while in Stockholm: 55% call the taxi by phone, 20% by going to a taxi rank and only 25% hail the taxi on the street [21].

The fact that in Lisbon taxis may operate in the three markets simplifies significantly the regulation of the market. In parallel, the taxi drivers' profession is also regulated by the national transport regulator (Mobility and Transport Institute – IMT). The taxis can be driven by licensed drivers, which have do take a course and pay a levy. IMT has surveyed recently taxis, and inspected the shifts of taxi drivers. The results showed that from the 3,500 taxis registered in Lisbon, only 3,100 taxis, in average, are active daily. The survey did also identify five main types of taxis drivers' shifts, which mainly depend on the ownership of the taxi (owned by the driver or by a taxi company). The resulting types of shifts of the taxi drivers in the city can be seen in Table 1.

Taxi fares are also strictly regulated by specific legislation, which set the price of the trip by three different components: a fixed starting fee, a distance related fee and a time related fee, linked to the delay time produced by congestion, set for time that is travelled for speeds under 30km/h.

In order to simulate the behaviour of the taxi market within the city of Lisbon, we gathered a large set of data required for the simulation. This data encompasses the estimation of the taxi travel demand in the city, including:

- the origin and destination of the taxi trips as well as their starting time;
- the road network;
- a calibrated traffic assignment model to obtain travel times in the road network;
- the taxi ranks location; and
- a zoning system, which was used to compute taxi concentrations along the city and help taxi drivers to decide where to go at any time during the day.

Table 1.Taxi driver shift considered in the simulation

Shift	1st driver shift	2nd driver shift
Type 1	6 am to 7 pm (idle from 12 pm to 1 pm)	
Type 2	8 am until 9 pm (idle from 2 pm to 3 pm)	
Type 3	1pm to 2 am (idle from 7 pm to 8 pm)	
Type 4	7 am until 6:30 pm (idle from 1 pm to 2 pm)	6:40 pm to 5:40 am (idle from 0:40 am to 1:10 am)
Type 5	9 am until 8:30 pm (idle from 3 pm to 4 pm)	20:40 pm to 9 am (idle from 2:40 am to 3:10 pm)

The simulation procedure uses as input the results of a synthetic travel simulation model, which was developed under the SCUSSE research project [25]. This model is based on a mobility survey of the LMA performed in 1994, with approximately 60,000 trips and 23,000 persons surveyed, and an activity database of 2009 that was used to update the travel patterns observed in the initial survey. This is a rule based model, which uses the reported travels by respondents and their connections along the day, to disaggregate a total population of trips of the LMA based on the 2009 activity generation (trip generation coefficients for different activities along the day) and transport network, generating specific origin and destination points, transport mode used and starting time of each trip.

The synthetic travel model generated 21,075 taxi trips during a week day inside the city of Lisbon. The distribution of these taxi trips along the day is presented in Figure 5, where we may observe a higher concentration of trips during the morning peak and some periods during the lunch break and the afternoon.

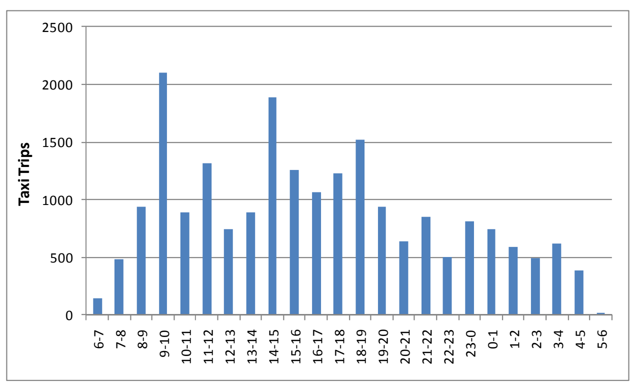

Figure 5. Distribution of taxi trips throughout a working day

We have to acknowledge, that the number of estimated taxi trips is considerably lower than the real demand, which should include trips from Lisbon to other municipalities (additional 3,435 according to the model), and non residents of the LMA as tourists and other visitors (e.g. professionals from other parts of the country), not represented in the survey sample. Furthermore, normally transport modes with lower shares tend to be misrepresented in a survey due to random sampling procedures.

All these facts may affect considerably the real representation of taxi trips in the municipality of Lisbon. Yet, the purpose of the paper is not to fully represent reality, but to show the proof of concept in using this simulation procedure to model an intermediate alternative transport mode. A full representation of demand is going to be used in the next stages of the research, namely through a survey of the taxi drivers and their businesses.

The simulated trips are randomly assigned to one of the network nodes within 200 meters away of the origin or destination points. The shared taxi passengers are then picked up and dropped off, in these nodes, for simplicity purposes.

The model was implemented in a road network model of the Lisbon municipality formed by the first four levels of the road hierarchy, comprising urban motorways, ring-roads, major arterials and the main local distribution network. This network contains 11,242 links and 7,106 nodes.

For determining the travel times of all links and intersections of the road network along the day, we used a calibrated micro-simulation traffic assignment model (AIMSUN - TSS) for the morning peak hour (8 to 9 o´clock). This model was calibrated using a Mobility Survey from 2004 used to develop the Lisbon Mobility Plan, and a zoning system of 66 TAZs.

The travel times for each link and intersection during the different hours of the day were estimated using the existing percentages of trips generated during the day. In Figure 6 we may see the percentage of private car trips which affect the travel time in the network.

The travel time of each time interval is then computed using the following equation:

$$Load\ Factor_i = \frac{Percentage\ trips_i}{Percentage\ trips_{8-9}}$$

Where the load factor of time interval *i* results from dividing the estimated percentage of trips in time interval *i* and the percentage of trips between 8 and 9 am. Thus the travel time (*TT*) of each link is given by:

$$TT_{ji} = TT_{j0} \cdot \left[1 + 2 \cdot \frac{Load\ Factor_i \cdot load_j}{capacity_j}\right]$$

Where TT_{ji} is the travel time of link *j* in the travel time interval *i*; TT_{j0} the free flow travel time of link *j*; $load_j$ the traffic load of link *j*; and $capacity_j$ the capacity of link *j*. This value delay function is available in the Highway Capacity Manual [26], being used with the parameter $\alpha = 2$ and $\beta = 3$.

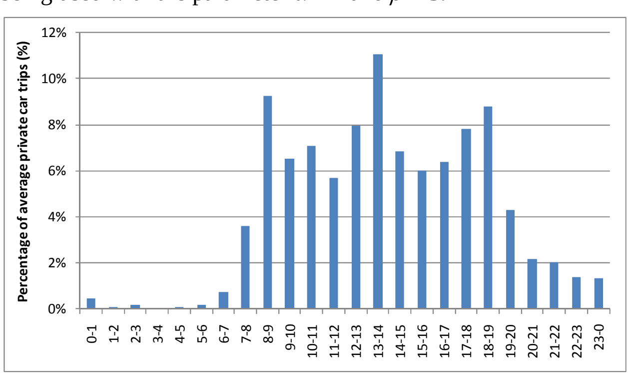

Figure 6. Distribution of the percentage of average private car trips throughout a working day

The travel time lost in each intersection of the road network was computed using a similar approach. The $Load\ Factor_i$ is once again used as a correction factor from a base value of the reference interval between 8 and 9 am. The value for node *j* and time interval *i* is given by the equation:

$$NT_{ji} = NT_{j0} \cdot \left[\frac{1}{1 + e^{2.4795 - 6.7378 \cdot Load\ Factor_i}}\right]$$

Without an available source of a generic delay function in an intersection related with the traffic volume, this equation was obtained by the calibration of an inverse logistic curve that was initially used to measure accessibility [27]. The general equation is given by:

$$y = 11 + e^{a - b \cdot x}$$

Where *a* and *b* are parameters that require calibration for the specific application. A calibration of this equation was done taken into account that values of the Load Factor do not present significant reductions on the intersection impedance (0.70 load factor leads to a corrections factor of 0.90), and that low congestion situations lead to a significant reduction of the time lost in an urban intersection (0.05 load factor leads to a corrections factor of 0.1).

The model also includes the location of all the taxi ranks in the city of Lisbon (82 taxi ranks), where the taxis can be idle or wait for a passenger call. All the agents and objects of the simulation were aggregated into a zoning system formed by 115 different zones. This zoning system was obtained using a zoning optimisation procedure for the city of Lisbon, using the 2004 Mobility Survey data [28]. This spatial discretisation considerably reduces the complexity of the model by collecting information of all taxis available and occupied within each area of the city, and simultaneously, retrieving information to the taxis about the most willing spots to find passenger.

6. TESTING A SHARED TAXI SYSTEM

The simulation model experiment developed for this paper consists on a performance comparison of the current regular taxi system in the city of Lisbon, and the new shared taxi system discussed in this paper. The experiment considers a static taxi demand to the new market configuration that might occur from introducing shared taxis allowing measuring the expected reduction of waiting time and fare paid by the customers. In the present paper we do not consider demand elasticity to price or waiting time.

This static formulation represents a first step on the assessment of the potential impact of the implementation of the service, focusing on a users' perspective which may lead to future induced demand. Thus, this assessment compares output operation indicators for the current taxi fleet with a mixed fleet of conventional and shared taxis.

Furthermore, the willingness of passenger to dial for a taxi service was not altered from the reference scenario, which in reality could be altered if the passengers expect a better service from the shared system when compared to the fee paid to dial for a taxi service.

For this simulation experiment the total taxi fleet of Lisbon was considered to be 2,000 taxis instead of the real 3,100 taxis that operate daily in Lisbon, this is due to the demand underestimation on the available data discussed above, which would considerably bias the performed analysis. The use of approximately 2/3 of the fleet derives from an experienced guess from the authors based on the knowledge obtained from the mobility survey, however this lacks from empirical verification. We will consider in this test that all the current taxi fleet connected to a central taxi dispatcher company would switch automatically to the shared taxi market (approx. 48%).

Different total taxi fleet sizes were tested in order to ensure the consistency of the results, and assess the impact of the shared system configuration under a more saturated taxi market.

The taxi discount scheme tested in the experiment was the following:

- Riding a shared taxi alone has a 15% discount;
- Sharing a taxi with another client has a 40% discount to each client;
- Sharing a taxi with two other clients has a 55% discount to each client;

The fare paid by each client results from the sum of the different stretches of the trip with different occupancy rates of the taxi, which present different discounts. The simulation will measure the discount obtained for each client of a shared taxi relative to the reference price of riding alone, thus allowing estimating the client's savings introduced by the new system.

Figure 7 presents a screenshot of an area of the city during the simulation, where we may observe the taxis (represented as larger circles) and the clients' states (represented as small circles).

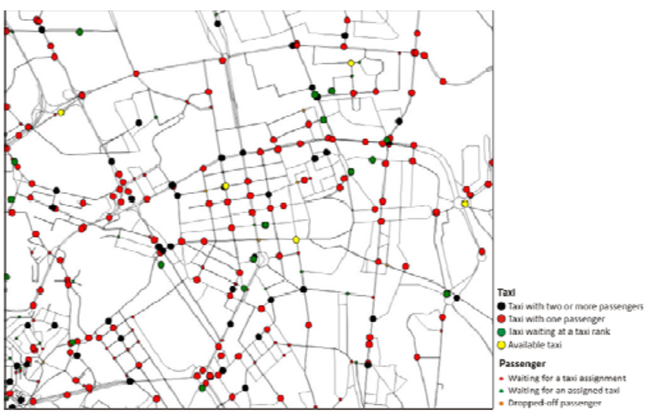

Figure 7. Screenshot of the Agent-Based simulation method working in the Anylogic simulation environment of Lisbon

In order to compare the resulting outputs of the model, we developed a set of indicators to measure the performance of the system compared to the base scenario of a fleet without shared taxis.

The obtained indicators for the base scenario, with a fleet of 2,000 taxis, were able to reproduce considerably well the main aggregate indicators of the system performance from the supply side as the average taxi revenue (79.76 euros per day against the measured 79.57 euros per day), and the average number of travelled km (14.24 against the 15.98 services obtained from real data).

The obtained results are presented in Table 2, showing that the shared system may lead to a significant reduction in the average passengers' waiting time and also the average taxi system fare, which present savings for shared riders close to 20 percent. Furthermore, the taxis may also benefit from an increase in operational efficiency, measured by the average revenue per travelled km, showing that the taxis enhance the estimated value for this indicator, although not observing a monotonous trend as in the other indicators.

Table 2.Performance indicators of the shared taxi system for different fleet sizes

Fleet size (48% shared)	Av. pass. waiting time (min)	Av. taxi fare [€]	Av. savings of shared riders (%)	Av. total travel time [min]	Av. revenue per taxi km [€/km]
1400	12.94 (-28.68%)	7.43 (-5.47%)	-19.02%	26.6 (-15.93%)	0.46 (5.78%)
1600	12.17 (-19.57%)	7.45 (-4.82%)	-17.92%	25.55 (-8.25%)	0.44 (4.82%)
1800	11.95 (-15.42%)	7.37 (-5.78%)	-15.56%	24.95 (-6.15%)	0.42 (7.38%)
2000	11.72 (-10.00%)	7.45 (-4.60%)	-15.01%	24.66 (-2.76%)	0.38 (1.94%)

The results show that the shared configuration may lead to considerable changes in the system performance from a users' perspective. This change, considering a static demand to the fare and waiting time reduction, leads to a reduction of the taxi system revenue derived from the offered discount. The average reduction in revenues for taxi drivers is approximately 10% for the chosen taxi fleets, which has to be compensated by a similar demand increase if the shared system is to produce a win-win situation for the clients and the taxi drivers.

7. CONCLUSIONS AND FUTURE WORK

This paper sets an innovative simulation procedure to assess the market potential of an advanced dynamic shared taxi service. This model was developed using agent-based simulation taking the advantage of modelling taxis and clients as agents who take decisions which are specific to their interests. At the same time an entity that manages the assignment between these two types of agents was identified and programmed to act in both the interest of the passenger and taxi in order to improve the level of service offered by taxis while still improving this business overall profit.

This new procedure was implemented in a large scale example: the municipality of Lisbon that counts about 3,500 taxi vehicles, from which 3,100 operate daily. This example allowed comparing different taxi fleet compositions, varying from the current fleet, where all taxis serve just one trip, to new scenarios where different taxi percentages acting in a sharing mode are introduced replacing the traditional ones.

Further developments of this research will include a thorough characterisation of the taxi market behaviour and also the assessment of the impact on the demand for taxi travel and operator revenue introduced by offering the shared taxi system.

8. ACKNOWLEDGMENTS

This research is being supported by the Portuguese National Science Foundation (FCT) under the SCUSSE Project - MIT Portugal Program.

9. REFERENCES

[1] Shaheen, S. A., Sperling, D. and Wagner, C. 1999. Carsharing and Partnership Management An International

Perspective. Carsharing and Partnership Management An International Perspective, 1666, 118-124.

[2] 1997. Indicators of energy use and efficiency : understanding the link between energy and human activity. ParisParis: OECD/IEA;

[3] 2001. WHITE PAPER - European transport policy for 2010: time to decide, European Commission.

[4] Kirby, R. and Bhat, K. 1974. Para-transit: Neglected Options for Urban Mobility. Washington D.C.Washington D.C.: Urban Institute;

[5] Teal, R. 1980. Shared ride taxi services as community public transit: final report. Washington, Springfield, Va.Washington, Springfield, Va.: The Office, for sale by National Technical Information Service;

[6] Lee, K. T., Lin, D. J. and Wu, P. J. 2005. Planning and design of a taxipooling dispatching system. Planning and design of a taxipooling dispatching system, 1903, 86-95.

[7] Vuchic, V. 2007. Urban Transit Systems and TechnologyJohn Wiley & Sons;

[8] Jeon, C. M., Amekudzi, A. A. and Vanegas, J. 2006. Transportation system Sustainability issues in high-, middle-, and low-income economies: Case studies from Georgia (US), South Korea, Colombia, and Ghana. Transportation system Sustainability issues in high-, middle-, and low-income economies: Case studies from Georgia (US), South Korea, Colombia, and Ghana, 132, 3, 172-186.

[9] Correia, G. and Viegas, J. M. 2011. Carpooling and carpool clubs: Clarifying concepts and assessing value enhancement possibilities through a Stated Preference web survey in Lisbon, Portugal. Carpooling and carpool clubs: Clarifying concepts and assessing value enhancement possibilities through a Stated Preference web survey in Lisbon, Portugal, 45, 2, 81-90.

[10] Hodges, A. 2006. 'Roping the Wild Jitney': the jitney bus craze and the rise of urban autobus systems 'Roping the Wild Jitney': the jitney bus craze and the rise of urban autobus systems 21, 3, 253-276.

[11] Cooper, J., Mundy, R. and Nelson, J. 2010. Taxi! : urban economies and the social and transport impacts of the taxicab. FarnhamFarnham: Ashgate;

[12] Dufour, D. "Shared taxis in Brussels : the missing link in urban transport?" Urbanicity Retrieved 10 of March, 2010.

[13] Lee, D. H., Wang, H., Cheu, R. L. and Teo, S. H. 2004. Taxi dispatch system based on current demands and real-time traffic conditions. Taxi dispatch system based on current demands and real-time traffic conditions, 1882, 193-200.

[14] Shrivastava, M., Chande, P. K., Monga, A. S. and Kashiwagi, H. 1997. Taxi dispatch: A fuzzy rule approach. Taxi dispatch: A fuzzy rule approach, 978-982.

[15] Wang, H., Lee, D. H. and Cheu, R. 2011. Microscopic Traffic Simulation based Dispatch Modeling for Taxi Booking Service. Microscopic Traffic Simulation based Dispatch Modeling for Taxi Booking Service, 187, 677-682.

[16] Von Massow, M. and Canbolat, M. S. 2010. Fareplay: An examination of taxicab drivers' response to dispatch policy. Fareplay: An examination of taxicab drivers' response to dispatch policy, 37, 3, 2451-2458.

[17] Seow, K. T., Dang, N. H. and Lee, D.-H. 2007. Towards an automated multiagent taxi-dispatch system. IEEE Conference on Automation Science and Engineering. Scottsdale, AZ, USA.

[18] Kim, H., Yang, I. and Choi, K. 2011. An agent-based simulation model for analyzing the impact of asymmetric passenger demand on taxi service. An agent-based simulation model for analyzing the impact of asymmetric passenger demand on taxi service, 15, 1, 187-195.

[19] Kim, H., Oh, J. S. and Jayakrishnan, R. 2005. Effect of taxi information system on efficiency and quality of taxi services. Effect of taxi information system on efficiency and quality of taxi services, 1903, 96-104.

[20] Alshamsi, A., Abdallah, S. and Rahwan, I. 2009 Multiagent Self-Organization for a Taxi Dispatch System. In: *Proceedings of the 8th International Joint Conference on Autonomous Agents and Multiagent Systems*, Budapest, Hungary.

[21] Darbera, R. 2010. Taxicab regulation and urban residents' use and perception of taxi services: a survey in eight cities. 12 th WCTR - World Conference in Transport Research. Lisbon, Portugal.

[22] Lee, D.-H., Wang, H., Cheu, R. and Teo, S. 2004. Taxi Dispatch System Based on Current Demands and Real-Time Traffic Conditions. Taxi Dispatch System Based on Current Demands and Real-Time Traffic Conditions, 1882, 193-200.

[23] Agatz, N., Erera, A. L., Savelsbergh, M. W. P. and Wang, X. 2011 Dynamic Ride-Sharing: a Simulation Study in Metro Atlanta. In: *Proceedings of the 19th International Symposium on Transportation and Traffic Theory*.

[24] IMT. 2006. Estudo Sobre as Condições de Exploração de Transportes em Táxi na Cidade de Lisboa, Instituto da Mobilidade e dos Transportes, I.P. Lisbon.

[25] Viegas, J. M. and Martinez, L. M. 2010 Generating the universe of urban trips from a mobility survey sample with minimum recourse to behavioural assumptions. In: *Proceedings of the 12th World Conference on Transport Research*, Lisbon.

[26] National Research Council (U.S.). Transportation Research Board. 2000. Highway capacity manual. Washington, D.C.Washington, D.C.: Transportation Research Board, National Research Council;

[27] Martinez, L. M., Viegas, J. M. and Eiró, T. 2011 A new approach to modelling distance-decay functions for accessibility and transport studies. In: *Proceedings of the World Symposium on Transport and Land Use Research*, Whistler, British Columbia.

[28] Martinez, L. M., Viegas, J. M. and Silva, E. A. 2009. A traffic analysis zone definition: a new methodology and algorithm. A traffic analysis zone definition: a new methodology and algorithm, 36, 5, 581-599.