A SIMULATION PROCEDURE FOR MEASURING THE MARKET POTENTIAL OF SHARED TAXIS: AN APPLICATION TO THE LISBON METROPOLITAN AREA

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ABSTRACT

This paper presents a simulation procedure to assess the market potential for the implementation of a new shared taxi service in Lisbon. This study is part of a broader project which intends to define and simulate a set of new intermediate transport modes and services in this region in order to enhance urban mobility sustainability and improve accessibility. The proposed shared taxi service has a new organizational 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 (time and space) compatible trips, while also increasing the revenue for the operator.

The paper establishes an agent based simulation model in which a set of rules for space and time matching between the shared taxis and passengers is identified which considers a maximum deviation from the original route and then presents an algorithm that seeks to optimize different objective functions such as minimum cost per passenger.km, maximum revenue per vehicle.km, minimum passenger total time in vehicle, minimum vehicle idle time.

An experiment for of the Lisbon road network will be presented for a proof of concept of the simulation model.

Keywords: Shared taxis, innovate transport modes, simulation, transport demand modeling

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 (Shaheen et al., 1999). 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 (IEA, 1997). This results in air pollution, energy waste and unproductive and unpleasant 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” (European Commission, 2001), 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 (Shaheen et al., 1999).

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 by services implying 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” (Kirby and Bhat, 1974), 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 several transportation alternatives may be reduced to four main alternatives: carpooling, carsharing, mini-bus and shared taxi. These may have variations and hybrid modes can be found, for instance: a mixture of carpooling with mini-bus services may arise, this is generally known as vanpooling.

The carpooling alternative consists of a trip in a private vehicle which is shared by people who have similar or aligned origins and destinations (the driver may alternate or not) for transport cost and/or travel time reduction or just for convenience purposes. Carpooling has faced many problems in trying to be a strong alternative to SOV trips because of its low flexibility in coping with different schedules but also and maybe more importantly due to the psychological, social issue of riding with strangers, which has to happen if you want to increase the scale of participation (Correia and Viegas, 2008).

The carsharing alternative, many times confounded with carpooling, comprehends a fleet of vehicles which are scattered in stations around a city and which people may rent for a short period. The advantage of this system is that it allows people to have access to driving a car, with the corresponding benefits of flexibility for specific trips and purposes, without having to own one. It has registered some effect in reducing private vehicle trips as persons cannot use a private vehicle every day, thus changing to PT for trips which have a good transit service offered (Shaheen and Cohen, 2007). Nevertheless a person must have a driving license because he is his own driver and this also represents a disadvantage as the person is responsible for his own safety and risk of injury. Moreover vehicles aren't always available in a near station, so a person is very dependent on the local number of vehicles supply and car models (Fan et al., 2008; Kek et al., 2009).

Mini bus services have appeared to supply lower demand areas while still providing a lower transport price usually associated with PT networks. It is best suited for areas and times of day with poor transit coverage areas. They may follow fixed routes or be demand-responsive, depending on the expected levels of “fixed” demand (and available subsidy). But, if the service is designed in a different way, they could provide a high-quality service with good load factors and good commercial speed, for instance in trips between suburbs and city central areas, with only a couple of stops at either end, and still very good average load factors and commercial speeds.

Finally 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. 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 allowing for a lower fare which should attract more passenger to this mode. Being a public transportation 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 (Lee, Lin and Wu, 2005).

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 other, unknown passengers. In this case this should be softened by the presence of the taxi driver when we compare this system with 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 modeled through simulation, studying the effect of different operational parameters on the system market potential in improving mobility 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 a simulation software (AnyLogic from xj technologies). In this experiment we have the objective of 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 sharing mode. In the final section of the paper we end with conclusions about shared taxi and the simulation method and finish with the presentation of a broader concept of simulating transportation alternatives by integrating several modes and using each one for what it is best for.

This is the objective of the SCUSSE (Smart Combination of passenger transport modes and services in Urban areas for maximum System Sustainability and Efficiency) research project, integrated in the MIT-Portugal Program, under which this specific work has been developed.

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 (Vuchic, 2007), a term which initially covered only unregulated services and is now extending to several offers being integrated in cities' 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[1].

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.

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. After some national press attention, this practice became a craze that swept the nation in early 1915. As the jitney experience blossomed into demands for more reliable autobus systems, urbanites began to consider the possibilities of motorized public transit, though they were divided by class and neighborhood" (Hodges, 2006).

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

[1] Retrieved at <http://www.korea4expats.com/article-taxi-korea.html>.

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 - in short, anywhere where small-vehicle shared transport makes sense. One may find them operating from suburbs into the city for big football matches, or from a railroad station to a nearby beach.

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 standardization 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 public transportation vehicles such as buses and subway systems. That is why shared taxi is being recovered as a modern transport option; one example is the case of New York city. This city started in February 2010 a shared yellow cab service, plying specific routes, for $3 and $4 a ride. Subway fares in New York are $2 (regular cabs across town generally are in the $6-$10 range). However the first day of the experiment, was that virtually no riders showed up. The stands, marked by small yellow signs, were without taxis and passengers alike. According to the authorities, only six shared trips took place. This is still an ongoing experiment however these first impressions do not let foresee a great impact on New York's mobility system[2].

More advanced initiatives have been tested in order to take advantage of modern communication technology, namely cell phones. A seed-stage company in the UK has developed a system that collates requests for point-to-point travel from a dispersed set of travelers via SMS (they text-message by cell phone their destination postcode to the system), and then packages travelers 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[3].

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. Professional taxi associations sit in on an advisory committee. There is no possible confusion with the public transport operators, whose core business is regular collective transport, based on fixed routes and timetables, integrated into bus, tramway and subway networks. The transit authorities provide a public service funded by the local administration, who set policy, enshrined in a regularly updated management contract. Both are struggling against their polarized 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 (Dufour, 2008).

[2] Retrieved at <http://www.newyorkology.com/archives/arrivology/index.php>.
[3] Retrieved at <http://www.texxi.com>.

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 optimization system technology, and has upgraded the necessary number of cabs of affiliated taxi operators. No extra vehicles or drivers were put into circulation: existing, ordinary taxis alternate between traditional taxi trips or shared taxi trips, as dispatched by the central. The service is subsidized by the regional authorities. 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.

A SHARED TAXI MODE FOR URBAN AREAS

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 even in large metropolitan areas, 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 may 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 and there can be a significant part of the trip which has to be done by walking.

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 public transport modes hence it makes it a transportation option for higher income people or for those who do not own a private vehicle (Institut pour la Ville en Mouvement, 2007). Sharing the taxi allows dividing the cost of the ride as already mentioned. However how can it be possible to maintain the advantages of the taxi while sharing the vehicles? We have seen that the most taxi sharing schemes which have been implemented are supported by pre-defined routes and or pre-located stops where people have to go and wait for the taxi or in the more advanced version request a seat by texting in a cell phone but still having to reach the stop, 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 which is the available taxi closest to a request (Taxi Dispatch System Based on Current Demands and Real-Time Traffic Conditions). However the task of matching passengers and vehicles is obviously not straightforward in the system we are testing as some of these 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.

A SIMULATION PROCEDURE FOR SHARED TAXIS

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. Independently of the type of simulation model, there should be a conceptual flow chart providing a way to easily understand the system which we want to test.

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 centralized operation assigning taxis to travelers using as his main information sources: the location of shared taxi vehicles, their current occupancy rate and the location of travelers (assuming for simplification purposes that all passengers will want to be picked up at their current coordinates) (Figure 1).

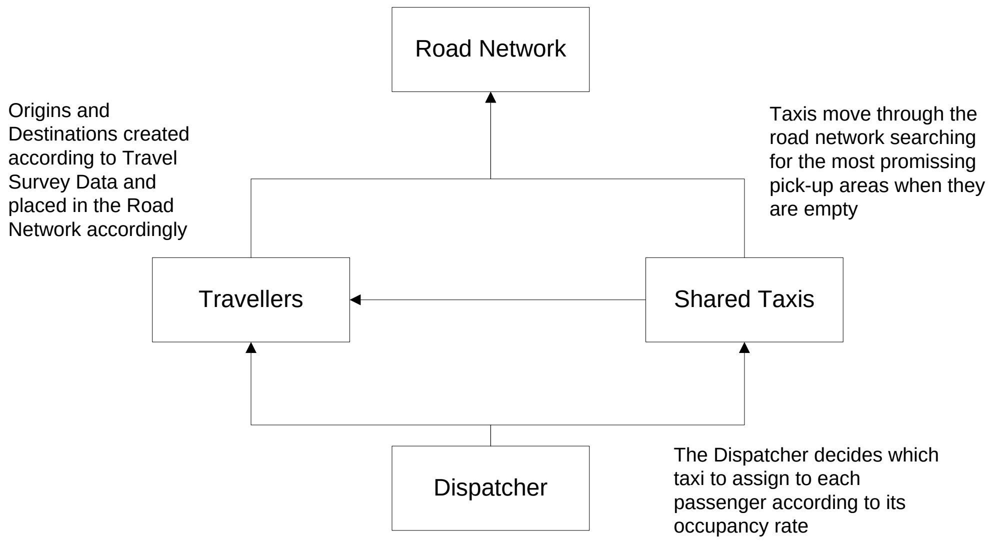

Figure 1 – Simulation Flow Chart

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 organizations 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 behavioral rules generate complex behavior.

The main characteristics of the agent-based model may be better summarized in the scheme proposed by Lin (2002) for defining an Agent-Based simulation model (Figure 2):

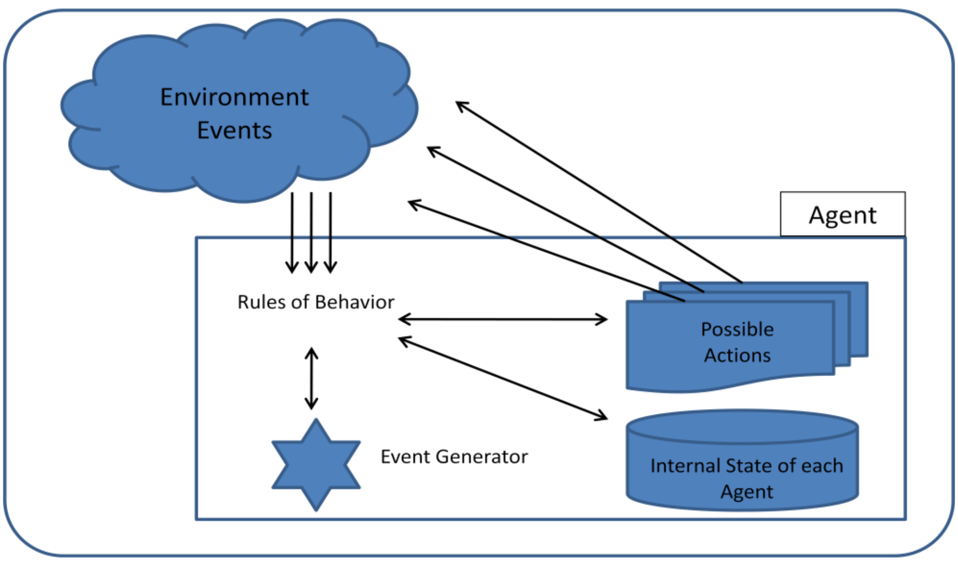

Figure 2 – Agent based model structure (Lin, 2002)

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 Travelers.

<u>Traveler Agent</u>

Rules of behavior:

- When it is created in the network it will search for a Shared Taxi for his trip;
- The traveler will search for a shared taxi until it is served.

Possible Actions:

- When a taxi is assigned to the passenger, the passenger automatically accepts that assignment, which is chosen by the dispatcher;
- If he does not find a taxi 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.

Internal State:

- Waiting for a taxi assignment;
- Waiting for an assigned taxi;
- Riding in the Taxi.

Event Generator:

No stochastic events were considered in the model, although some options could be the passenger giving up waiting for an assigned taxi or changing destination during a current trip.

<u>Taxi Agent</u>

Rules of behavior:

- The taxi is normally routing through the network covering mainly the areas which historically have had higher demand for taxi trips (information retrieved by the Dispatcher) in the current period of the day;
- If a certain limit of time in routing but waiting for a passenger call is surpassed, the taxi goes to a taxi rank where he waits to be assigned to a client;
- Taxis have shifts not being always active. These are city and country specific and must be specified because it determines the percentage of active taxis searching for passengers.

Possible Actions:

- The taxi complies with the assignment which is proposed by the Dispatcher.

- He goes to a new destination area searching for a passenger, using the information given by the Dispatcher.

Internal State:

- On route to pick-up a specific passenger (allocated by the Dispatcher);
- On route, in service with one or more passengers on board;
- On route to a taxi rank;
- Browsing the area for passengers;
- Waiting at a taxi rank for an assignment;
- Vehicle idle at a taxi rank.

<u>Simulation Environment:</u>

The simulation environment is common to both agents, taxis and passengers, as we have said this is a road network as detailed as possible, namely it should provide the possibility of computing different travel times for different periods of the day and within each period it should translate well the impedance of travelling from point to point in the simulated urban area. The model should also include a study area zoning scheme in order to improve the simulation efficiency, gathering data at a zone level.

In order to compute the shortest paths for each Traveler OD pair, the simulation needs to 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 traveling speeds on the links of the network (several periods have been defined, with different speeds).

Simulation environment events:

- A Passenger Agent is created in the network based in survey data and associated with a zone;
- Taxis are created in the beginning of the simulation and stay active until its end.

<u>The Dispatcher</u>

The Dispatcher does not need to be an Agent, it is an entity that defines a set of rules for matching together taxis and passengers and concentrates all real-time information that it needs to produce and accompany these trips.

The choice of which taxis to match with each traveler follows a linear programming optimization model. The problem was formulated with an objective function that aims to combine the minimization of passenger travel times, while also considering the revenues of each individual taxi and the equity among them (always a strong concern in the real world).

The problem formulation is presented in the scheme in Figure 3, in it we may see multiple taxis available within a coverage area centered in the traveler's coordinates.

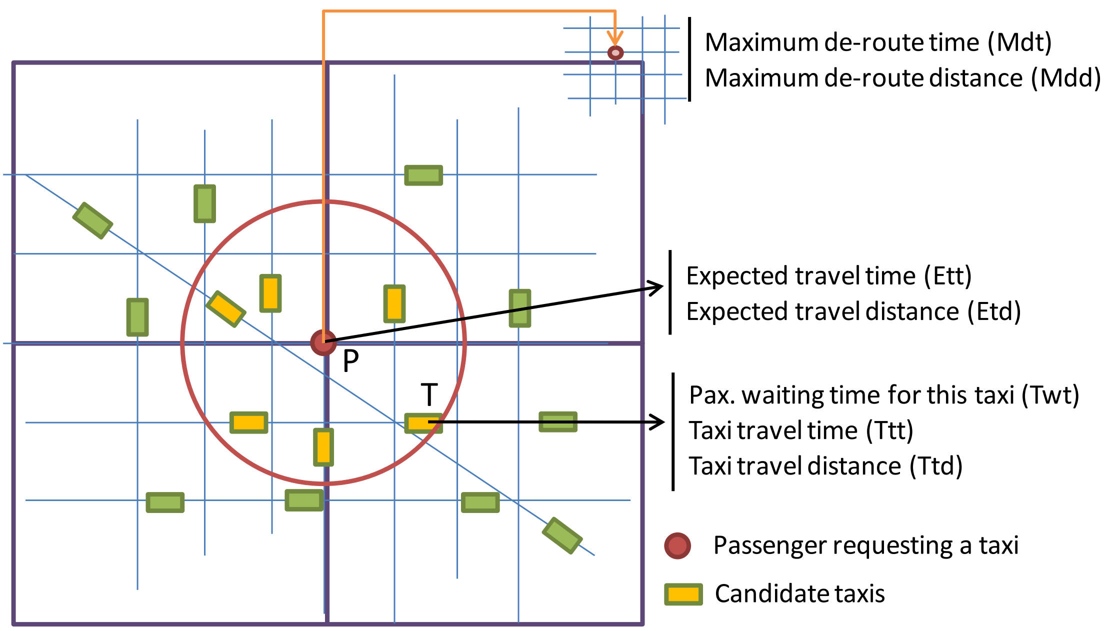

Figure 3 – Formulation of the taxi-traveler matching problem

In order to solve this combinatorial problem, we start 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, and they are a percentage of *Ett* and *Etd* values respectively, computed through following functions of travelled time and distance:

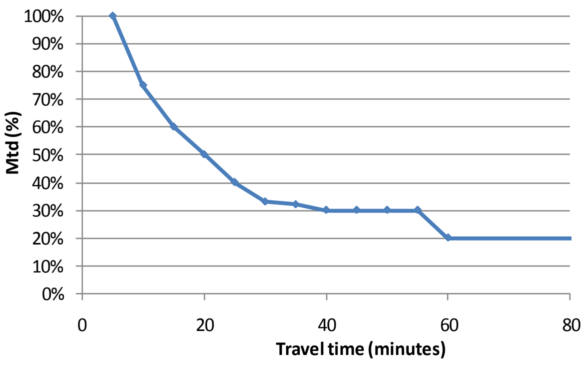

Figure 4 – Maximum de-route time (*Mdt*) function

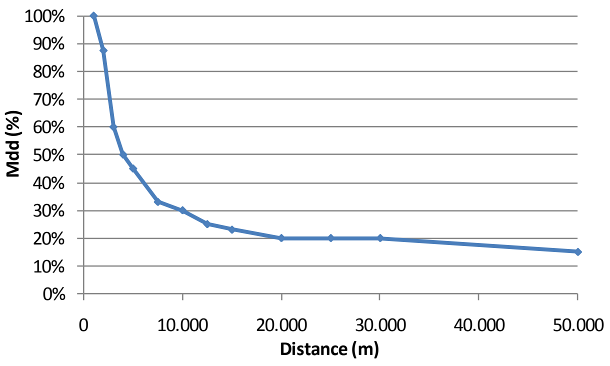

Figure 5 – Maximum de-route distance (*Mdd*) function

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 (Dijskstra's Algorithm included in the agent-based model).

It also computes for each taxi *j* and each client *i* in time instant *t*, the following variables:

- The waiting time for the taxi (Tw*t*), computed using the shortest path algorithm.
- The taxi travel time (*Ttt*) and travel distance (*Ttd*) for a trip in the current condition of the taxis. 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 traveler. This time is also computed using a combinatorial problem which can be expressed by:

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

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

The estimation of the taxi travel time (*Ttt*) is estimated using the procedure presented in Figure 6, where we may see the different approaches depending on the number of passengers already on-board of the taxi.

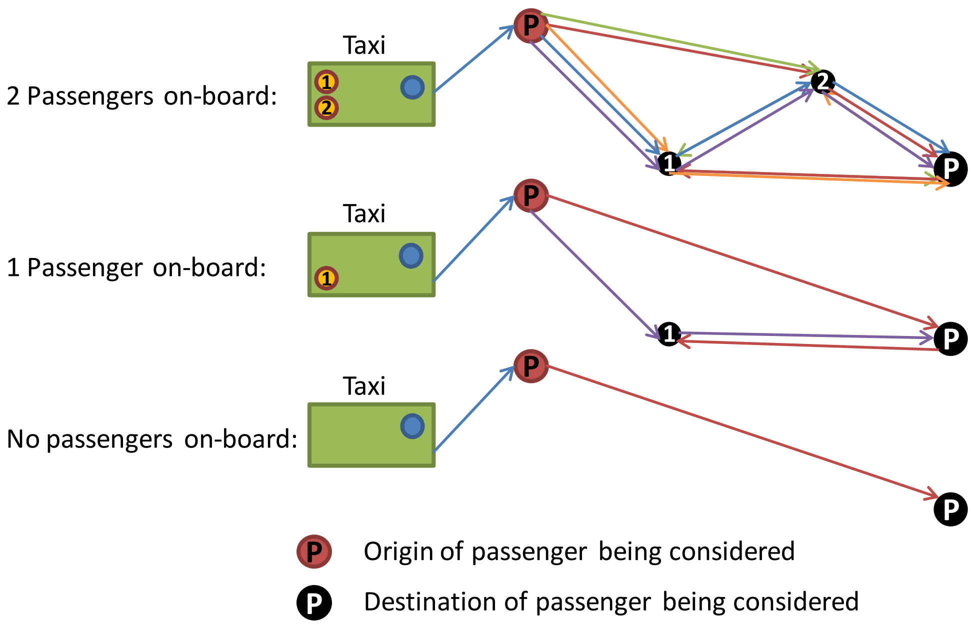

Figure 6 – Example of the Taxi travel time (*Ttt*) estimation for different number of passengers on-board

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 neighboring zones (vector *Nz*).

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

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

$$subject\ to:$$

$$\forall\ j \in i : Ttt_j \leq Ett_i\,(\,1 + Mdt_j\,)$$

$$\forall\ j \in i : Ttd_j \leq Etd_i\,(\,1 + Mdd_j\,)$$

Where Twt_{ij} is the waiting time of traveler 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 minimizing the client travel time, also assigns preferentially travelers to taxis which have been empty during the last five minutes and also to taxis with two travelers already on-board, presenting the same premium as the previous (weights in the Objective function), and especially to taxis that have one traveler already on-board, which lead to greater taxi revenues and maximum discounts to the travelers.

This optimization procedure, while not corresponding to a NP-Complete problem, also presents increasing computing times with the problem dimension, which has been resolved in the simulation by reducing the subset of candidate taxis in each optimization procedure. The considered subset includes 25% 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 computing 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 browse 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 travelers 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 the utilities of the different zones. The zone *i* utility function for time period *t* is given by:

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

$$EstimatedDemand_{ti} = 0.75 \cdot \sum_{k=1}^{N} TaxiCalls_{kti} + 0.25 \cdot Taxishare \cdot \sum_{d=1}^{N} OD_{tid}$$

Where $EstimatedDemand_{ti}$ is the estimated taxi demand of zone *i* for the time period *t* (an hour), $TaxiCalls_{kti}$ are the collected taxi calls for zone *i* for the time period *t* in the *k* day, $Taxishare$ the estimated taxi share for the study area, and OD_{tid} 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.

Simulation programming language

The model presented here was developed in the JAVA Programming Language, using Anylogic (Xj Technologies). This is a software framework for creating agent-based simulations, system dynamics modeling and discrete event simulations using the JAVA language.

Anylogic provides a library of JAVA classes for creating, running, displaying and collecting data from an agent-based simulation. In addition, Anylogic allows the user to customize simulation outputs.

JAVA simulation programs that use Anylogic libraries typically have at least two classes: object class and agent class. The agent class describes the behaviors and characteristics (states, capabilities) of agents and it is largely simulation-specific. The agent class sets up and controls both the representational and infrastructure parts of an Anylogic simulation.The object class sets the backbone of the environment modeling, allowing a flexible set of tools for its characterization and interaction between object classes and agent classes, and also between object classes.

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 (Figure 7).

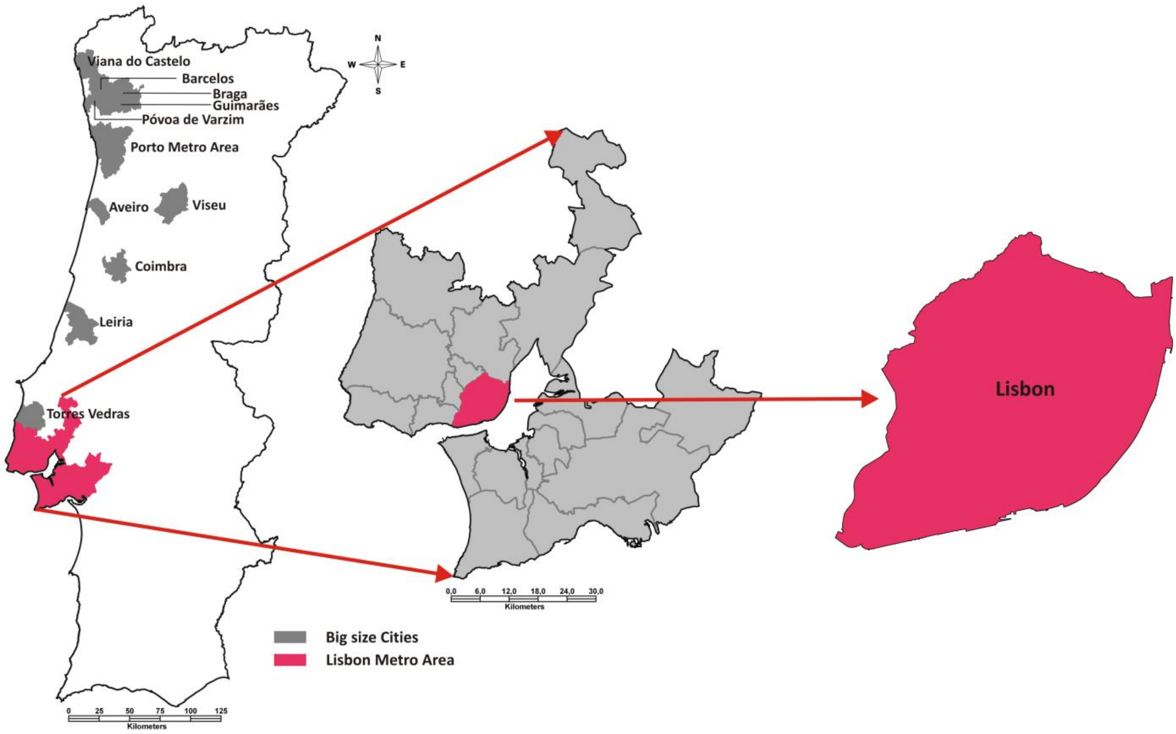

Figure 7 - Lisbon location and metropolitan structure

The taxi sector in Portugal is highly regulated when compared with either countries in Europe or in the rest of the world. The taxi market in Lisbon is formed by approximately 3,000 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.

In parallel, the taxi drivers' profession is also regulated by the national transport regulator (Mobility and Land Transport Institute – IMTT). The taxis can be driven by licensed drivers, which have do take a course and pay a levy.

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 behavior 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.

The simulation procedure uses as input the outputs of a synthetic travel simulation model, which was developed under the SCUSSE research project. 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 current 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 carried out.

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 8, where we may observe a higher concentration of trips during the morning peak and some periods during the lunch break and the afternoon.

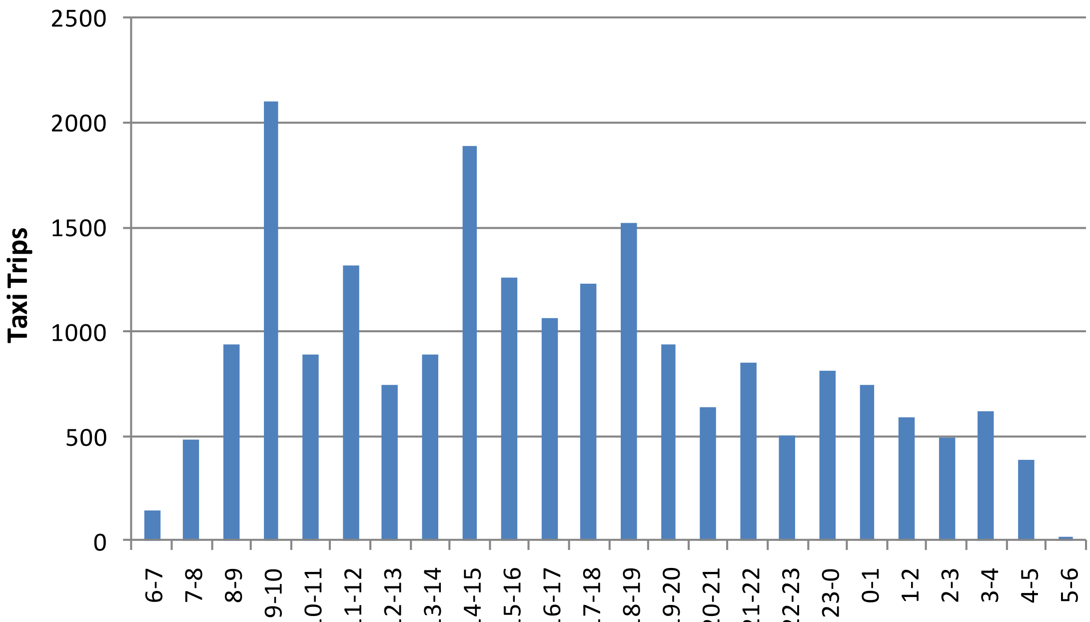

Figure 8 – Distribution of taxi trips throughout a working day

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 fuller understanding of the demand is foreseen to be used in the next stages of the project, 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 9 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:

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

Where the load factor of time interval *i* results from the quotient between 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:

$$TT_{ji} = TT_{j0} \cdot \left[1 + 2 \cdot \left(\frac{Load\,Factor_i \cdot load_j}{capacity_j} \right)^3 \right]$$

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 (2000) , being used with the parameter $\alpha = 2$ and $\beta = 3$.

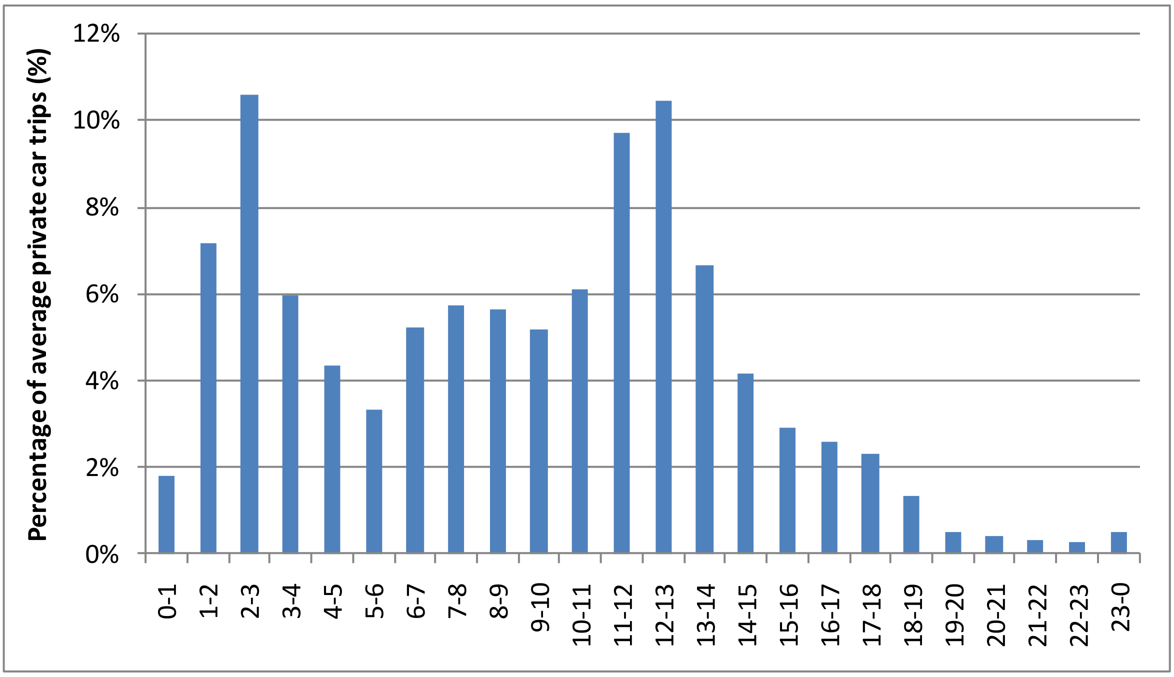

Figure 9 – Distribution of the percentage of average private car trips throughout a working day

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 travel time (NT) *i* is given by the equation:

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

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 (Kocks Consult GmbH, 1978). The general equation is given by:

$$y = \frac{1}{1 + exp(a - b \cdot x)}$$

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. The shifts of the taxi drivers can be seen in **Error! Reference source not found.** which are based in current working conditions. One third of all simulated taxis were assigned to one of the three classes of shifts.

Table 1 – Taxi driver shift considered in the simulation

	1st Class	2nd Class	3rd Class
1st driver shift	8 am until 4 pm with a break between 1 and 2 pm	7 am until 5 pm with a break between 12 am and 1 pm	8 am until 6 pm with a break between 1 and 2 pm
2nd driver shift	4 pm until 12 pm with a break between 8 and 9 pm	5pm until 4 am with a break between 10 and 11 pm	6 pm until 5 am with a break between 11 and 12 pm
3rd driver shift	12 pm until 8 am with a break between 4 and 5 am		

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 optimization procedure for the city of Lisbon, using the 2004 Mobility Survey data (Martinez et al., 2009). 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.

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 procedure discussed in this paper. The experiment compares resulting operation indicators for the actual taxi fleet, with a reduced mixed fleet of conventional taxis and shared taxi with equivalent performance indicators (e.g. waiting time for a taxi), measuring the changes in the average travel cost for passengers.

If we take total demand for taxi services as fixed, and the award of discounts for passengers sharing a taxi, total revenue per taxi would inevitably fall, but it is expected that, if taxi sharing reaches an interesting proportion of the taxi market, the average price paid by travelers will be lower and so demand should increase. This aspect is not covered in the present paper.

This experiment does not intend to simulate the real current situation of the taxi market, due to the lack of detailed characterization data related with costs, statistical distribution of working times, etc. The analysis presented in the paper only aims to demonstrate the value of this type of simulation procedures and assess the potential benefits for clients with the introduction of shared taxis as part of the operating fleet.

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

For this simulation experiment the total taxi fleet of Lisbon was considered as 2,000 taxis instead of the real 3,000 taxis, due to the demand underestimations on the available data, which would considerably bias the analysis performed. The consideration of 2/3 of the fleet derives from an experienced guess from the authors of the demand available from the data, which lacks from empirical verification. Four different taxis fleet compositions were tested in this experiment:

- A full taxi fleet of regular taxis – **Fleet I**;
- A mixed taxi fleet, with 250 shared taxis (12.5% of the total fleet) – **Fleet II**
- A mixed taxi fleet, with 500 shared taxis (25% of the total fleet) – **Fleet III.**
- A mixed taxi fleet, with 1,000 shared taxis (50% of the total fleet) – **Fleet IV.**

The use of different taxi fleet compositions may allow deriving the expected travel costs reduction for travelers as well as the expected waiting, which may induce additional taxi demand.

The taxi discount scheme tested in the simulation present the following specification:

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

The fare paid by each traveler 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 travelers of a shared taxi relative to the reference ride alone system, trying to estimate the total saving for travelers introduced by the new system.

After the initial presentation of the simulation procedure for the Lisbon municipality case study, we illustrate the simulation platform developed for this experience. **Error! Reference source not found.** presents a screenshot of an area of the city during the simulation, where we can observe the different taxi (represented as larger circles) and traveler (represented as small circles) states.

In order to compare the resulting outputs of the model, we developed a set of indicators to measure the performance of the system, considering the taxi and the traveler perspective. These indicators are:

- Average waiting time per traveler;
- Average number of taxis working for the different day periods
- Average taxi revenue per working hour
- Average taxi occupancy rate
- Average % of de-route time of travelers
- Average % of de-route distance of travelers

The results of the simulation were not already available at the data of the paper submission to the conference. The results will be announced during corresponding conference presentation.

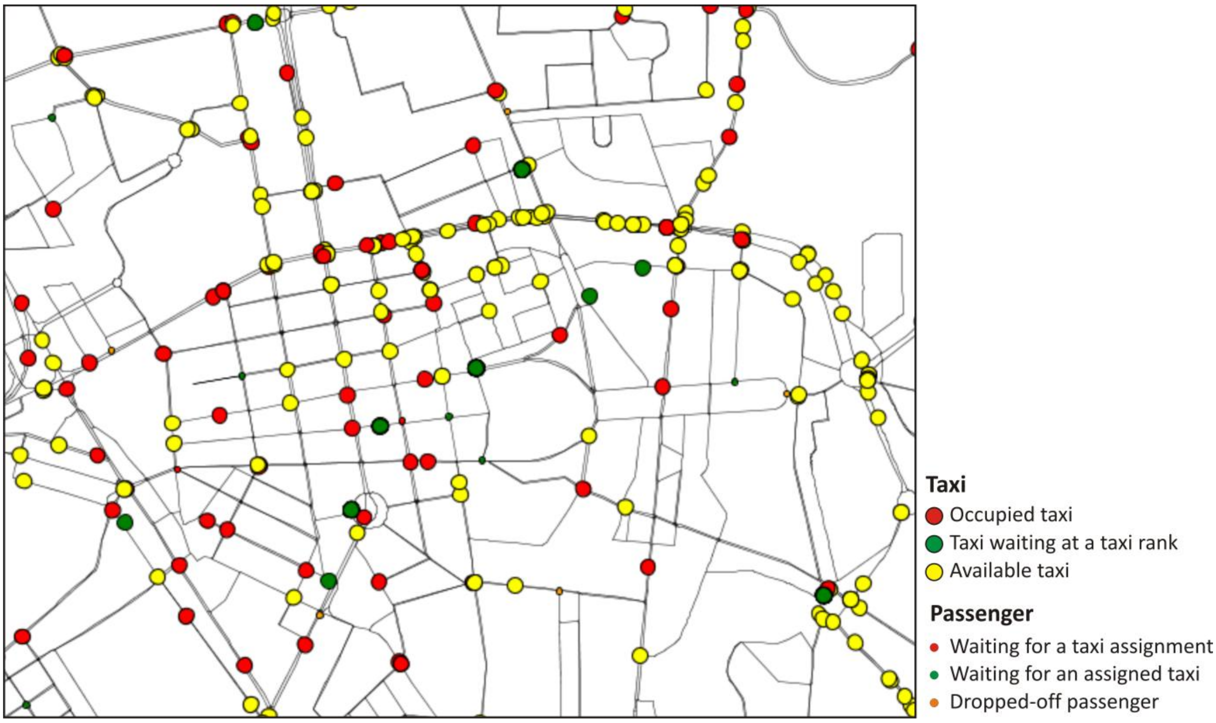

Figure 10 - Screenshot of the Agent-Based simulation method working in Anylogic simulation environment of Lisbon

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 modeling taxis and travelers as agents, who take decisions which are specific to their interests. At the same time an entity which manages the assignment between these both 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 businesses overall profit.

This new procedure was implemented in a large scale example: the municipality of Lisbon which counts now about 3000 taxi vehicles (2010). This example compared different compositions of the Lisbon taxi fleet, varying from the current fleet, where all taxis serve just one trip, to new scenarios where different percentages of taxis acting in a sharing mode are introduced replacing the traditional ones.

The simulation runs for the different taxi fleets were very near to completion at the time this paper was submitted. However due to some extra analysis of the great amount of data which has resulted from the model it wasn't possible to reproduce in the paper a summarized version of the most significant numbers and charts. Nevertheless, all results will be presented during the conference presentation which we foresee to produce great interest amongst the conference participants.

The broader concept

Urban mobility has gained extra complexity due to the growing number of trips which multiply with the need to participate in more activities. In the other hand we were never so worried with the sustainability of these trips as we are today. Not only the environment sustainability but also the economic and social sustainability of urban traveling.

The new urban transportation alternatives to the traditional modes have been generally analyzed in an isolated way, being scarce the reference of their interaction effect in mobility management in our cities. Many research initiatives have tried to prove that each mode is or is not the solution for congestion and urban mobility in general.

We believe that added value may arise from considering multiple alternatives in an inter modality perspective. Thus we intend to study the integration between several of these alternative modes by modeling their supply-demand interaction in the same Agent-Based environment which was used for modeling shared-taxi.

This will require a choice model for the decision to use not only the alternative modes but also the classical options as the private car, suburban train or bus. This data is already available to us through the SCUSSE project of the MIT-Portugal program.

The conceptual model will have the same macro-structure: there will still be a dispatcher which should aid in the decision of which mode to assign to assign to each trip (request). However, with the increased complexity brought by considering more than one of these transportation alternatives, so does increase the complexity of deciding which mode to assign to each trip. Multiple transportation options mean multiple interests on profit maximization which brings extra challenges in setting up and testing this broader system.

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