MODELLING THE TAXI MARKET FOR THE LISBON MUNICIPALITY

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ABSTRACT

Taxis represent a significant share of urban trips in most cities around the world. Historically this market has been in the hands of private companies whose business is regulated by public authorities. Due to the duality of interests of both these actors, it has been difficult to establish the position of this mode among the rest of the urban transportation modes. There have been attempts to model accurately this market; however these have always lacked realism due to the spatio-temporal complexity of this mode. Thus, better models are needed to correctly support decisions on the number of licenses and fares to charge in order to reach a desired level of service. Agent based models have emerged in the last years as a modelling tool that allows to micro model the behaviour of complex systems. In this paper we present an agent-based model for translating the complex spatial-temporal matching between taxi service supply and trip demand match in a city network. The proposed model was designed for the taxi market of the city of Lisbon (Portugal).

Keywords: Taxis, simulation, transport demand modeling

INTRODUCTION

Taxis provide an important transportation service to the people of many communities across the world, especially those living in urban areas. This service is often classified in transportation research as being part of the “Para-transit” transportation alternatives. The expression was first used by Kirby (1974) in the report: “Para-Transit: Neglected Options for Urban Mobility”. In that document Para-transit was presented as “… those forms of intra-urban passenger transportation which are available to the public, and distinct from conventional transit (scheduled bus and rail) and can operate over the highway and transit system” (Kirby, 1974). Latter a more modern definition has been presented for the concept: Para-transit is “any form of ground, passenger transportation that is demand-responsive, that requires the passenger to place a request with the service provider (by hail, telephone, or other electronic means), and operates with flexible routes and/or flexible schedules tailored to the passengers’ trips” (Lave and Mathias).

Taxi services have been provided for centuries, independently of the vehicle used for supplying the service. The first documented services started in Paris and London using Horse-drawn vehicles. It was also in these two cities together with New York that the first gasoline automobiles were used as taxis. Despite the enormous growth on the use of the private automobile or the construction of heavy rail transit systems during the 20th century, taxis have not lost their interest and have been able to maintain a considerable market share. Their attractive characteristics as a Para-transit service that you can hire from door to door have assured their endurance.
In some cases the share of this mode represents a very important part of the total daily trips. For instance, in Honk Kong taxis combine to serve more than one million passengers each day, which is approximately 10% of the total passenger transportation volume in the region (Yang and Yang, 2011). In London this percentage drops to 4% for residents without cars and 1% for residents that have cars (Darbera, 2010) but in this case motorization rates are much higher which explains a lower use.
Despite its importance, this transport mode has often been neglected by transportation authorities mainly because taxis have been and still are entirely in the private sector. The general trend has been to develop regulations in order to provide a good quality service to the users. However this is not easy to guarantee because in the other side there are private companies whose main purpose is to profit as much as they can from the service they offer to the public. Generally speaking, the public sector is concerned with social welfare, while the individual private taxi firms are interested in profits. Hence, there are two partially conflicting objectives in the taxi market, i.e., maximizing social welfare versus maximizing total taxi profits. This fact has led to different regulatory realities across the world, from totally deregulated markets, like the case of Stockholm, to fully controlled markets, which is the example of Paris (Darbera, 2010). Taxis have been regulated using two main tools: entry restrictions (imposing a cap on the number of taxis) and price control (regulated fare). But their effect has been difficult to determine. Control has had unintended effects in the past, for instance in Honk Kong, the freely traded taxi licenses' price is more linked to the general economic conditions of the region than with level of service provided (Loo et al., 2007). There are also other type of quality regulations that cities apply to taxis: standard of vehicles, drivers and operators, as well as market conduct regulations which include rules regarding the pick-up of passengers or affiliation to a radio network (Salanova et al., 2011).
Due to the great variety of existing regulatory frames of the taxi market and also the different ways these operations have been managed by the operators, it is not easy to take strong conclusions on the principles to follow in defining the taxi position in the mobility configuration of each city. For instance, among the capital cities that have the least use of taxis in Europe we have Amsterdam, which underwent a total deregulation in 2000, and Paris, which is one of the most controlled markets, hence making it difficult to conclude on the principles to follow (Darbera, 2010).
There is the need to build models that allow a good representation of the taxi supply and demand reality of each region describing accurately the existing regulations and management systems and reproducing accurately the behavior patterns associated

to each city. The objective, afterwards, as in any other model, is to be able to change and test these principles considering them experimental factors and forecast the impacts of applying them in the perspective both from the user and from the managing company.

Modeling the taxi market is more than just building an aggregate balance between supply and demand. It is a fact that there is a documented tendency for taxi shortages originating many passengers having difficulties finding a cab and that some passengers are outright refused service which denotes the typical supply shortage behavior. The inverse process is also true: an overabundance of service has been problematic for both the industry (which experiences a drop in revenues) and public safety, setting up dangerous competition for passengers among taxi drivers (Schaller, 1999). However in the case of taxis, as in other service markets, the conditions in which this supply is offered to the clients may be reached under different operational configurations which may not depend on the amount of the commodity offered to the clients itself. The taxi fleet size is a supply indicator, however, the same number of vehicles may lead to very different results in terms of service level indicators such as average waiting time for a taxi, and this may be enough to change the attractiveness of this mode, hence affecting greatly service and economic performance.

The travel pattern associated to a daily taxi operation is the result of a complex interaction between service providers and users. Taxi drivers must choose a direction after a passenger has been dropped-off. So, it does not depend just on the demand patterns but also on the behavior of the taxi driver. In the other hand, passengers may call for a cab, hail him on the street or catch it in a taxi rank. When the taxi is called there are usually dispatching systems that assign a taxi to that particular service, the more or less sophisticated method for doing this assignment influences both the level of service provided as well as the profitability of the taxi company.

From the literature review we verify that there is scant research attempting to address the accurate modeling of the special structure and behavior of the taxi systems. Hence, in the present paper we aim at describing and building a disaggregated simulation model for the urban taxi market, detailing the movement and behavior of taxis and passengers in a realistic way. The agent-based type of models is chosen due to the difficulty in representing the complex relation between taxi supply and passenger demand by other types of aggregated or disaggregated approaches. The usefulness of agent-based models has been demonstrated in several areas of transportation analysis (Davidsson et al., 2005; Arentze et al., 2010; Roorda et al., 2010; Vliet et al., 2010; Tang et al., 2012). These models allow a detailed representation of the interactions of multiple agents in a realistic synthetic environment where the intent is to re-create and predict the appearance of complex phenomena. The objective is to obtain the emergence of higher level phenomena from describing accurately the lower level reality.

The paper is structured in the following way: in the next section we present a review of the research work that has been done on this transportation mode relevant for the development of our model. In the next section we present the Lisbon case study that will be the focus of the developed model. This is followed by the description of the agent-based model that simulates taxi systems. Then the model is applied and validated for Lisbon. The paper ends with the main conclusions that can be taken on the usefulness of the model in preparing changes to this market's regulations, operation principles or the introduction of new technologies.

REVIEW ON MODELLING TAXI SERVICES

There are two main research streams respecting to modeling taxi services. The most fruitful stream has been the one developed in the field of economics where mathematical models have been used to describe supply-demand equilibrium through an aggregated or disaggregated approach, with a higher or lower detail level in characterizing taxis daily operation and matching between vehicles and clients. The second research stream has focused on the optimization of the taxi dispatching process in order to improve the economic performance of the taxi company, while aiming at the same time to improve, the level of service provided. Both research streams will be described in the next two sections.

Taxi market equilibrium

Research on taxi transportation systems is diverse and has begun in the 70's with the first studies about the taxi market. An overview of the taxi industry and the early discussion of some of the challenges it faced and the regulatory response implemented to deal with these challenges, at that point can be seen in (Weiner, 1975) and (Abe and Brush, 1976). Economists started to address the problem of setting up a regulatory framework for controlling the quality and profitability of the sector. One of the first models ever built for that purpose was an aggregate model for helping solving the following regulator's dilemma: "how to select a price, and implicitly a single service standard, for a population of customers with diverse preferences for service quality" (Douglas, 1972). In this article the author proposed to find the market equilibrium between an aggregated supply and demand for taxi services.
The model by Douglas (1972) was subsequently used as basis for other work such as the work by (Devany, 1975), (Beesley, 1973) and (Beesley and Glaister, 1983), where different regulatory scenarios were tested. Other studies approached the same equilibrium using structural models in order to try to obtain more realistic results, upgrading the previous ones by considering explicitly the technological and informational aspects of the problem (Manski and Wright, 1976), (Foerster and Gilbert, 1979), (Arnott, 1996), (Cairns and ListonHeyes, 1996) and (Fernandez et al., 2006). Results from applying these aggregate models under small scale theoretical examples have lead the authors to conclude that, a deregulated industry does not lead to an optimal equilibrium between supply and demand, thus it is beneficial to have some kind of Public Administration intervention over the system. Motivated by the complexity of the taxi supply-demand system (Bailey, 1987) proposed a system dynamics aggregated causal model in which a balancing loop between Fleet Utilization, response Distance and Service rate was in the center of the system. This

author concluded that customer waiting time, thus service quality, is highly dependent on changes in the number of taxis.
Recognizing the importance of the spatial and temporal aspects of the taxi system, supply and demand models evolved towards characterizing in a more accurate way the matching between clients and vehicles in a spatial context. (Yang and Wong, 1998) presented a model of vacant and occupied taxis cruising in a network. They assumed stationary taxi movements and customer demands, no demand elasticity, no congestion, "all-or-nothing" routing behavior and that a taxi minimizes his travel time to pick-up a client. They concluded that taxi fleet and information of taxicabs must be regulated in order to reach a higher taxi use while maintaining a good level of service. This work continued through developing further the algorithms and realism of the models (Wong and Wong, 2002; Wong et al., 2002). The most recent papers establish a so called bilateral relation between vehicles and clients taking into account the willingness to pay of customers in order to improve the realism of the matching between supply and demand (Wong et al., 2005; Yang et al., 2010; Yang and Yang, 2011).
Despite the theoretical interest of the aforementioned research, the models have rarely been validated with real data. There were some cases where the authors used real data in order to extract the behavior and performance of the market in specific case-study cities, such as (Schroeter, 1983) that used data from a taxi company in Minneapolis or (Schaller, 2007), who used data from 43 cities and counties of the United States and Canada. (Flores-Guri, 2003) used the data from (Schaller, 1999), which included records on the number of miles driven, the number of metered trips, and the total revenue since the previous inspection of a fleet of New York cabs, with the objective of estimating an aggregate model of a cruising taxi service.
We may conclude from the previous papers that, despite the interest of trying to reach unifying rules for the taxi markets, these are in fact very hard to take, given the spatial and temporal characteristics of this transportation mode. There are also several ways of managing its operation influencing greatly the economic performance of the system, in a way which is difficult to model in an aggregate supply and demand framework. A strong example is the several possibilities of taxi dispatching rules that can be applied, which is the topic of the next section.

Taxi dispatching methods

One important field of operations research applied to the taxi services has been the use of optimization techniques to improve the system's eficiency towards some objective. The problem of taxi dispatch from a pool of taxies, either waiting at the taxi rank or driving free in a city, is certainly the most significant one in the literature which denotes its influence on taxi management and the generall worries of practitioners. Calls for taxies may emanate from different parts of the city. The taxi operator is aware about the status (i.e. waiting, busy, free) and position of all taxies associated with the taxi stand at any time. The usual way to dispatch a taxi for a specific call is to consider the available taxis in the vicinity of the client in order to reduce the service time. On the other hand, the operator also wants to be fair to all the taxi drivers, and maintain proper distribution of opportunities to each one of them so there are two main classical rules for the dispatching: 'nearest vehicle first' and 'least utilized vehicle first'. However, frequently it is not possible to comply with these two objectives simultaneously. (Shrivastava et al., 1997) proposed a fuzzy combination of the two rules to fulfill both the objectives at the same time. The fuzzy combination approach has the potential to take many such contradicting parameters into simultaneous consideration. A simulation model was also presented to demostrate the results of such fuzzy combination of rules. The authors concluded that it was possible to have a service time not far from the nearest vehicle rule while maintaining a uniform taxi workload. Still, the method was not tested for a real case study city, only a small scale numerical example was used.

Lee et al. (2004) approached the problem from the side of the client, vouching for the perspective that satisfied customers are returning customers. In this case, researchers worried about providing the true closest taxi to the client request, which is affected by real time traffic conditions and not the simplification of a straight line between the request and the closest taxi. They used the case-study of Singapore taxi companies and concluded that their system lead to significant reduction of the customers' waiting time.

A more recent paper by (Wang et al., 2011) used the same case-study area, Singapore, to try to optimize further the assignment of taxis to pre-booked requests. Currently, when receiving one such request, a taxi is assigned to the service without considering any more possibilities. Thus, reserving a vehicle with some time in advance represents an extra cost to the company, which is being transferred to the client. This is contrary to most of the services and products we buy in our daily life. Hence, the authors proposed an optimization method to bundle a set of requests in the same taxi trying to align the drop-off location of one service with the pick-up location of the other service, in a chaining process. The method used a customized algorithm of the Pickup and Delivery Problem with Time Window which was applied in a micro-simulation test bed in which shortest paths were computed in a link-to-link basis. (Von Massow and Canbolat, 2010) explored how individual drivers respond to the specific dispatch policies and the implications for customer wait times. They propose dispatching policies that may be more equitable among drivers, reduce customer waiting times and, therefore, increase customer satisfaction.

Agent based simulation has been used for the same process of dispatching more efficiently a taxi for a specific request. Making use of the capacity of agents to negotiate and adapt to different system configurations (Seow et al., 2007) developed a multi-agent architecture, populated with software collaborative agents that can actively negotiate on behalf of taxi drivers for being assigned to customer bookings. The results of this process were very encouraging, showing both reductions on customer waiting time and empty taxi cruising time, and giving proof for the usefulness of this type of simulation for taxi modeling.

Kim et al. (2011) proposed an agent-based simulation model for describing taxi services. They set up their model distinguishing two agent types: 1) taxi drivers and 2) passengers. In their work, they modeled the taxi driver learning process for finding a location to pick-up passengers and included a stochastic trip generation process.

However, despite considering a time depend continuous model, space was discretized in nodes where taxis and passengers meet and form queues, not considering space continuity. The learning process had been previously explored with positive results on level of service because it demonstrated to improve the efficiency of the taxi driver search for a client (Kim et al., 2005).
Alshamsi et al. (2009) developed a simulation model to translate the existing dispatching system in a city in the middle east, divided in areas, for which a virtual queue of taxis and clients is formed. The company operated manually searching for available taxis to serve each trip inside each area. The common procedure was that when taxis are not available, they search in the adjacent areas, which do not have to be physically adjacent and are preselected by human judgment over large periods of time. In their research work, the authors proposed that these areas should act as agents and self-organize as adjacent to each other according to a behavior that takes in consideration several factors, such as current traffic conditions, number of vacant and occupied taxis and number of times an area is adjacent to another. With this approach they demonstrate through simulation that it is possible to reduce service time to clients.
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.

LISBON CASE-STUDY

As reviewed previously there are multiple ways of regulating the taxi market in a city and several schemes for managing taxi business. With the objective of simulating taxi services in an urban environment we could not define a micro simulation model that fits all these combinations. Instead we focus on describing accurately a specific case study city, Lisbon (Portugal), as a proof of concept for the model and afterwards explain how it is possible to adapt it to other cities.
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. The city is situated on the Atlantic Ocean coast on the Tagus estuary, being the most western capital in mainland Europe. Lisbon is the center 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 to and pay a municipal license (IMT, 2006). 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 types of market regarding the way clients access the service: rank market, hail market and pre-booked market (Salanova et al., 2011):

- 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 center 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 (IMT, 2006).

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 (Darbera, 2010).

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.

Table 1 – Taxi driver shifts in Lisbon

	1st driver shift	2nd driver shift
Type 1	6 am until 7 pm with a break between 12 am and 1 pm	
Type 2	8 am until 9 pm with a break between 2 pm and 3 pm	
Type 3	1 pm until 2 am with a break between 7 pm and 8 pm	
Type 4	7 am until 6:30 pm with a break between 1 pm and 2 pm	6:40 pm until 5:40 am with a break between 0:40 am and 1:10 am
Type 5	9 am until 8:30 pm with a break between 3 and 4 pm	20:40 pm until 9 am with a break between 2:40 am and 3:10 pm

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, which is set for the time that is travelled under speeds of 30km/h.
According to a survey done to travelers in Lisbon, 60% of the people use taxi services "occasionally" or "regularly" and only 5% assume never to use the taxi alternative (Darbera, 2010). The taxi is used for a great diversity of trip purposes, but the highest share goes for the night time leisure, business and work trips, while among the lowest is going shopping. Almost 25% of the sampled population has their trips paid by the employer or by social security. Regarding the three ways of getting a cab, the share is equally distributed (Darbera, 2010).
There are 82 taxi ranks in Lisbon where taxis may pick a passenger using the FIFO rule or wait for a passenger call. The city has at this moment nineteen taxi dispatching companies, where the three largest ones detain more than 75% of the connected taxi fleet. At this moment except for Hotels and companies it is not possible to call a taxi through the web.

AGENT-BASED MODEL DESCRIPTION

Conceptual model

The simulation model for the taxi market which we present was developed through agent-based simulation. This class of computational models is used to simulate 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 agent based model that we propose and test in this paper considers the three different taxi markets (rank, hail and call) already described. These have different implications in modeling the matching between taxis and clients:

- when taxis are placed at ranks, the taxi driver only has to decide on which rank to choose, whereas the client has to move towards the rank that best suits his needs;
- in the case where the taxi is hailed on the street, the paths chosen by the taxi drivers are paramount for the process of matching vehicles with clients, thus taking the most active role in the process. However, the client also plays an active role by moving towards a place where he is more likely to catch the cab;
- in the pre-booked market, taxis are called to the client's origin point which is good for the client who does not have to search for a taxi, and good for the taxi that does not have to search for a client. However both taxis and clients pay to access this market.

The general framework of the simulation model is presented in Figure 1, showing an event driven model representation with the different states and decisions for each agent (taxi and client) and environment component.

The environment where the agent based simulation takes place is the road network of Lisbon 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 public transport vehicles).

For determining the travel times of all links and intersections of the road network along the day, a calibrated micro-simulation traffic assignment model (AIMSUN - TSS) was used for all the hours along the day. 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 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 traveling speeds on the links of the network (several periods have been defined, with different speeds using a calibrated 24 hours network model for the study area).

The model also includes a zoning of the study area for modeling and evaluation purposes. During the model run, taxi drivers have in their minds the knowledge about the normal demand that exists at each zone during the day, using this information to evaluate to which taxi rank they should go or through which city area they should browse. For evaluation purposes this zoning scheme is used to obtain detailed

outputs about taxi supply and demand behavior during the day, allowing a detailed assessment of the performance of the system by city area. The used zoning scheme was obtained using an optimized traffic analysis zones (TAZ) design model developed by the authors, which aims to minimize the information loss resulting from the spatial discretisation (Martínez et al., 2009).
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 between the agents and between the agents and the environment can also be seen in Figure 1.
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 taxis browsing the network. 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, but it is also used to choose the most attractive routes for finding clients in the street. An additional layer of connection between the taxi operation and the road network was considered in the dynamic travel times discussed above that might impact route choices, thus influencing taxi service times and consequently the fee charged to each client.
The key actions and decisions of the two main agent of this system can be seen in Figure 1, where the taxis evolve during the simulation between the active and inactive states, and the users enter in the simulation searching for a taxi, deciding which market option is more suitable for their trip and ride a taxi from their origin to their destination. The detailed behavior of both types of agents is described next.

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 to bring them a taxi at their origin point. 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 usually have on taxi supply in the city.

Rules of Behavior:

- Hail for a taxi in the initial node or walk to a better hailing location (based on experience – simulated in the model using historical data of taxi traffic);

- Walk to the closest or largest taxi rank within a walking threshold of his current location (utility function generated for each client setting the trade-off between the probability of finding a taxi and the willingness to walk);
- Dial to a dispatching service available in the city (random selection among the existing available options in the city, proportional to the number of affiliated in each dispatching company);
- When the client goes to a road network 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 $waiting_{max}$, the client leaves the system.
- When the client calls for a taxi and one is assigned to him, he automatically accepts that assignment, which is chosen by the dispatcher;
  - 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 chosen using the same probabilistic procedure;

    After waiting more than the limit threshold ($waiting_{max}$) without a taxi being assigned him, he gives up from the service and goes out of the system.

Possible Internal States:

- Searching for a taxi;
- Waiting for an assigned taxi;
- Riding a Taxi.

Taxi Agent

A taxi can be connected to different taxi dispatching companies (nineteen as referred above) and can be operated by a single driver (owner of the car) or belong to a taxi firm where several drivers work in shifts. The organizational model of supply is an input of the model, where the size of the taxi fleet, the percentage of connected taxis to a central dispatching service and the different types of taxi drivers shifts and their percentages in the market are set as parameters. To start the simulation all there are set for the current situation in Lisbon as described in the previous section.

Rules of behavior:

- 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 current service time in the taxi queue leads to a waiting time greater than 30 min. In this situation, the taxis either search for another taxi rank or route through the network searching for a passenger (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 became inactive.

Possible Internal States:

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

The time period of the simulation is 5 days, trying to incorporate in the analysis an average week of taxi operation, which may present variability in operation outputs for the different taxis of the system. The consideration of this longer period instead of a single day allows for a better assessment of the model accuracy in reproducing the average aggregate indicators that are available for the Lisbon market, reducing the impact on the indicators of a very "positive" or "negative" day for one particular taxi. The model described was developed using JAVA Programming Language, implemented through the software Anylogic (Xj Technologies). This is a package that allows creating totally customizable and capable of building an extensive range of simulation models using the JAVA language.

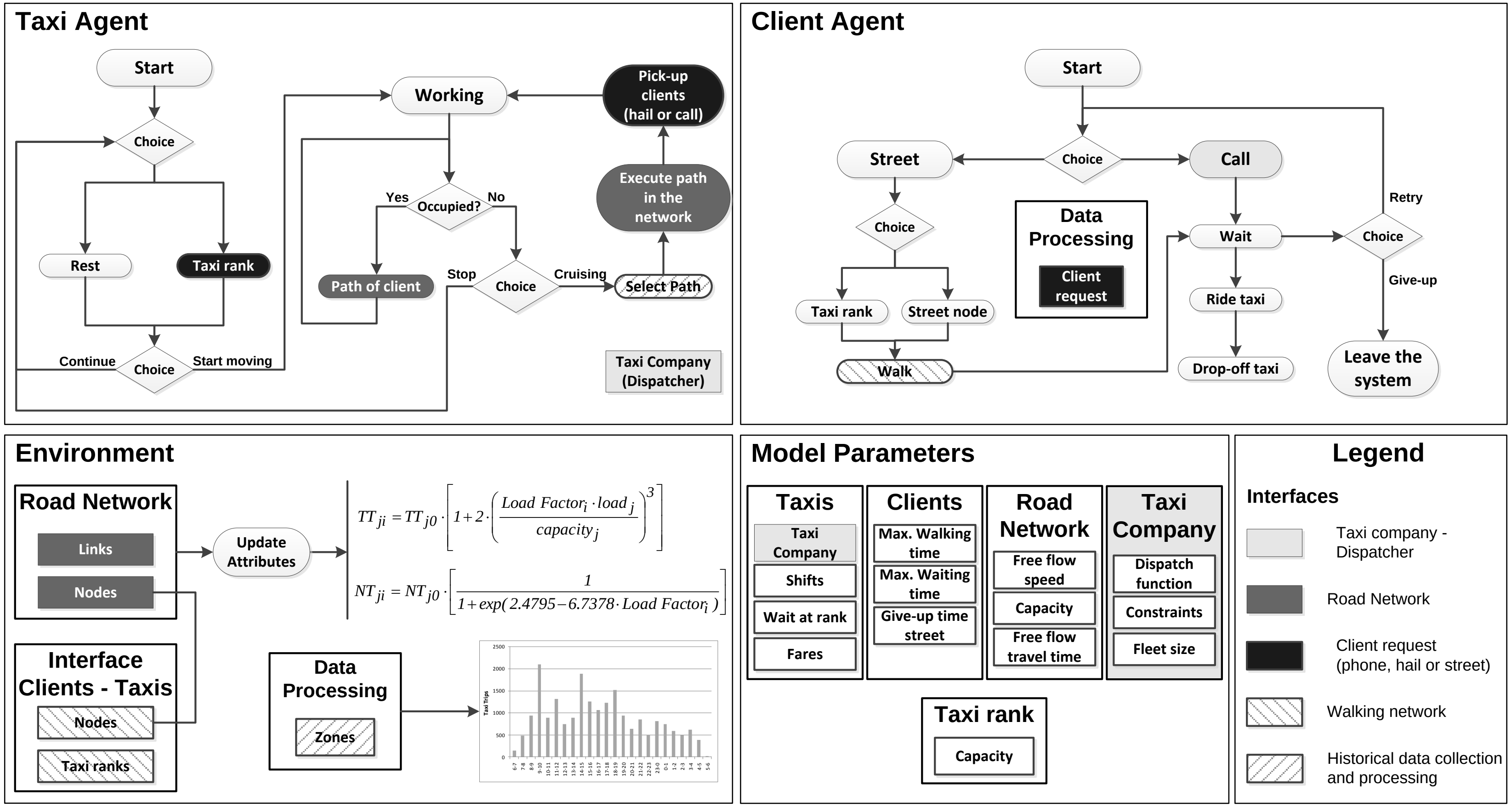

Figure 1 - Simulation model architecture.

Data

In order to simulate the behavior of the taxi market in the city of Lisbon we needed to have accurate data to characterize this market. Namely the following data is crucial:

- the origin and destination of the taxi trips as well as their starting time;
- the topological 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 demand input the results of a synthetic travel simulation model, which was developed under the SCUSSE research project (Viegas and Martinez, 2010). This model used as seed a mobility survey of the LMA performed in 1994 with approximately 60,000 trips and 23,000 persons surveyed. The database has been updated in 2004 and 2009 with additional 4,000 surveys, allowing an assessment of the evolution of the region's mobility. This statistical procedure was also supported by an activity database of 2009, used as source and destination of trips in the study area. The model generated 21,075 taxi trips during a week day inside the city of Lisbon. The distribution of these taxi trips along the day has a higher frequency in the morning peak and some periods during the lunch break and the afternoon. 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, 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, apart from the usual underreporting of small share travel modes observed in the literature (Ampt and Gleave, 1997; Transportation Research Board, 2008). The percentage of Lisbon's taxi demand that might be underrepresented in the available data was estimated as 40%.

VALIDATION OF THE SIMULATION MODEL

In order to validate the model results in the base scenario without the sharing possibility, one validation simulation run was performed for a fleet of 2,500 taxis, which represent approximately 80 percent of the total number of taxis that daily operate in the city of Lisbon. The use of a smaller taxi fleet intends to reproduce the lack of demand in the model from people with destinations outside Lisbon and of non-residents (i.e. tourists). This validation considered three main aggregate indicators from the taxi supply characterisation collected in a study from IMT and a log-file of the operation of one taxi dispatching Company during the month of May 2011.The following table presents the obtained results from the simulation against the available data, showing a considerable adherence. Nevertheless, the average number of services does also contain services outside the Lisbon municipality and trips of non-residents, which explains the observed deficit in this indicator in the simulation results.

Table 2 - Comparison of the daily model simulation results (2,500 taxis fleet) with real aggregate data

Indicator	Simulation outputs	Real data source
Average daily revenue	76.46	79.06 euros[1]
Average number of travelled kilometres	208.16	207.18 km [1]
Average number of services	9.38 services	15.98 services[1]
Average number of dial services per connected taxi	4.46 services	4.47 services[2]

CONCLUSIONS AND FUTURE WORK

This paper sets an innovative simulation procedure to assess the dynamics of the taxi market and evaluate the effects of the introduction of new policies and regulation of the market, as well as the total number of licenses available in the market or the service license segmentation.
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. This new procedure was implemented in a large scale example: the municipality of Lisbon which counts now about 3,500 taxi vehicles with a single type of license, having just a portion of them connected to a central dispatcher.
Several policies could be tested in the developed simulation platform and assess the balance between society welfare, measured through the number clients served and the average waiting time for a taxi; and the taxi operators' revenue, assessed by the average revenue per taxi under the different scenarios. The model has the capability to test: the optimal cap value for taxi licenses; the optimal share of taxis connected to a central dispatcher service; the optimal number of central dispatcher companies; the introduction of license segmentation by type of service; the introduction of a shared taxi scheme.
This last system may present two types of configuration depending on the technology available for the system: either by street hailing, stopping the taxi and assessing if the taxi is moving on the intended path of the traveler, which might be very inefficient, both for passengers and taxi drivers; or by booking in an internet or smartphone application a service with the origin and destination coordinates. A central dispatcher will then match the taxi (empty or with clients already on-board) that is more suited the serve each client. This system would require that shared taxis are connected to a central dispatcher service.

[1] Relatório IMTT 2010.
[2] Retatis - Radio Táxis log file May 2012.

All these policies and regulations of the market may not only have impact on the operational indicators of the system but also in the global demand of the system, which might be assessed by the induced or repressed demand resulting from the operational output of the tested measures. This assessment may be done by a calibrated discrete mode choice model, where the taxi attributes are re-evaluated, leading to changes on the probability of choosing the taxi as an alternative to perform a specific trip. This dynamic component of demand may be introduced in the model with an incremental approach until reaching a global equilibrium, where no more passengers intend to join or leave the system.

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REFERENCES

Abe, M. A. and B. C. Brush (1976). On the regulation of price and service quality: The taxicab problem. *Quarterly Review of Economics and Business* Vol.16, pp. 105-111.

Alshamsi, A., S. Abdallah and I. Rahwan (2009). Multiagent Self-Organization for a Taxi Dispatch System. *8th International Joint Conference on Autonomous Agents and Multiagent Systems*, 10-15, Budapest, Hungary.

Ampt, E. and S. D. Gleave (1997). Current Issues in Travel and Transport demand surveys. *25 th*
European Transport Conference, Cambridge University.

Arentze, T. A., D. Ettema and H. J. P. Timmermans (2010). Incorporating time and income constraints in dynamic agent-based models of activity generation and time use: Approach and illustration. *Transportation Research Part C: Emerging Technologies* Vol.18, No.1, pp. 71-83.

Arnott, R. (1996). Taxi travel should be subsidized. *Journal of Urban Economics* Vol.40, No.3, pp. 316-333.

Bailey, W. (1987). A simulation analysis of demand and fleet size effects on taxicab service rates. *Winter Simulation Conference*, 14-16 December Atlanta, GA, US.

Beesley, M. E. (1973). Regulation of Taxis. *Economic Journal* Vol.83, No.329, pp. 150-172.

Beesley, M. E. and S. Glaister (1983). Information for Regulating - the Case of Taxis. *Economic Journal* Vol.93, No.371, pp. 594-615.

Cairns, R. D. and C. ListonHeyes (1996). Competition and regulation in the taxi industry. *Journal of Public Economics* Vol.59, No.1, pp. 1-15.

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*.

Davidsson, P., L. Henesey, L. Ramstedt, J. Törnquist and F. Wernstedt (2005). An analysis of agent-based approaches to transport logistics. *Transportation Research Part C: Emerging Technologies* Vol.13, No.4, pp. 255-271.

Devany, A. S. (1975). Capacity Utilization under Alternative Regulatory Restraints - Analysis of Taxi Markets. *Journal of Political Economy* Vol.83, No.1, pp. 83-94.

Douglas, G. W. (1972). Price Regulation and Optimal Service Standards - Taxicab Industry. *Journal of Transport Economics and Policy* Vol.6, No.2, pp. 116-127.

Fernandez, J. E., J. D. Ch and J. Briones (2006). A diagrammatic analysis of the market for cruising taxis. *Transportation Research Part E-Logistics and Transportation Review* Vol.42, No.6, pp. 498-526.

Flores-Guri, D. (2003). An economic analysis of regulated taxicab markets. *Review of Industrial Organization* Vol.23, No.3-4, pp. 255-266.

Foerster, J. F. and G. Gilbert (1979). Taxicab Deregulation - Economic Consequences and Regulatory Choices. *Transportation* Vol.8, No.4, pp. 371-387.

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.

Kim, H., J. S. Oh and R. Jayakrishnan (2005). Effect of taxi information system on efficiency and quality of taxi services. *Transit: Bus, Rural Public and Intercity, and Paratransit*, No.1903, pp. 96-104.

Kim, H., I. Yang and K. Choi (2011). An agent-based simulation model for analyzing the impact of asymmetric passenger demand on taxi service. *Ksce Journal of Civil Engineering* Vol.15, No.1, pp. 187-195.

Kirby, R. F. (1974). Para-transit: negleted options for urban mobility. Urban Institute.

Lave, R. E. and R. G. Mathias (2003). Paratransit Systems. *Transportation Engineering and Planning: Encyclopedia of Life Support Systems*. (T. J. Kim, Eds.). Oxford: Eolss Publishers. I.

Lee, D. H., H. Wang, R. L. Cheu and S. H. Teo (2004). Taxi dispatch system based on current demands and real-time traffic conditions. *Transportation Network Modeling 2004*, No.1882, pp. 193-200.

Loo, B. P. Y., B. S. Y. Leung, S. C. Wong and H. Yang (2007). Taxi License Premiums in Hong Kong: Can Their Fluctuations be Explained by Taxi as a Mode of Public Transport? *International Journal of Sustainable Transportation* Vol.1, No.4, pp. 249-266.

Manski, C. F. and J. D. Wright (1976). Nature of equilibrium in the market for taxi services. *Transportation Research Record* Vol.619, pp. 11-15.

Martínez, L., J. Viegas and E. Silva (2009). A traffic analysis zone definition: a new methodology and algorithm. *Transportation* Vol.36, No.5, pp. 581-599.

Roorda, M. J., R. Cavalcante, S. McCabe and H. Kwan (2010). A conceptual framework for agent-based modelling of logistics services. *Transportation Research Part E: Logistics and Transportation Review* Vol.46, No.1, pp. 18-31.

Salanova, J. M., M. Estrada, G. Aifadopoulou and E. Mitsakis (2011). A review of the modeling of taxi services. *Procedia Social and Behavioral Sciences* Vol.20, pp. 150-161.

Schaller, B. (1999). Elasticities for taxicab fares and service availability. *Transportation* Vol.26, No.3, pp. 283-297.

Schaller, B. (2007). Entry controls in taxi regulation: Implications of US and Canadian experience for taxi regulation and deregulation. *Transport Policy* Vol.14, No.6, pp. 490-506.

Schroeter, J. R. (1983). A Model of Taxi Service under Fare Structure and Fleet Size Regulation. *Bell Journal of Economics* Vol.14, No.1, pp. 81-96.

Seow, K. T., N. H. Dang and D.-H. Lee (2007). *Towards an automated multiagent taxi-dispatch system*. *IEEE Conference on Automation Science and Engineering*.

Shrivastava, M., P. K. Chande, A. S. Monga and H. Kashiwagi (1997). Taxi dispatch: A fuzzy rule approach. *Ieee Conference on Intelligent Transportation Systems*, pp. 978-982.

Tang, J., S. Alam, C. Lokan and H. A. Abbass (2012). A multi-objective approach for Dynamic Airspace Sectorization using agent based and geometric models. *Transportation Research Part C: Emerging Technologies* Vol.21, No.1, pp. 89-121.

Transportation Research Board (2008). Standardised Procedures for Personal Travel Surveys. Transit Cooperative Research Program - The Federal Transit Administration, Washington D.C.

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

Vliet, O. v., B. d. Vries, A. Faaij, W. Turkenburg and W. Jager (2010). Multi-agent simulation of adoption of alternative fuels. *Transportation Research Part D: Transport and Environment* Vol.15, No.6, pp. 326-342.

Von Massow, M. and M. S. Canbolat (2010). Fareplay: An examination of taxicab drivers' response to dispatch policy. *Expert Systems with Applications* Vol.37, No.3, pp. 2451-2458.

Wang, H., D. H. Lee and R. Cheu (2011). Microscopic Traffic Simulation based Dispatch Modeling for Taxi Booking Service. *Sports Materials, Modelling and Simulation* Vol.187, pp. 677-682.

Weiner, E. (1975). The characteristics, uses and potentials of taxicab transportation. *Transportation* Vol.4, No.4, pp. 351-367.

Wong, K. I. and S. C. Wong (2002). A sensitivity-based solution algorithm for the network model of urban taxi services. *Transportation and Traffic Theory in the 21st Century*, pp. 23-42.

Wong, K. I., S. C. Wong, M. G. H. Bell and H. Yang (2005). Modeling the bilateral micro-searching behavior for urban taxi services using the absorbing Markov chain approach. *Journal of Advanced Transportation* Vol.39, No.1, pp. 81-104.

Wong, K. I., S. C. Wong and H. Yang (2002). A Network Equilibrium Model for Urban Taxi Services with Explicit Consideration of Perceived Profitability. *Transportation in the Information Age: Proceedings of the 7th Conference of Hong Kong Society for Transportation Studies*, pp. 297-299.

Yang, H., C. W. V. Leung, S. C. Wong and M. G. H. Bell (2010). Equilibria of bilateral taxi-customer searching and meeting on networks. *Transportation Research Part B-Methodological* Vol.44, No.8-9, pp. 1067-1083.

Yang, H. and S. C. Wong (1998). A network model of urban taxi services. *Transportation Research Part B-Methodological* Vol.32, No.4, pp. 235-246.

Yang, H. and T. Yang (2011). Equilibrium properties of taxi markets with search frictions. *Transportation Research Part B-Methodological* Vol.45, No.4, pp. 696-713.