Agent Based Modeling for Simulation of Taxi Services

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***Abstract*—This paper presents an agent based model for simulating taxi services in urban areas. The three operation modes (hailing, stand and dispatching) are modeled and tested in the Sioux Falls network. Taxi models presented in the literature are divided into aggregated and equilibrium models, with a very small presence of simulation models. The different programmed modules are presented together with the behavior rules of the agents. Performance indicators are calculated for each operation mode and compared in terms of driver earnings, user cost and vacant versus occupied time.**

***Index Terms*—Agent based modeling, taxi modeling, taxi services.**

I. Introduction

Taxis are present in most of the cities around the world. They combine the comfort of door-to-door transportation of private vehicles with the advantages offered by public transport services. Most of the taxi markets in urban areas combine three operational modes: stand, hailing and dispatching. In the stand market, taxis and users meet each other at predetermined meeting points, called taxi stands or ranks, where a first-in-first-out (FIFO) system applies for both the drivers' and the users' queue. In the hailing mode taxis circulate continuously searching for a user, and users wait for taxis at their origin, while in the dispatching market taxis circulate or just wait for a call from a dispatching center. In the dispatching market, a user contacts the operator asking for taxi services and the nearest taxi in the zone (respecting the queue) is assigned to him/her. Taxi markets in small cities are composed by one or two operational modes, usually the dispatching and stand markets, reserving the hail market only for large cities with high densities of population and a Business District concentrating a high percentage of daily trips.

Since most of the taxi markets are regulated, there is a need for developing models for understanding the behavior of these markets in regard to policy regulations and deregulations. Most of the taxi models developed up to now have studied only one operational mode, using aggregated values or finding equilibrium assignment conditions for calculating system performance indicators, such as level of service of users, earnings of taxi drivers or vacant versus occupied distance. On the contrary, only a few simulation based models have been developed.

The model presented in this paper, proposes the use of agents circulating in an urban road network, taking their own decisions for completing as many trips as possible. There are different types of agents, including the three basic types of agents corresponding to the operational modes listed before, as well as the users of the system.

The paper is structured as follows: A literature review is presented in section two, reviewing the aggregated and equilibrium models and presenting the simulation models developed by various authors. The proposed agent based model is analytically described in section three, while the obtained results are presented in section four. Finally, conclusions and future research guidelines are presented in the last section.

II. Literature Review

A. Aggregated and Equilibrium Models

The initial studies related to the taxi sector (1970-1990) focused on the profitability and the necessity for regulation using aggregated models. Following these, more realistic taxi sector models were implemented in the studies of Yang et al. developed in 1998 for a small taxi fleet [1] until the most sophisticated models of Yang and Wong ([2] and [3]) that are able to simulate congestion, different user classes, elasticity of demand, external congestion and non-linear costs. The first taxi model was developed by Douglas [6] in an aggregated way, using economic relationships from other sectors (goods and services). Other authors based their models on the work presented by Douglas and tested their own models in different market configurations, e. g. de Vany [7], Beesley [8], Beesley and Glaster [9] and Schroeter [10]. An intermediate type of models was developed by Manski and Wright [11], Arnott [12] and Cairns and

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Liston-Heyes [13], obtaining more realistic results with their structural models. Yang and Wong presented accurate and detailed models, where the spatial distribution of demand and supply in the city was taken into account by including traffic assignment procedures in their models ([2] and [3]). The models of Wong et al. [4] and Yang et al. [5] analyzed the user-driver meeting through a bidirectional function and accounted for the willingness of users to pay. Various models have been tested and validated by using real world data. Beesley [8] and Beesley and Gaister [9] used data obtained from questionnaires in various cities in the UK; Schroeter [10] used data from taximeters in his model; Schaller [14] used questionnaires and interviews from taxi drivers and users in various cities of the USA. Recently, Kattan et al. [15] investigated the regression models obtained from work trips conducted by taxi in 25 Canadian cities. A detailed review of the aggregated and equilibrium models can be found in Salanova et al. [16].

B. Simulation based Models

The concept of agent based models was developed in 1940, but it was in 1990 when the advances in computation procedures allowed them to widespread. The first use of the word agent, as it is used today, was initiated by Miller in 1991 [17]. Bailey and Clark [18] investigated changes of performance in the dispatching market related to the number of vehicles, concluding that the waiting time is relatively insensitive to changes in demand but highly sensitive to changes in the number of taxi cabs. Bailey and Clark [19] used a discrete-event method to simulate dispatching taxi services, obtaining a linear relation between total distance and fleet size. Kim et al. [20] developed a simulation based stand taxi services which includes a knowledge building process, proving that the use of information technologies could improve the quality of the service by 20%. Song and Tong [21] and later Tong [22] presented dynamic taxi demand models using the simulation model approach of the taxi stand market. They highlighted the limitations of traditional aggregated models (time-dependent patterns, imperfect information, learning convergence and non-equilibrium in taxi market due to regulation) and tested the effects of Advanced Transport Information Systems (ATIS) in this specific market. Recently, Lioris et al. [23] developed a discrete-event simulation model for reproducing the real taxi on demand market conditions since the mathematical models are out of reach for such a complex multi-agent system (network, stochasticity).

III. The Proposed Agent-based Model

A. Variables Presentation

The two basic variables are supply and demand related. The supply variable is composed by the city's road network and the total number of taxis, while the demand variable is composed by the users in need for taxi trips. The three basic actors of the model are the city, the taxi drivers and the users.

All variables are listed below:

1) Exogenous variables (demand and supply, network geometry and links congestion and taxi fares)

2) Endogenous variables (obtained from the simulation)

- City related variables (number of vehicle-kilometers and vehicle/hours Total system cost (drivers' earnings, city and users' costs)
- Taxi drivers' related variables (circulating time and distance (total, occupied and vacant, taxi occupancy and vacant taxi headway, earnings)
- Taxi users related variables (waiting time and travel time, cost of trip)

B. Vehicle-Agent Rules

Three basic agents are designed for the taxis, related to the three operational modes.

1) Hailing market vehicles

Vacant Movement: While the taxi moves along a link, the distance traveled within the time period is related to the duration of the time period and the congestion of the link, using a constant free flow speed for taxis. When the taxi arrives to an intersection, it randomly chooses the next link based on its weight (attractiveness).

Picking up a User: If the taxi finds a free user (not waiting for an assigned taxi or at a stand), he picks him/her up. The taxi state changes to occupied, and the shortest route to the user's destination is calculated, depending on the traffic congestion of each link at that moment, setting the route to be followed by the taxi.

Occupied Movement: Taxi and user move along the links, as in the vacant movement, but when arriving to an intersection, the link correspondent to the shortest route is followed until the destination is reached. While moving, the taxi is calculating the trip cost using either a distance-based or a time-based charge, charging always according to the first value that reaches a threshold value (either by distance covered or minutes traveled).

Delivering a User: When the destination of a user is reached, the taxi calculates the cost of the last interval and the user disappears. The trip cost is then charged to both agents (income for the taxi and cost for the user). The taxi becomes free and continues looking for a user.

2) Stand market vehicles

Arriving to a Taxi Stand: When a taxi arrives to a taxi stand, it joins the taxi queue (if exists ant). If there are no taxis on the stand, the taxi picks up the first user in the queue. If there are neither taxis, nor users, the arriving taxi forms a taxi queue.

Vacant Movement: Vacant taxis running in stand mode are always looking for a taxi stand near their current location (following the shortest route between their current location and the nearest and most attractive in terms of waiting time taxi stand). When the taxi arrives to an intersection, it chooses the next link based on the calculated shortest route to the nearest taxi stand.

Picking up a User: Taxis and users are assigned in each taxi stand based on a FIFO system.

Occupied Movement and Delivering a user: As in the hailing mode.

3) Dispatching market vehicles

Assignation of a User: When a user asks for a taxi, the nearest free dispatching taxi is assigned to him, according to the distance calculated within the network (not Euclidian). The taxi then finds the shortest route between its actual location and the user, and follows it until the user is reached.

Picking up a User: As in the hailing mode, with the exception that only the assigned user can be picked up.

Vacant Movement, Occupied Movement and Delivering a User: As in the hailing mode.

4) The users

Three basic agents are designed for the users, related to the three operational modes. Users appear in each zone following a two-dimensional geographic distribution. Once the user is assigned to a zone, random coordinates are defined for the location of the user within the zone (if it is a stand user, random taxi stop is chosen within the zone). Hailing users wait until a hailing taxi reaches them. Stand users wait at taxi stands, forming queues served by a FIFO system. Dispatching users call for a taxi service and wait until the assigned taxi reaches them. If there are no free taxis, the user is added to a virtual queue for later assignment as soon as a taxi becomes available.

C. Developed Modules

The diagram below shows the agent-based model of the taxi market. As the taxis and users are being generated, the variables are being created and updated. Each module is represented and explained below.

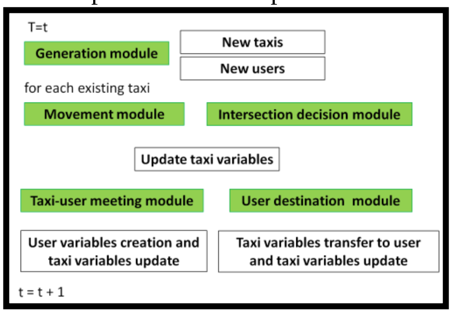

Figure 1. Flowchart of the agent-based model

1) Generation module

The generation module generates the demand and the supply. Users and taxis are statistically generated, depending on the time of the day. Characteristics of both agents, such as origin zone, destination zone or operational mode are also statistically generated.

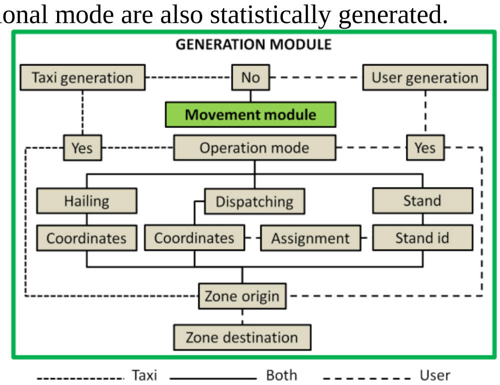

Figure 2. Generation module

When a taxi is created, it is assigned to an origin zone and an operation mode. If the operation mode is hailing or dispatching, random coordinates within the zone are defined for the starting position of the taxi. If the taxi operation mode is the stand mode, a random stand within the zone is assigned to it. If there is a user queue in the stand, the first user in the queue is assigned to the taxi. If there is not a user queue in the stand, the taxi joins the taxi queue.

When a user is created, origin, destination and operational mode are defined. If the operation mode is hailing or dispatching, random coordinates within the zone are defined for the waiting position of the user. In the dispatching case, the nearest (in real network travel time) available taxi is assigned to the user. If there are no available taxis, the user is added to a virtual queue for later assignment as soon as a taxi becomes available. If the operation mode is the stand mode, the user is assigned to a random stand within the zone, while if there is a taxi queue in the stand, the user is assigned to the first taxi in the queue. If there is no taxi queue in the stand, the user joins the user queue.

If neither taxis, nor users are created, the model goes directly to the movement module.

2) Movement module

The movement module moves each taxi depending on the congestion of the correspondent link. If the taxi arrives to an intersection, the intersection decision module decides the route that the taxi will follow (the next link). If the taxi continues in the same link, the position of the taxi is updated.

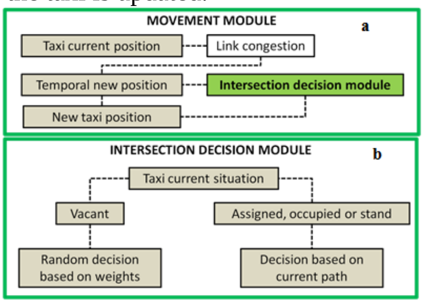

Figure 3. Movement (a) and Intersection decision (b) modules

3) Intersection decision module

When a hailing or not assigned taxi reaches an intersection, it randomly chooses the next link. When an occupied taxi, stand taxi or assigned taxi reaches an intersection, it follows the defined shortest route (between the origin and the destination of the user, looking for the nearest stand or looking for the assigned user respectively). All taxis are informed about the conditions on the network. This is in fact a realistic assumption since nowadays most of the taxis are equipped with real time traffic information technologies.

4) Taxi/user meeting module and user destination module

If a vacant or assigned taxi meets a user while circulating, the taxi/user meeting module decides if the taxi picks up the user or not. If an assigned taxi meets its assigned user, the taxi picks him/her up. The same happens in the case of a vacant hailing taxi and a hailing user. Dispatching taxis pick up only their assigned users. Stand taxis pick up only users at taxi stands. Hailing taxis pick up only hailing users. When a taxi picks up a user, the shortest route between the user's origin and destination is calculated and stored in the intersection decision module.

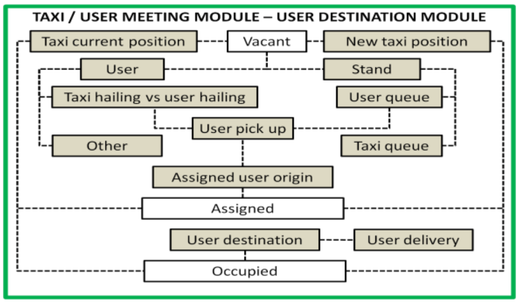

Figure 4. Taxi/user meeting and user destination modules

If an occupied taxi passes by the destination point of its user, the user is delivered, and the taxi is free for the next time interval. A stand taxi finds the nearest taxi stand and the correspondent route for reaching it. A hailing taxi circulates randomly until a new user is found. A dispatching taxi circulates randomly until a new user is assigned, finding the shortest route for reaching the user.

IV. Use Case: Sioux Falls Network

The agent-based model is tested in the Sioux Falls network [24]. The agent-based model has been applied with a fixed origin-destination demand matrix and 25 different supply levels. In order to calculate average results of the performance indicators each supply level has been run 50 times, creating a total of 125.000 trips satisfied by 32.500 vehicles. The results obtained are presented for both the drivers and the users in the graphs below. Performance indicators have been obtained for each operation mode and agent. The driver indicators are total distance, occupied and vacant time, occupied and vacant distance, income and earnings. The user indicator is waiting time. Finally, the system costs and the optimum fleet size are also presented.

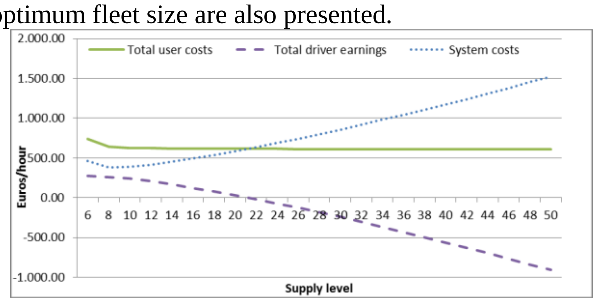

Figure 5. User costs, system costs and driver earnings related to different supply levels and to a fix demand for the dispatching mode model

Fig. 5 shows the relation between total earnings of drivers and total system and user costs in the dispatching market. The system optimum fleet can be observed where the system cost is minimum. Smaller fleet size than this optimum produces more benefit to the taxi drivers due to the higher number of trips, but the users' costs due to the increased waiting time are higher. Higher fleet size than the optimum has no significant effects on reducing the waiting time of users, but the earnings of drivers are reduced dramatically.

The graph below shows the relation between vacant and occupied kilometers and the rate between both terms for each supply level. When the supply level is low, the occupied time is high, but the vacant time is also high; at the same time the waiting time of users is high. When the supply is high, the number of occupied kilometers is low, while the number of vacant kilometers is high.

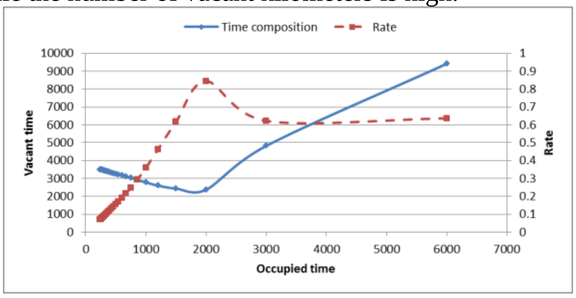

Figure 6. Relation between the vacant and occupied times for the dispatching mode model

The driver optimum fleet corresponds to the maximum rate between occupied and vacant times, as shown in Fig. 7. This driver optimum fleet is smaller than the system optimum fleet. The rate value of the system optimum fleet is 0.65, which means that the occupied time is 35-40% of the total time. Average results from the simulations are presented in the table below.

TABLE I: Simulation Results of the Three Operation Models

	Dispatching	Stand	Hailing[1]
Optimum fleet for system cost (vehicles)	8	10	14
Average occupied distance (m)	6.100	4.900	3.500
Average vacant distance (m)	4.200	330	14.000
Average occupied time (min)	25	20	14,5
Average vacant moving time (min)	35	16	90
Average vacant stopped time (min)	0	24	0
Income (euros/h)	67	54	38
Driver unitary earnings (euros/hour)	32,5	30	-8
Ratio occupied/vacant moving time	0.65 (35-40%)	1.3 (55-60%)	0.16 (10-15%)
Rate occupied/vacant distance	1.5 (60%)	15 (94%)	0.25 (20%)
Average user waiting time (sec)	136	65	392
User unitary cost (euros/hour)	6,45	6,25	7,5
System cost (euros/hour)	385	325	865

V. Conclusions

An agent-based model for simulating taxi services in urban areas has been presented. The model is capable of simulating the three operation modes (hailing, stand and dispatching). Results for the dispatching model have been

[1] In the hailing case more than one hour was needed most of the times for completing all trips since the taxis are randomly looking for users.

compared to a mathematical aggregated model, presenting similar tendency and results. The model outputs in terms of system costs and total time composition (vacant and occupied time) have been presented, concluding in the system's optimum fleet size and the drivers' optimum fleet size, obtained from the system costs and from the relation between occupied and vacant times respectively. The drivers' optimum fleet is smaller than the system's optimum fleet.

The system optimum fleet of the dispatching mode for the same demand is the smallest one; the hailing optimum fleet is the highest one. The ratio of occupied versus vacant time is 10-15% for the hailing market, since the taxis are constantly circulating and randomly looking for users; the respective ratio for the dispatching market is 35-40%, where users call taxis, reducing the vacant distance. Finally, the ratio for the stand market is 55-60%, since taxis wait at taxi stands, having to return there before picking up a new user.

Future research should focus in the users' behavior, giving them the possibility of changing operation mode if the waiting time exceeds a threshold value, or presenting user classes with different willingness to pay for taxi services. In order to obtain more realistic and representative results there is a necessity for testing different demand profiles and levels in different network geometries, calibrating the parameters of the model with real world data. Finally, new technologies should be tested using simulation models, creating the necessary rules for providing information to drivers about the hot spots of the city or demand forecasts in the city.

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