Modeling collective taxis in a multi-agent traffic simulation framework

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Abstract

This paper report on ongoing work aimed to explore new solutions to urban traffic problems. The use of collective taxi services at a large scale is proposed. It is seen, if used and properly integrated together with other flexible systems, as a mean to reduce private car travel. The paper discusses motivations and possible factors of success of the system, and sketches the characteristics that such a service should have. Moreover, the problem of estimating the potential of a new transport option in a reliable way is confronted. It is suggested that the use of agent based microsimulation might be appropriate. The planned implementation in an existing modelling framework of this kind, MATSim-T, is also described.

Keywords

Collective Taxi – Demand Responsive Transport – Agent Based Simulations – MATSim-T – STRC

1. Introduction

The search for solutions of the growing transportation problems of metropolitan areas is a challenge for researchers of many different disciplines. Rising traffic volumes involve an increasingly diverse travel demand which requires a more efficient use of environmental and financial resources. This paper reports on ongoing work aimed to explore the use of on-call collective taxi service as a mean to mitigate urban traffic problems. Collective taxis - or more in general -demand responsive transport, are sporadically implemented in western countries; but their application is usually intended to answer to some special needs or to be used in some special area. Demand Responsive Transport is of on-going interest to the scientific and policy making community. The widespread diffusion of some technologies, such as GPS devices and mobile phones, open new perspectives for DRT systems, and might help to extend their use to new categories of customers. Most of the recent literature on this subject goes in this direction (Khattak and Yim, 2004; Brake *et al.*, 2007). However, none of these studies, maybe with one exception (Cortes and Jayakrisnan, 2004), is really trying to enhance the concept of DRT envisaging large scale use of the system. On the contrary, the main claim of this work is that the use of such services at a large scale could help to reduce the use of private cars. The tasks to be achieved in order to deliver such a conclusion are multiple. First, it is necessary to explain why a large scale collective taxi system would be desirable and it is worth to be evaluated for such application. Second, the characteristics of the collective taxi system and its operator have to be defined. Third, the reasons and the possible factors of success must be discussed. According to that, some possible future scenarios need to be proposed. Fourth, we need to find, or to create, a modelling framework which allows the assessment of its practical feasibility and potential. Fifth, the chosen model has to be run and the potential of the systems, with the characteristics previously sketched, and its effects on the whole transportation system, are to be estimated under the different scenarios' conditions.

The work presented here deals with the first four of the listed tasks. Motivations lying behind the idea of a collective taxi system at large scale are related to environmental and social issues. These arguments are presented in Section 2. The taxi system which will be modelled would deliver mainly two type of services, short trips within a limited area not well served (or not at all) by public transport, with the goal of linking such area with the public transport network; longer trips on fixed or slightly flexible routes where the destination is not well served by public transport. This is described in more details in Section 3. Some of the mobility habits of the population might help to determine the success of the system or at least suggest his theoretical feasibility. These factors are discussed in section 4. On the modelling side, an agent-based micro-simulation approach is proposed. An already existing simulation tool, MATSim-T (Multi-Agent Transport Simulation Toolkit, Balmer, 2007) will be the basis for this work. This is the subject of Section 5, while in Section 6 some conclusions and the outlook on the future work are presented.

2. Collective taxi at a large scale: motivations

It is well known that the current transportation system imposes a heavy burden on society in terms of energy consumption and external costs such as accidents, noise emissions, pollution, space consumption etc. But it is often neglected that this system also entails social exclusion, and that it is for different reasons inaccessible to various categories of people. The idea of collective taxi at large scale should be seen as a part of an effort to rethink urban travel and try to mitigate such problems. In particular, the goal is to find ways to substitute private car travel. The taxi system would be part of a global system where also other services, like car-sharing, car-pooling, bike sharing, etc., are also deployed at large scale. The integration of such systems should make realistic the hypothesis of a major shift from private oriented, individually driven, urban transport; to a more sustainable multi-modal shared transport.

The current discussion on car pollution mainly focuses on car emissions in the air, in particular on oxygen dioxide emissions. However, it has been stated that a large part of environmental cost related with the use of the car are coming from its production, and not depending on its travel. In fact according to some researchers (Umwelt- und Prognose-Institut Heidelberg e.V., 1993), the largest part of the pollution related to a car life cycle is coming from its manufacturing. A smaller, but not negligible, contribution comes from car disposal at the end of its life cycle. This is a good reason to focus not only on emissions reduction (either directly reducing car emissions or indirectly reducing car travel), but also on the reduction of the number of cars overall. Actually, the reduction of the overall number of circulating cars is probably the main objective to be achieved by the proposed system, but possibly also the main barrier to be overcame. A car is a long term investment in mobility and thus, in a way, a commitment to use it for travel instead of other modes. This behaviour has been described in Ciari *et al.* (2008). Indeed, using the car, the investor is amortizing the initial investment. The investor therefore, using another mode instead of the car, is preventing his investment to pay off, which is in principle against its interest. However the situation has not to be seen as static and immutable, some other experiences, like Mobility Car-sharing in Switzerland (Mobility, 2009) or Velib (Velib, 2009) in Paris, France, demonstrated that when a credible alternative to private car travel is offered, a major shift in persons habits is definitely possible, even if not necessarily an easy, and fast, path.

Links between transport and social exclusion has been discussed, among others, by Hine and Mitchell (2003). Such problems are much stronger in North America, due to a weak public transport system and a development style strongly oriented toward private car mobility. However such problems are not aliens to European societies either, and could be addressed by a system like the one proposed in this work.

3. The service

It was mentioned that the taxi system should be seen as part of an integrated system of different innovative transport options and traditional public transport. If the system as a whole would be conceived to respond to most of the mobility needs of the population, this particular service would have very specific targets. The first important target are individuals living in an area where public transport is not well developed or absent, and service that we want to model avoid to drive in traffic, possibly a more comfortable trip (maybe possible to work), more cost effective than car even if more expensive than public transport, more practical than public transport

As already reported, the taxi would have two main functions:

- Proximity transport, conceived to link the start/destination with the nearest point of the public transport network. The access to the network would become more convenient also in areas where public transport is not directly available.
- Urban flexible transport, conceived to act more like a public transport service but with more flexibility in terms of schedule and path and linking a destination which is not well served by public transport.

Some of the characteristics that the system that we want to model would have are:

- The service is available 24h per day, 7 days a week.
- The vehicles are ranging from large minivans to minibuses (approximately 6 to 15 passengers)
- The service works on an on-call basis, without fixed stations, it can be reserved in advance or on the fly.
- Taxis dedicated to the proximity service are based at local stations which are well connected to the public transport network and placed in a way that their catching area is optimized.

4. Possible factors of success

Here is proposed a discussion on possible factors of success of the proposed system in Switzerland. Note that here for success is intended that the system would be able to draw customers from the group of individuals presently using the car or, otherwise formulated, car trips would be substituted by collective taxi trips. This is important to specify because the number of potential users could also include individuals shifting to collective taxi from other modes, included walk, bike or public transport, which is not the goal of the deployment of such a system. Exceptions are categories which are now limited in their mobility and which would gain new access to the transportation system. Some of the arguments are supported by analysis of Microcensus data (ARE and BFS, 2006).

4.1 Last mile travel

A category of persons which are potential customers of a collective taxi service are persons using the car because their "last mile" of travel, either on the home-end or on the other end of the trip is not well served by the public transport (always or during a specific time of the day). In this case the service could be seen as a mean to get to the public transport network, replacing a car trip previously made to do so, or as mean to perform the whole out-of-home tour, replacing the whole car tour if it is happening on a relatively small area. A high number of such trips in some specific area would suggest a larger potential for the taxi system in its vicinity transport application. Unfortunately from the available data it is hard to say how many such trips and tours exist in Switzerland, the Microcensus doesn't report why a specific mode of transport has been chosen in a specific situation. However, in some literature about car sharing (Millard-Ball *et al.*, 2005) it is reported that the number of such trips, that especially in sub-urban areas, is relatively high.

4.2 Travel on a regular basis

Persons travelling on fixed routes on a regular basis are the most obvious potential customers for a collective taxi system. It is not a coincidence that many attempts to deploy car-pooling, which is conceptually very similar to collective taxi, have been oriented to groups of commuters working in a same firm or in the same area (the main difference is the fact that the driver is not a professional but driving his own car to go to work or another activity). According to Microcensus a very consistent number of global trips are Home-Work and Work-Home trips (Fig.1). Obviously, it doesn't mean yet that a potential for the system is there, but at least it is possible to investigate how many of such trips could be travelled with such a service, and which of them could be matched and be performed on a same vehicle. The real potential among this category of individuals would depend…

4.3 Car occupancy

The idea of collective taxi can be seen as a way to improve the efficiency of the transportation system in terms of transported persons per vehicle, providing a service which is more flexible than traditional public transport and cheaper than classic taxi services. A low value of average car occupancy would suggest that there is room to optimize the current system. According to Microcensus (ARE and BFS, 2006) the average car occupancy in Switzerland is 1.6 persons per vehicle, and more of 70% of all car trips are travelled by the driver alone. Clearly, this is not enough to affirm that all individuals travelling alone would be ready to use the collective taxi service, but it suggests that the potential for this kind of optimization is there.

4.4 Multimodality

Travel in urban areas, at the present, is basically subtour based (see Ciari *et al.*, 2008). A subtour is any sequence of trips starting and ending at the same point. From the Microcensus it is possible to see that most of these subtours are travelled with one single mode of transport or, in other words, very few of them are multimodal. The main reason is the predominance of travel with private mobility tools (more than a half of trips in Switzerland, with a large predominance of car travel). If one is starting from home with a car it is clear that in the large majority of cases this subtour will be closed with a car trip to home. The idea of offering a collective taxi service has to be seen as step in the direction of multimodality. The integration of such system in a larger system where for example also car-sharing and bike-sharing are included would help a shift from sub-tour based to trip based mobility. From sub-tour based to trip based mobility.

4.5 Car availability

The number of persons having access to a car in western countries experienced an incessant growth in the last decades (reference). Even if in recent time this growth was slowed down by the economical crisis, it is a matter of fact that the large majority of the Swiss population has access to a car. The Swiss Microcensus reports that about 80% of households own a car. There lies probably the most critical point for the success of the collective taxi system and, indeed, also for the success of other innovative, flexible, transport systems implemented at a large scale. It has already been showed that mobility tools are bought by individuals according to a “planned behaviour” (Ciari *et al.*, 2008). Individuals buy a car if they think that they will need it, and since this acquisition represents a large initial investment it generate the necessity to amortize this investment. Therefore, the diffusion of other systems at large scale has there a barrier. However it can be argued that the presence of a credible alternative system can influence in the long run this planned behaviour and, thus, influence the car ownership rate, has it has been shown for example in the case of car-sharing (Millard-Ball *et.al*, 2005).

5. The proposed modelling framework

The modelling of a large scale collective taxi system is challenging. Traditional transport modelling does not seem to be well placed for the concerned problem, having known limits assessing the potential of new transport modes in general and of innovative transport systems in particular (Shaheen and Rodier, 2004). A key to overcome such limits is to have a more precise representation of the service. This means, for example, high spatial and temporal resolution because access time to the service is a fundamental parameter in customer choice. An explicit representation of trip chaining of individuals would allow detecting who could meaningfully use the taxi service in his/her out-of-home tour. For this, a representation of travel at the individual level with explicit modelling of modal choice would be necessary. The representation of individual travel needs would further increase the precision of the model (shopping, work, leisure, etc.). Here, an agent-based micro-simulation approach is proposed. This technique allows to model the system at high spatial resolution, but also to consider the behaviour of single individuals. Agent based modelling is a suitable tool to implement direct interaction between demand (agents) and supply (collective taxis) and, therefore, predict the potential of a large scale collective taxi system and evaluate its operational feasibility. An already existing simulation tool, MATSim-T (Multi-Agent Transport Simulation Toolkit, Balmer, 2007) will be the basis for this work. MATSim is an agent based and activity-based traffic microsimulation tool, which produces individual daily transport demand as output. The tool will be extended to represent all the different aspects of the new system.

5.1 The taxi operator agent

Every actor of the transport system, both on the supply and the demand side, can be simulated in MATSim-T according to the agent paradigm. In the current version each traveller of the real system is modelled as an individual agent while the supply side is modelled through fixed constraints. A first effort introducing an agent modelling for supply side actors of the system is Ciari *et al.* (2008). In the context of this project the taxi operator will be modelled as an agent. The operator agent is the decision maker having the control of the whole collective taxi system and is able to modify its characteristics, it will be provided with attributes, knowledge, one or multiple objectives, a strategy to pursue it, a methodology to implement this strategy and a group of allowed choices. The operator agent's objective function can be assumed to be more or less complex. In the simplest case the agent would seek to maximize the number of customers, or its profit or the social welfare. The knowledge of the agent - similar to those of individuals - is the memory of some previous score and the corresponding configuration of the service. In the case that costs are not part of the objective function of the operator a posterior evaluation of the financial feasibility should be performed. The dimensions on which the agent will be allowed to act are:

- The fleet (number of cars and composition)
- The stations (number and location)
- The price schedule (price level; distance and time dependency)

The pricing structure (prices for the different services, special conditions, etc.) will be part of the scenario constraints and not be managed by the agent. This is basically to avoid excessive complexity of the system.

The whole system can be optimized with an evolutionary approach. The operator would change some of the characteristics of the car-sharing scheme in order to try to obtain a better score. It would be possible to isolate also the effect of a single decision dimension, annulling the possibility to modify the others.

5.2 The mode choice module

Until now the mode choice module was not optimized but fixed at the start of the simulation. The simulator assigned a transport mode to each agent depending on the socio-demographics characteristics and distances involved. The available modes were Car, Public transport, Bike, Car passenger and walk; taxis of any kind were not considered as an option. A new mode choice module is being introduced at the optimization stage of MATSim, in some parallel work. This allows agents to consider different modal options during the iterative optimization process. With this new module it is in principle possible to vary the characteristic of different modes and observe the reaction of agents to such variations. In particular, taking into account monetary costs explicitly, agents can seek the maximum satisfaction within their budget constraints. This way the potential of new transport options, like a collective taxi systems, can be modelled.

6. Summary and Outlook

This paper reported on ongoing work on the possibility of implementing a collective taxi system at large scale in an urban area. This work is on a very early stage and results are not yet available. The motivations to try to implement such a system have been reported as well as the type of the service that will be modeled. A crucial point is the modeling methodology, since the evaluation of a new transport options is always problematic with traditional transport planning techniques. Here the opportunities opened by the use of an agent based approach have been discussed, the implementation steps which will be undertaken using an already existing traffic simulation tool, MATSim, have been described.

In the near future the first implementation effort will be directed to the enhancement of the mode choice module of MATSim. The collective taxi option will be offered to agents with some predefined, fixed, characteristics. This will allow for a first, even imprecise, estimation of the potential of such a system. After this, the collective taxi system will be explicitly modeled and a specific agent, representing the system's operator, will be introduced. This agent will be able to modify some of the parameters of the taxi service, allowing the system to iteratively let the equilibrium emerge from the simulation. The test area for the simulations will be the Zurich agglomeration.

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