

An Investigation on the Use of Navigation Devices in Smart Transportation Systems

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***Abstract.** In large urban areas, until recently, people used to choose a route having in mind the general, high-level mental map of the urban traffic network. With the dissemination of the use of navigation devices such as GPS, all roads may now be part of a path. Therefore two questions arise, that are related to the performance of the traffic network as a whole, and to the effects of the use of these navigation devices on travelers that usually only do short trips in their own neighborhoods. Our preliminary results show that the average overall travel times indeed decrease with the use of GPS. However, travelers who used to avoid arterial roads are strongly penalized.*

1. Introduction

The number of large metropolitan areas with more than ten million inhabitants is increasing rapidly, with the number of so-called mega-cities now at more than 20. For comparison, in 1950 there were 83 cities with populations exceeding *one million*, with New York being the sole city with population above ten million. This increase in the number of mega-cities has strong consequences to traffic and transportation.

It is intuitively assumed that smart transportation can be benefited from smart-gadgets. Indeed, such devices are changing the paradigm in many systems, including transportation. This can be observed, e.g., in urban areas such as the city of São Paulo: until a decade ago or so, people used to choose a route having in mind the general, high-level mental map of the urban traffic network, that means, the main arterials were known to a lesser or greater extent, while the rest of the network links remained basically unknown, except for those areas close to the traveler origin and destination. This has led to some traffic patterns that were more or less predictable. Moreover, users of residential or secondary roads used to use these roads for trips within their own neighborhoods. With the dissemination of the use of navigation devices such as GPS, all roads may now be part of a path. Therefore two questions arise. The first relates to the performance of the traffic network as a whole, i.e., does travel time decrease (as intuitively believed) if navigation devices get widely used? The second question relates to the effects of these navigation devices use on travelers that usually do only short trips in their own, known neighborhood, thus tending to avoid jammed arterials.

The goal of this work is to answer these two questions by means of an agent-based model. In the next section we present some work that is related to ours though in fact the second question has barely been addressed. The agent-based model is detailed in Section 3, while the settings and results achieved so far are discussed in Section 5. Conclusions and the future work are then presented in Section 6.

2. Background and Related Work

Smart transportation systems are likely to depend more and more on a good modelling of the transportation system at hand because only this way can the effect of new technologies be tested and evaluated. Basically, there are two approaches to the modelling of traffic: macroscopic and microscopic. The former is mainly concerned with the movement of vehicles, that means, with the aggregate level. In the microscopic modelling, one may go to the individual level. Each road user can be described as detailed as desired (given computational restrictions), thus permitting the model of travelers' behaviours. Travel and/or route choices may be considered, and this is a key issue in simulating traffic, since those choices are becoming increasingly more complex. Using agent-based simulation is a promising technique for microscopic traffic models as the driver's behaviour can be described incorporating complex and individual decision-making.

Modelling of traffic scenarios with multiagent systems techniques is not new. However, the focus has been mainly on logistics regarding transportation scenarios. On the other hand, the work proposed here focuses on a fine-grained level. At this level, there have been an increasing number of research studies. Very few works investigate the effect of navigation devices, and, to the best of our knowledge, none at the agent-based level. Therefore, here we refer to some that are related to agent-based assignment of demand (without use of navigation devices): [Balmer et al. 2004, Bazzan et al. 2012, Chmura and Pitz 2007, Klügl and Bazzan 2004]. In summary, agent-based modelling and simulation can be used in transportation systems in various ways. In this particular paper we use agent-based simulations as a way to investigate what happens in traffic networks when some conditions change, as, e.g., what happens when navigation devices increase the travelers' awareness of the traffic network.

3. Methods

The agent-based microscopic simulation proposed here was implemented using the traffic simulator called SUMO¹. The main parameters are: the network G to be simulated, the number $|N|$ of travelers that will have their trips distributed according to the origin-destination (OD) matrix, and a boolean indicating whether or not GPS navigation devices are used by the travellers.

The following procedure is then repeated until there are vehicles in the network (i.e. until not everyone is at its destination). For each traveler i , the simulator will move i through its path. At each link, SUMO checks whether each i is at its destination. If yes, i computes its own travel time.

This procedure is used no matter navigation devices are used or not. What distinguishes these two cases is the kind of knowledge traveler i has about the network. This of course determines its route. When navigation devices are used, the procedure works as usually in routing, i.e., it is as if a centralized mechanism considers the full graph and computes shortest paths routes for everyone. However, when those devices are not used, then the knowledge of the network is a private knowledge of i and must be explicitly kept for each i . This means that we have implemented a new module in SUMO, which handles the agent knowledge and do the routing in a different way than SUMO does, considering partial information that the agent itself has about its environment.

¹<http://sumo.sourceforge.net/>

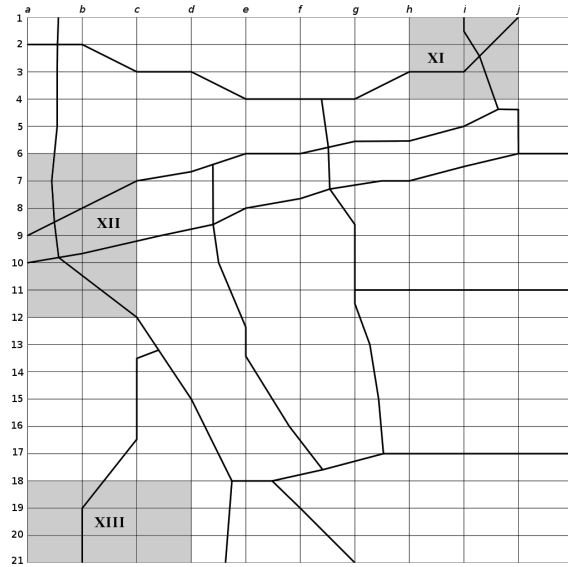


Figure 1. Map of eastern part of São Paulo with arterials and secondary roads. The 3 main destinations (morning peak) are shown in roman numerals.

4. Scenario

The map used stems from the eastern part of São Paulo. Open street map (OSM, www.osm.org) was used to export the objects existing in this area. For this work we are using only links labeled as motorways, trunks, and primaries (OSM terminology). For short, we call them all as arterials. However, since secondary links are also necessary for our work, to mimic these we have created a grid of one-way links, which was added to the arterials extracted from OSM. The resulting network is shown in Figure 1.

The following naming scheme is adopted here: Vertical, secondary links are labeled with lowercase letters, from *a* to *k*. Horizontal, secondary links are labeled with numbers, from 1 to 21. The arterial at the top of the map (roughly from nodes *a2* to *j1*) is a motorway (Marginal Tietê) that is a major source of traffic congestion. Traffic lights were used in all intersections between two arterial roads, generated by SUMO with 40 seconds of green time for each direction and 1s of yellow time on transitions.

The demand pattern corresponds roughly to that observed in the eastern region of the city. Although all regions may serve as origins and destinations, to reflect the morning peak, there are three main destinations districts shown in the map (Figure 1) as roman numerals: one of them is downtown (*a6*–*b12*), one at *a18*–*c21*, and one through a major motorway to the northeast (*h1*–*j3*). Regarding origins, the network G is divided in 10 rectangular origin districts, each stretching along 5 horizontal edges and 4 vertical. All origin/destination pairs have the same probability of being chosen for a vehicle.

A few special vehicles called probe or floating cars (FCs) were added to the simulation to analyze the impact that the GPS-based routing has on neighborhood (local) traffic. To do this, these FCs were created with custom routes that are restricted to secondary, local links. Henceforward we refer to these FCs by their route names: East (meaning route $j20 \rightarrow j8 \rightarrow i8$) and Center (route $f10 \rightarrow f18$).

Two routing strategies were used, both based on the A* algorithm. For simulating

Table 1. Travel times (average over all travelers) with increasing demand, for situations without and with navigation devices.

Demand N	Without Navigation Device			With Navigation Device		
	Mean (s)	Std. Dev.	Mean (min)	Mean (s)	Std. Dev.	Mean (min)
5000	1948	3.33%	32	1116	1.36%	19
10000	4012	2.88%	67	1910	0.59%	32
15000	6313	2.40%	105	2940	2.06%	49
20000	9017	2.02%	150	4063	2.36%	68
25000	12803	7.43%	213	5240	6.17%	87

the usage of navigation devices (thus all links may be used), all routes were computed with global topological knowledge, favoring wider roads: the cost of each link was computed as its length divided by its number of lanes. The other case is the one in which the traveler has only restricted knowledge. We remark that this means that each driver only has a mental map containing the arterials links plus the knowledge of the links that belong to its origin and destination districts. Therefore routes were computed considering the real costs for these links. Farther or unknown secondary links were assigned a high cost so that they are avoided.

As mentioned, all simulations were performed in the SUMO traffic simulator. The routing strategy - with or without navigation devices, i.e., global or partial topological information - and the number of generated vehicles were varied orthogonally. For each combination of those parameters, the new implemented module in SUMO was used to create the drivers and generate the trips from the OD matrix.

5. Results

The results obtained so far are the average over five repetitions of the simulations for each combination of parameters. We have varied the demand created in the network G , i.e., the number of travelers, as well as the type of routing (with/without navigation device). $|N|$ was set from 5K to 25K users. We note that although the morning peak for the city of São Paulo (apart from other parts of the metropolitan region) may reach 700K simultaneous users, we are only considering a portion of the eastern part of the city. Besides, only a fraction of the secondary roads were represented. Hence the reduced demand.

Table 1 shows the mean travel time in seconds as well as the standard deviation. To facilitate the comparison, the travel times are also given in minutes. As expected, the travel time increases with the increase of the demand.

Regarding the comparison between the situations without and with use of navigation devices, there is a remarkable decrease in these times in the latter case. The reason is that the demand is more distributed in the network. Moreover, the higher the demand, the higher the utility of using those devices. When $|N| = 25000$, there is a decrease of approximately 60% in the travel time.

These results refer to the overall travel time (over all travelers). We now turn to more microscopic analyses that are possible when agent-based simulations are used. In the case here we are analyzing travel times of travelers with different route lengths. Due to lack of space we do not show the plots of travel times for travelers in each class of

Table 2. Travel times for the floating cars; situations without and with navigation devices.

Demand N	Trip	Without Nav. Device Mean (min)	With Nav. Device Mean (min)	Increase
5000	Center	5	5	$\approx 0\%$
	East	10	13	$\approx 30\%$
10000	Center	5	6	$\approx 20\%$
	East	23	39	$\approx 70\%$
15000	Center	5	15	$\approx 200\%$
	East	37	61	$\approx 65\%$
20000	Center	5	24	$\approx 380\%$
	East	49	103	$\approx 110\%$
25000	Center	6	36	$\approx 500\%$
	East	61	135	$\approx 120\%$

trip length. The main conclusion drawn is that travel time when not using GPS is higher only if the trip is longer than 5 kilometers. Below this, for each class of length, trips take roughly the same time, no matter whether GPS is used or not. Thus, the above mentioned conclusion that navigation devices do pay off was drawn from the fact that most trips take longer than 5 kilometers.

Another kind of analysis that an agent-based simulation allows aims at answering the second question that we want to investigate in this work, namely what happens to those travelers called neighborhood or local travelers. As presented in Section 4, we have defined some special floating cars whose travel times were also measured. These travel times appear in Table 2.

If we look at the travel times of the FCs, here the opposite behavior is observed regarding travel times. When the whole population of travelers does not use navigation devices, neighborhood travelers realize their trips in a lesser time because they, by definition, use only secondary links. When all travelers may use the resources that were previously used only by the neighborhood travelers, these are penalized. This penalty increases with the size of the demand. For instance, taking the floating cars driving in the center route, when the demand is 10K travelers, their average travel time is 5 minutes (no navigation device) versus 6 minutes (device is used by other drivers). However, when the demand is 25K travelers, these figures increase to 6 and 36 minutes respectively. This means an increase of more than 400% in travel time for this particular floating car.

6. Conclusion

In many metropolitan areas, one may nowadays observe the spreading use of navigation devices such as those based on GPS. Although we all seem to enjoy this help, little has been investigated about the effects of this use, especially on the travelers whose routes did not involve major arterials, being restricted to secondary links of the traffic network, while the majority of other travelers would use primarily arterials (secondary links only close to their origins and destinations), which are part of their respective mental maps. Two questions then arise. The first is whether travel time decreases if navigation devices gets widely used, while the second question relates to the effects of the use of these devices on

travelers who use the network only for short trips in their own neighborhood, thus tending to avoid arterials.

Our long term goal is to develop an agent-based infrastructure (possibly over SUMO) that can be used for this and further investigations that are key to evaluate concepts of smart transportation systems. With this prototype, we have simulated thousands of agents that compute their own route based either on global knowledge of the traffic network, coming from navigation devices, or based on their mental maps of the network, which are necessarily partial.

By means of the agent-based approach we were able to derive conclusions that would not be possible if only macroscopic methods were used, as for instance the fact that there are differences in the value of the navigation devices depending on the trip length. Also, we have shown that although the population of travelers have decreased travel time, this impacts a minority of them, namely those that do neighborhood trips and/or avoid arterials, concentrating their trips on secondary links. For these, the increase in travel time can be manifold.

We are aware that this model is a preliminary one. As part of a joint work with DLR, the developer of SUMO, we are working together in order to provide SUMO with the modules that will facilitate the modelling and simulation of agent-based transportation systems. The focus is of course on simulating new technologies such as use of smart-phones and other devices, as well as car-to-car communication. We are also aware of the necessity of calibrating the model, but this has probably to be done with data freely available (e.g., the repository www.bgu.ac.il/~bargera/tntp), given the lack of data for the scenario used here.

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