SUSTAPARK: An Agent-based Model for Simulating Parking Search

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ABSTRACT

SUSTAPARK is a project with the objective to develop a computer program able to simulate the traffic effects of parking search behaviour. This is based on a model where numerous drivers move for various purposes on the network towards different locations. Each one has an activity schedule throughout the day. We use the principle of an agent-based system, meaning that each individual traveler (agent) is modelled separately. The activities of all the agents, the required trips, and the interaction with other agents in traffic are taken into account.
The movement of the car when searching for a parking place is determined by a search strategy and by the physical movement of the car. Understanding the search strategy is a complex problem, depending on many considerations from the drivers. The translation of the vehicle movements into a computer program is based on the principle of a cellular automaton. The network is divided in cells, which can only hold one car at the time. The cars can move from cell to cell, under the conditions determined by the model.

INTRODUCTION

Parking problems are a growing topic these days in many cities. Pressure on the urban traffic increases as more people are cruising in search of a parking place, which can lead to congestion. This is highly dependable on space and time (Shoup, 2006). Cities have to search for innovative solutions to deal with these problems. Pricing of public parking places is one of these solutions to regulate parking. Drivers can experience parking as a problem from the moment they have to search for a suitable place (Zwerts & Nuyts, 2005).

Many previous used approaches for modelling parking choice lack in behavioural influence as they assume perfect information knowledge of the system (Thompson & Richardson, 1998). Perfect information is not known in advance; information can only be collected by evaluating several situational parameters or by making some assumptions based on former experiences. This information develops the driver's parking search strategy.

In this way, agent-based modelling (ABM) is an interesting modelling approach in the development of a parking model because it is a flexible and dynamic way to approach this problem. ABM can be defined as a computational modelling technique where actions and interactions of autonomous individuals, following their own rules and interests, can be simulated to re-create a complex phenomenon and gain information on a higher level. Several activity-based models of transportation behaviour were recently developed and published. One type of application is oriented towards the modelling of land-use policies and travel behaviour choices (Shiftan Y, 2008). ABM can also be used for parking models, where it has the advantage that the driver's parking search behaviour can interact on a micro-scale level with the environment as the driver is seen as the agent in the system (Castle & Crooks, 2006; Benenson & Kharbash, 2005, Benenson et al., 2008). The driver's parking behaviour can be influenced by a whole range of situational factors, mainly availability of parking spaces, trip purpose, walking time, parking fee and comfort. The perception of these factors can change with the elapsed time spent in search of a place. In neighbourhoods in the city with safety problems, security can also play an important role in the choice of a parking place (Teknomo & Hokao, 1997). Important to notice is that all these factors are treated from the viewpoint of what the car driver perceives. An impression of parking availability from the driver's view can defer from reality (Laurier, 2004).

The type of parking (on-street parking, parking lots, private parking…) can include some of these factors like a specific price, security or availability of parking space. Taste heterogeneity is a major factor in this parking type choice, together with the journey purposes (shopping, working, visit …) (Hess & Polak, 2004). To classify this taste heterogeneity, different parking search behaviours can be isolated (f.e. a resident, a frequent visitor, a tourist). The parking search behaviour will determine specific personal demands for a parking space. This creates a value that every parking place is worth to a specific driver at a specific time. That value can change in time as other parkings gain interest when search time is increasing. This type of parking choice model can be described according to a utility/disutility function (Thompson and Richardson, 1998; Arentze & Timmermans, 2005).

The city can use these behaviour-influencing factors to manage their parking policy in a certain way by implementing restrictions on these factors (Vlaamse Overheid, 2008; Litman, 2008). Underpricing of on-street parking, for example, can lead to an increase of congestion due to cruising for on-street parking which is the behavioural reaction of drivers (Shoup, 2006; Anderson & de Palma, 2007). Other examples of management techniques are time restrictions for parking and introducing resident parking cards in the city, to differentiate the parking possibilities for residents and visitors. These general restrictions must be fine-tuned, adapted to the local situation.

SUSTAPARK has the objective to provide a tool that can be used in parking policy to simulate the local parking situation in changed circumstances. In this paper we start with a description of the general concepts and structure of the model. We then discuss data needs, followed by some preliminary results for a case study in the inner city of Leuven, Belgium with the focus on the gathering and preprocessing of the data.

THE SUSTAPARK MODEL

General

The goal of the model is to have a spatio-temporal tool for modelling traffic generated by parking search behaviour. This model can be used to provide strategic advice on urban parking measures. Therefore, agents (car drivers) must have the ability to move over a network and park their vehicle to follow their planned activities during a day. The most basic component is the traffic flow model, which uses a road network and parking places. This traffic model updates traffic by using rules.

As it is an agent-based model, a set of agents are created. Every agent has an activity schedule and parking search behaviour. The activity schedule is needed to know which trip the agent wants to execute at a specific point in time. An initial route (shortest path) is calculated from origin to destination and can be recalculated based on network parameters (f.e. congestion). The parking search behaviour determines when an agent starts searching for a parking place and consists the rules followed when choosing a parking place. This choice depends on local parameters (f.e. available parkings, price, distance, search time…). A schematic representation is made in Figure 1.

The programming of the SUSTAPARK model is done object-oriented using the Java programming language developed on the Eclipse platform.

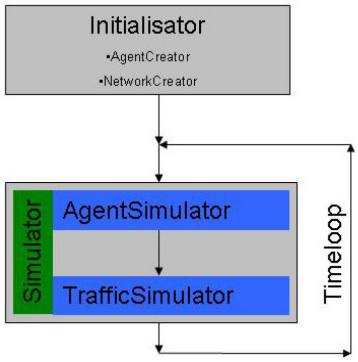

Figure 1: Schematic representation of the SUSTAPARK model. The *initialization faze* creates the agents and the network. Every time step, the *AgentSimulator* controls the agents (activity schedule, routing, parking search…) and the *TrafficSimulator* updates the traffic on the network according to the agents' needs.

Input

The SUSTAPARK model requires high-level detailed data. It can be divided in two main groups: spatial and non-spatial data. The spatial data include roads and parking places (parking lots, private parking and on-street parking). The import format for the spatial data is ESRI shapefile. The non-spatial data include parameters for the creation of agents, activity schedules and their parking behaviour and are stored in a Access-database.

Roads

The road-features from the GIS-layer are imported and translated into a road network with roads, links, lanes and intersections based on the attributes of the features (Figure 2). The attributes that are needed therefore are a 'from-intersection' identifier, a 'to-intersection' identifier, the driving direction (one-way, both ways or none) and the number of lanes that each driving direction has. Based on this knowledge the model translates each road in one link (one way) or two links (both ways). Each link can have several lanes. Also attributes for maximum speed are coupled to each link.

The boundaries of the road network are entry/exit gates connected to one intersection of the road network where agents can enter or leave the network of the study area. These gates can be seen as a box that can be filled with an unlimited amount of agents. They enter or leave the network according to their planned activities.

Parking places

The SUSTAPARK model can create different types of parking places based on the imported GIS-layers for parking places: parking lots, private garages and on-street parking. Each feature is referenced to a single lane. The attributes necessary therefore are: 1) a road identifier, 2) the distance from the start of the road and 3) the side of the road. With this information, the model can couple each parking to a position on a lane (Figure 2).

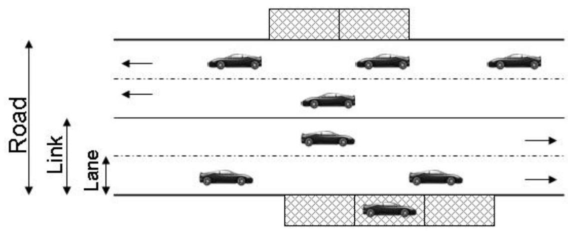

Figure 2: Representation of a road consisting of links and lanes. The crossed zones represent parking places coupled to a position on a lane.

Agents

Agents are classified as: students, employees, retired people, unemployed people, people with a liberal profession, people working in the household, tourists and other. This is based on a local travel survey (OVG Vlaams-Brabant) which reveals that these groups tend to have different activity schedules. A cross-table is imported in the model to create for every agent type an amount of agents with a particular activity schedule.

Activity schedules (spatio-temporal)

Activity schedules are imported as a list of trip motives with destination in or outside the city. For this model, we used the following trip motives based on a local travel survey: going home, going to work, following education, shopping, business, services, recreation and tourism.

To allocate a spatial component to each trip motive, a relative attraction value for every road segment in the road network is needed. The case study for Leuven will explain the method used to determine this attraction. The list of trip motives is then transformed in a list of locations on the network that the agents want to reach. Figure 3 shows the relationship between agent, activities and location.

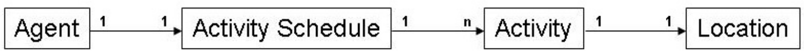

Figure 3: Relationship between agent, activity schedule and locations. Every agent has one activity schedule, consisting of several (n) activities. A location is added to every destination of an activity based on the road attraction for the motive of that trip. The origin is always the current position of the agent.

To add a time component to every trip, time-charts from the same travel survey are used (Figure 4). This results in an activity schedule for every agent as can be seen in this example:

Example activity schedule Agent A:

- *Schedule: Working-Shopping-Home*
- *Activities (hour // destination):*
  - *Going to work (8.00 // street X)*
  - *Going to the shop (16.30 // street Y)*
  - *Returning home (17.30 // outside city)*

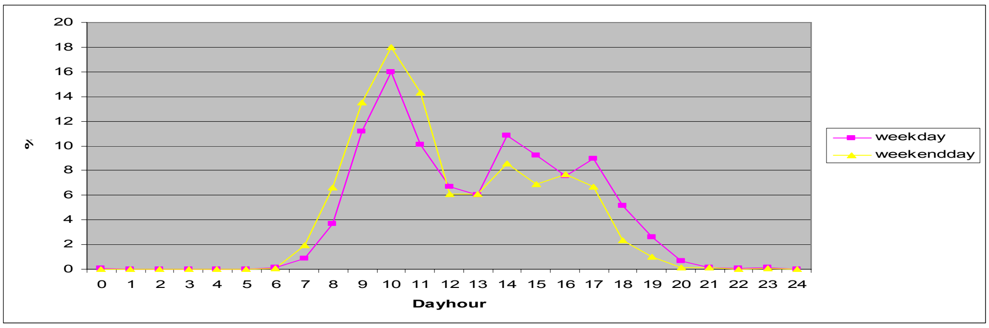

Figure 4: A time-chart for the trip motive 'Shopping'. It shows that on weekdays, 18% of shopping people shop around 10h. Source: OVG Vlaams-Brabant.

Parking strategy

For the development of the model, a simplified version of a discrete choice structure is implemented (Hess & Polak, 2005). Two alternatives are evaluated: on-street parking and off-street parking. This model determines the initial parking strategy for every agent based on access time, search time, egress time and expected parking fee. Agents with a specific constant parking strategy (f.e. agents with a private parking) are not evaluated by this discrete choice structure. The access time is the expected time to drive to the area around the destination, which is the area where the driver intends to park. Once the driver starts searching for parking this value will remain constant. The search time is the time a driver is searching for a parking place once he has arrived at his parking area. The egress time is the time a driver needs to walk from the place he parked to his actual destination. Every 30 seconds, the discrete choice model is re-evaluated with the current parameter values, so a change in parking strategy can occur. In the current discrete choice structure, the coefficients used come from a study in a British city. The value of time might not be representative for the value of time in Leuven. The value of time also strongly depends on the purpose, which is only taken into account in a limited way in the current simplified version.

Parallel to this research, a qualitative research on parking search strategy is done by one of the project partners 'Centre de Recherche Urbain' of Université Libre de Bruxelles. It consisted of an experiment where volunteers were asked to simulate certain activities in town (shopping in a certain area, delivery at a specific address …). The driver and the street were filmed during the trip and the search for a parking place. Afterwards, an interview was taken. These data were used to map the behaviour by locating the point on the trip when certain decisions were taken. All these trips were used to find rules for different search strategies that take economical, cognitive as situational factors into account. These findings have to be translated into a quantitative description of the parking search strategies to implement in the model.

Simulator

The simulation loop of the SUSTAPARK model simulates a one-day period (24 hours). The temporal resolution is 1 second to ensure the high detail. Start time is set at 4AM, assumed this is the moment of the least traffic. The simulation consists of three steps: 1) an initialization, 2) an agent simulator and 3) a traffic simulator.

The *initialization faze* is responsible for translating the input of the model. Road network, parkings and agents are created. The agents are given a composed activity schedule, a home location and an initial parking place. All cars are parked close to their home. Cars outside the city are placed in the entrance gates of the road network.

Once initialization is finished, a time loop starts. Each time step, the *agent simulator* updates all agents. The model time is compared with the activity schedule of every agent and the state of the agent is set to ‘driving’ if an activity needs to start.

The *traffic simulator* ensures the road network is updated. Every time step intersections are solved by intersection rules and roads are updated using a traffic cellular automaton (TCA). The TCA, used to model the traffic flow, is a discretised representation of a network consisting of several cells. SUSTAPARK is a so-called single cell model, where each cell can only hold one vehicle at a time, in contrast to the more complex multi-cell models. The TCA is kept simple to avoid computational burden. As time advances, vehicles can move from one cell to another. The spatial resolution for the TCA is initially set at 7,5 m based upon the space between cars. This spatial resolution together with the temporal resolution of 1 second determines the possible speed rates of the vehicles:

$$7{,}5\ m/s = 27\ km/h$$

Possible speed rates for this resolution are: 0, 27, 54,…km/h depending on the amount of cells a vehicle advances in 1 time step. The actual speed of each vehicle is limited by several factors: the maximum speed of the vehicle and the link, the parking search behaviour (parking speed) and the vehicle before.

$$\text{Actual speed} = f(v_{vehicle}, v_{link}, v_{parkingmode}, v_{traffic})$$

Based on the parking search behaviour of the driver, the vehicle changes from ‘driving’ mode to ‘parking search’ mode. From that moment, possible empty parking spaces (that the vehicle can reach in one time step) are proposed to the driver. The driver decides to use a parking place regarding the utility of these places. When parking search time is increasing, also the utility of the parking places is changing. Figure 5 shows the decision strategy in a schematic representation.

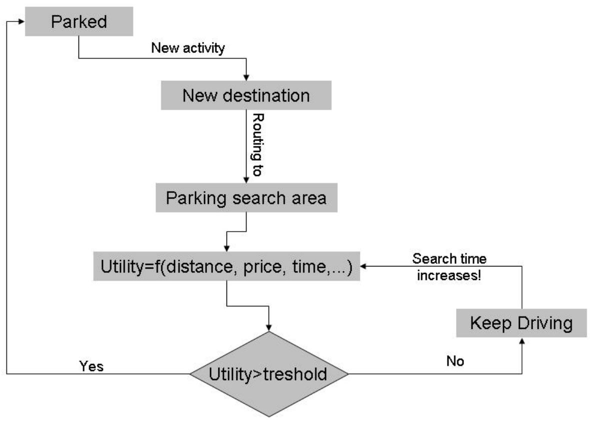

Figure 5: Schematic representation of the parking decision strategy. The driver parks if the utility of a parking place is greater than a threshold.

Output

As the total situation of the whole network and the agents is known on every time step, several statistics can be extracted from the model: Time series can be produced for the parking occupancy for every street segment, parking zone bottle necks can be found, (average) parking search time for all agents can be calculated,…. Combined with the identifiers of the spatial input data, visualization is possible.

CASE STUDY FOR LEUVEN

General

Leuven is a Belgian city, 30 kilometers East of Brussels, with a historical city centre surrounded by a ring road (Figure 6). It has a large population of students, employees and shoppers. Parkings are mainly on-street, private or parking complexes.

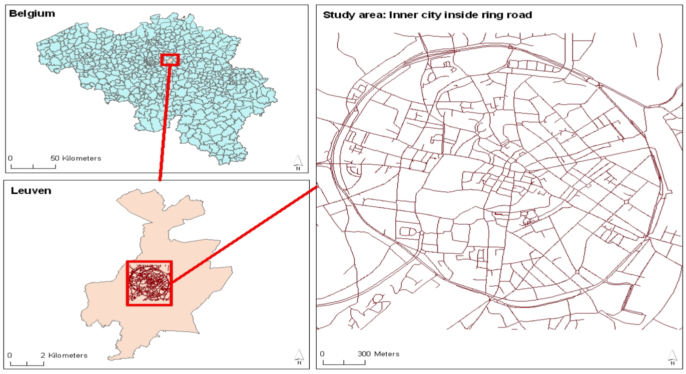

Figure 6: Location of the inner city of Leuven.

Pre-processing

Data gathering

Detailed spatial data were provided by the GIS service of the city, G@lileo. These data include a road network, parking complexes and buildings. Where no data was available estimations had to be made. This was the case for the number of private parkings. On-street parkings were available as the number of parking places per street. Data for agents and activity schedules is based on local statistics and a local travel survey (Onderzoek Verplaatsingsgedrag Vlaams-Brabant).

Estimation of private garages

The car possession for the total province equals 396 vehicles per 1000 inhabitants. Given the inhabitants per street, an estimation of the number of vehicles per street can be made:

$$vehicles_{per\ street} = inhabitants_{per\ street} * 0{,}396$$

The city provides resident parking cards. Residents can use this card to park on-street for free without time-restrictions. The assumption is made that all cars that do not have a resident parking card, have access to private parking for their vehicle. This is the basis for an estimation of private parking places.

$$private\ parkings_{per\ street} = vehicles_{per\ street} - resident\ cards_{per\ street}$$

Conversion of tabular data in GIS data

As on-street and private parkings are given as tabular data, they have to be converted to spatial data. These parking places are divided into equal distances along the road. Road ID, distance from start point and side of the road are stored as attributes so they can be referenced to a lane (Figure 7).

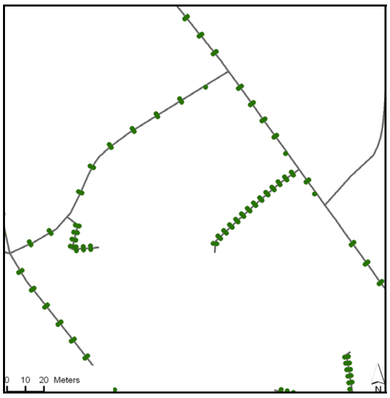

Figure 7: Parkings are placed on equal distances along the road.
Network data source: G@lileo Leuven

Determination of the attraction of road segments for different trip motives

The attraction is used to determine the destination for every trip in the activity schedule. This calculation is based on all buildings that are addressed to a street. As the function and surface is known for every building, a relative attraction can be calculated. Figure 8 illustrates this method.

(a)

(b)

RoadID	SumOfHOME	SumOfWORK	SumOf
16268	1917	71	
16274	1167	0	
16546	2822	166	
16570	159	0	
16582	3595	36	

Figure 8: Determination of the relative attraction for every trip motive. An attraction value for every motive is determined based on the building function multiplied by the area of the building. (a) shows the buildings with a different function in different colors. (b) A summarization is made for every road and trip motive.

Preliminary results

Parking situation for Leuven

The result of dividing the parking data equally over each street can be seen on Figure 9. With this method, the parking supply is spatially divided over the city. Table 1 shows a comparison between the calculated number of on-street parkings and the real-life situation.

Because of the lack of data of private parking places, this is more difficult to calibrate. An overestimation of private parking places is expected because car possession in cities is usually lower than the average for the total province. More detailed data is needed to improve the reliability.

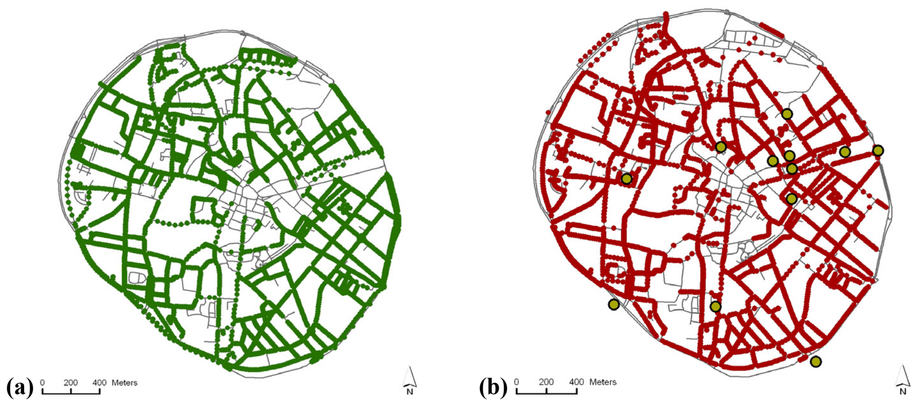

Figure 9: (a): The small dots show the on-street parking places. (b): The small dots along the roads show the estimation of private parkings, the big dots show the public parking complexes. *Network data source: G@lileo Leuven*

Streetname	calculated	counted
Parkstraat	12	12
Prelatenstraat	18	23
Monnikenstraat	15	18
Vlamingenstraat	14	18
Lintstraat	28	30
Vesaliusstraat	38	31
Maria-Theresiastraat	11	8
Blijde In-komststraat	22	24
Deberiotstraat	20	21
Tiensestraat	8	10

Table 1: Comparison between the calculated and counted number of on-street parkings for 10 random streets.

Relative attraction for road segments

Figure 10 shows the relative attraction for work and home locations. The bigger the streets, the more they attract agents with that objective. Based on these values the destination of the agent is chosen. As we look for the trip motive 'shopping' in Figure 10, a comparison is made between the calculated attraction and the known shopping streets. The zones with the highest attraction are the known shopping streets of the city. It is clear that with this method we can spatially divide the attraction for every motive.

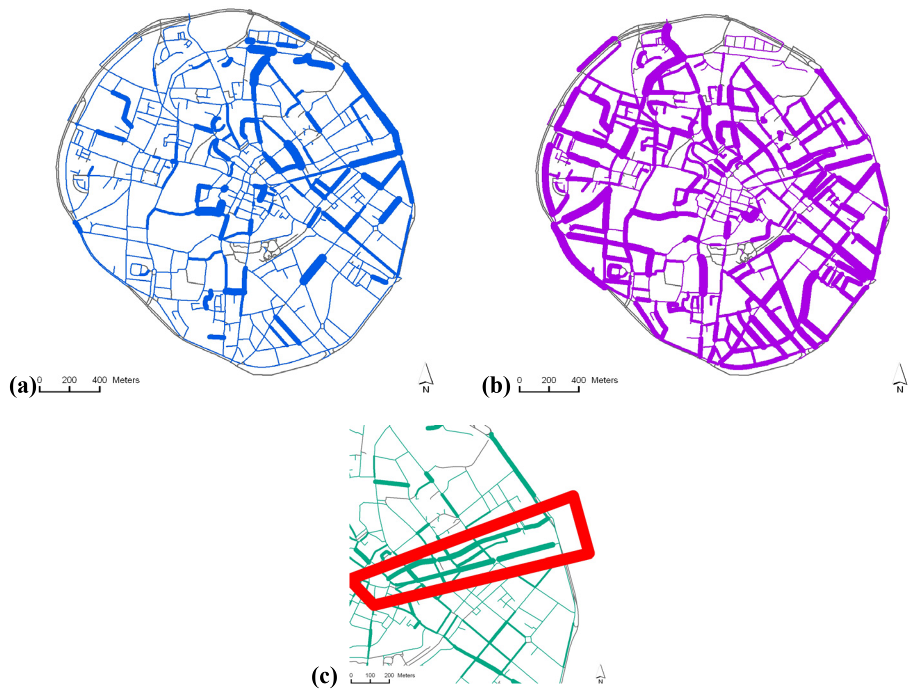

Figure 10: Relative attraction of streets for (a) work, (b) going home and (c) shopping. In (c), the known shopping area is indicated. This area clearly shows the highest relative attraction for the city. *Network data source: G@lileo Leuven*

CONCLUSION & FUTURE WORK

This paper describes the general concepts that are used in the development of the SUSTAPARK model to simulate on a high-detail level the parking situation in an urban environment. It shows that even with that amount of detail, an agent-based approach can be used to simulate an entire city. In fact, the complexity of modelling parking in a city can be decreased by dividing the problem into its basic components, resulting in simple rules that agents have to follow. The model can be improved by further refinements of one of its components without affecting the others.

At this stage of the project, the first runs of the model show promising results. The next step is the simulation of different scenarios (events, …). Further refinement of the parking search behaviour will be based on the results of the parking experiments. Important to notice is that this model is a parking model and not a traffic model. The keys to ensure realistic output are a good understanding of the parking behaviour and a representative agent population with activity schedules that approximate real life. This project can be a good backbone for further development such as multimodality.

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