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Evaluation of Smart Parking & It's Applications

Avvuru Tharun
M.Tech Scholor
Nalanda Institute of Engineering and Technology, Kantepudi (V), Guntur, A.P.

M.Srinivasa Reddy, M.Tech
Assistant Professor,
Nalanda Institute of Engineering and Technology, Kantepudi (V), Guntur, A.P.

Abstract

This research focuses on the derivation of an assignment model that can be used for the evaluation of Smart Parking It's applications. Behavioural research is conducted in order to gain understanding of the individuals' behaviour concerning parking, on three behavioural levels (Strategic, Operational and Tactical), and for two user classes (Familiar and Unfamiliar users). A Parking Decision Process model, which represent the decisions that individuals have to take when parking is suggested. A Stated Preference experiment is conducted –designed using efficient designs– for the investigation of decisions for familiar and unfamiliar users and discrete choice models are derived for familiar users. The outcome of the behavioural research (Parking Decision Process model & MNL Parking Discrete Choice model) is applied in the development of a Parking Assignment Model for simulation on the behavioural levels for both user classes. The components of the Parking Assignment Model are verified and the applicability of the model is examined. Finally, the Parking Assignment Model is applied for the evaluation of the Smart Parking application, developed for the Sensor City project in Assen. The results of the evaluation illustrate the positive impact of the Smart Parking application to the reduction of individuals' and total travel times.

INTRODUCTION

Parking in urban areas is an issue of increasing importance, especially the last few years. There is voluminous literature concerning the problems consequential to the high parking demand, with researchers indicating that the average volume of the total traffic related to parking during peak hours in city centers can reach 30 to 50 percent of the total traffic (Shoup,2006; Arnott and Inci, 2006). As each trip ends to a parking spot, searching (cruising) for parking is a phenomenon widely met in the urban environment, and it is related to problems in terms of to name but a few: lost time, fuel consumption, traffic flow, safety and emissions (Kaplan and Bekhor, 2011). The main instrument for reducing the impact of parking is the development of parking-related policies. Those balance the demand and supply for parking with the most prominent to be parking pricing (Lam et al., 2006). However, as parking pricing policies reach their limits due to social and political reasons, the need to develop new systems to alleviate the parking impact has become imperative. Lately, Intelligent Transport Systems (ITS), and more specifically Smart Parking applications are being designed and require evaluation before being implemented on a wide scale.

The evaluation of a Smart Parking application can be achieved by the evaluation of the situation without the application (reference case) and then, the evaluation of the situation –as predicted– with the application (proposed case). The evaluation on a real network and in a wide scale is most times impossible and for that reason models are being developed to represent the decisions and actions taken, in both the reference and the proposed case.

The parking process includes decisions and actions on how individuals cruise for parking, the parking destinations chosen and the routes taken to reach those destinations. The difference between the reference and the proposed case is found on the affect the Smart

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Parking application has on those decisions and actions. This directly suggests that the model definition of the parking process at the reference case and the effect Smart Parking application has on it are the two modelling modules required for the evaluation of a Smart Parking application (Figure 1.1).

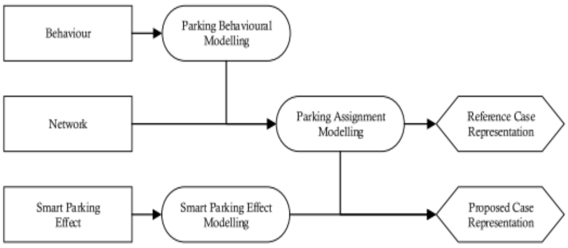

Figure 1.1: Components of the evaluation and evaluation approach

For the reference case, the need for the development of a Parking Assignment Model, on the basis of models that represent the behavior concerning parking was found to be imperative for two user classes (Familiar and Unfamiliar parking users). This should be accomplished in a way that enables the introduction of the Smart Parking applications effect. The investigation of the decision involved and the modeling of those decisions for assignment purposes implies the conduction of behavioral research.

The starting point of the behavioral research is the investigation of the Parking Decision Process, which involves the decisions taken when travelers need to park at an urban environment on defined behavioral levels (pre-trip and on-trip). The decisions should then be modeled as an assignment of individuals pre-trip and represents the reactions with the network on-trip. Modeling in various decision levels and for multiple user classes increases the complexity of the Parking Assignment Model. For this reason it is chosen to implement it in a simulation environment.

Smart Parking

Smart Parking is a parking reservation system that can be described as it consists of mainly three entities: the user, the parking facility agent and the parking management agent (Figure 1.2). The user entity is connected to the system via a device able to communicate (GPRS-3G) and to track position (GPS/GNSS/Galileo). The parking facility entity that provide services (parking spaces) and information to users. The third entity is a control agent that gathers information from the user and the parking entities as well as from various other sources (traffic counts, road sensors) in real time and combines all pieces of information into a suggestion for reserving a specific parking space (Jonkers et al., 2011). The conceptual design of the system informs the driver about the closest - to the destination - available parking spots 15 minutes before arrival to the destination and encourages the driver to reserve a parking spot.

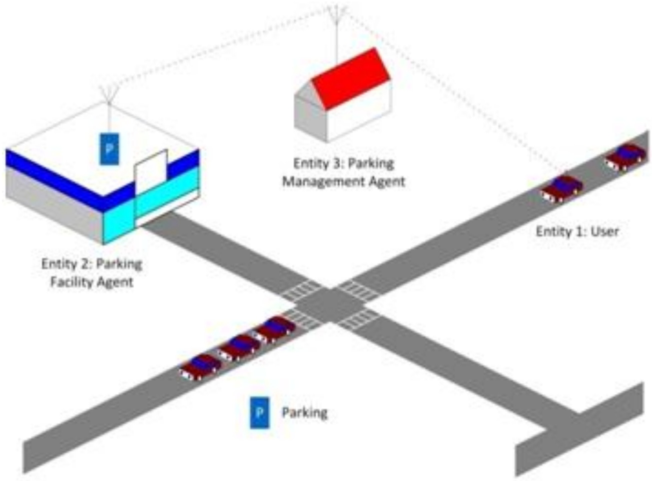

Figure 1.2: Smart Parking entities

Problem Definition & Objectives

The main problem identified is the lack of a consistent way to model parking for the reference case and for the proposed case. Starting from the motivation of this research, which is the evaluation of the Smart Parking application and given the literature review presented in Chapter 2, a clear need is found to develop a framework that can accommodate the evaluation of Smart Parking applications, based on parking related choice characteristics.

Given the aforementioned need the following objective is formulated:

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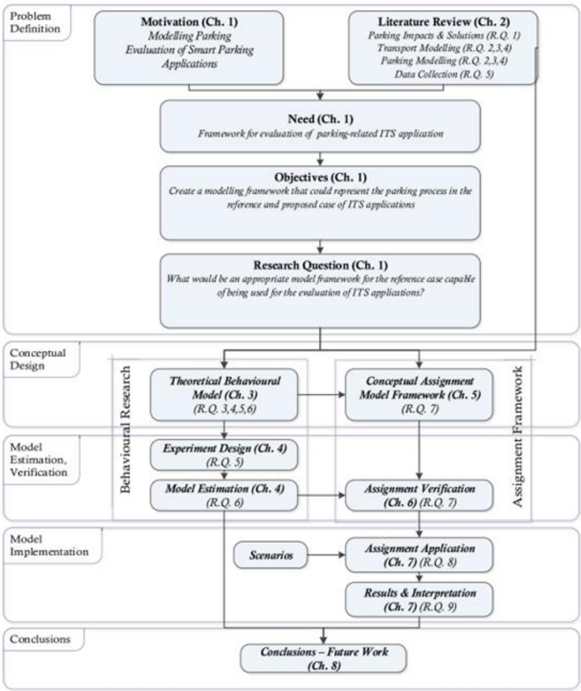

Figure 1.3: Research Framework

RELATED WORK

One of the first papers for parking indicated that parking-related problems are the result of people wanting to park exactly outside the door of their destination (Behrendt, 1940). The increase of transportation demand changed the problem towards the difficulty of finding a vacant parking spot at all. Searching for a parking spot became a reality and solutions were proposed oriented towards increasing supply by building (usually) off-street parking. As this approach was found to create problems, the solutions were then oriented towards managing demand with policies or information applications.

The need to find solutions to the parking related problems arose the need for representing parking choices and derive models that would represent the parking dynamics. Starting from the very basics, a model is a "simplified representation of a part of reality " used to investigate a part of the real world and what will happen in case of changing something (Bovy et al.,2006). In the beginning models were very simple. However, managing demand requires more detailed characteristics of demand, yet representing the way individuals behave in relation to parking, more sophisticated models arose.

The main reason for modeling parking is to test applications or policies which would be disturbing and costly in real life. As transportation is closely interrelated to human behavior a rather big part of transport modeling is the representation of the discrete decisions taken by decision makers. Data is required in order to derive models with data collection methods to be of increased importance.

This chapter answers to the following research questions on what the literature suggests in those fields:

1. Which are the problems caused by parking and which are the solutions proposed?
2. What is the state of the art in parking model ling?
3. Which are the decisions involved in the parking process?
4. Which are the characteristics that shape individuals decisions concerning parking?

In this part, the related work on the problems caused by parking on the parking modeling and data collection are presented.

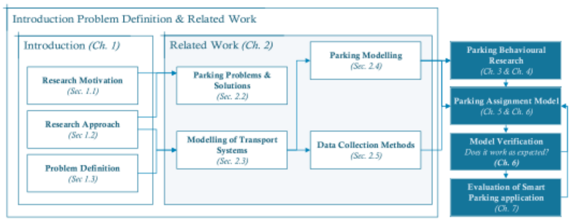

Figure 2.1: Chapter's components and connections

Process model & Choice model Derivation Process

The derivation of a Parking Decision Process model including the conceptual design of the choice models incorporated and the conceptual experiment design are conducted based on a systematic process presented in fig. The need for a choice model that would accommodate the representation of some parking-related decisions, taking into account the interaction with the transport system was used as a guideline. The starting point of this process is the available literature on parking modeling. The models used to represent parking behavior, the user classes for which behavior was modeled, and the data collection methods were investigated (presented in Chapter 2). Furthermore, the modeled attributes were identified and categorized based on their frequency of appearance.

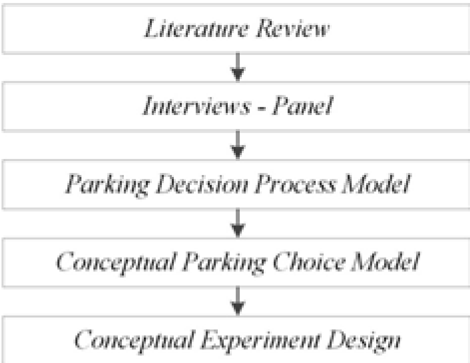

Figure 3.2: Derivation Process

The process for the derivation of a conceptual decision process flow model includes interviews of 5 individuals and a panel of 4 students. The interview structure, the questions asked and the participants characteristics are presented in the Appendix A. Based on the results of the interviews the panel and the input of the thesis supervisors the decision process model was derived.

The decision process model was used as the starting point for the definition of the conceptual choice model and as a consequence of the components of the experiment. The definition of the experiment's components and its process is referred to as experiment design.

Data Collection & Data Analysis

Sample Preparation & Stratification

The final questionnaire was distributed by a private company with a goal of getting 400 respondents in total constituting a representative sample of the Dutch population. Two questionnaires were and distributed (due to blocks). The total number of responses was 474 (208 and 266), giving a fair margin for sample stratification. From the 474 responses 426 were fully completed (89.9 percent).

The average completion time was 5.7 minutes. Due to the the fact that the data collection scheme was under payment, it was chosen to further eliminate responses which followed a pattern of random responses, given the time taken to process the information and by comparing it to the average. The average time taken to answer one question in the Familiar Users section was 16 second. In that context, the responses which were found to have an average completion time of under 5 seconds were eliminated. After the stratification of the sample –by the elimination of the uncompleted questionnaires and those who followed a pattern of random answers–, the number of completed responses was reduced to 397.

Socio-demographic Characteristics of the Sample

Table 4.7 summarises the Personal Characteristics section and the Unfamiliar Users section. For the comparison with data concerning the population of the Netherlands the values which refer to the Dutch population are presented in Table4.8).

Table 4.7: Socio-Demographic Characteristics of the Sample

Used participations	397, (83.8% of total)
Average age	45.64
Age- standard deviation	14.9
Age - Classes	5 [18-19), 147 [20-40), 192 [40-65), 53 [65-80)
Age -Classes (Perc)	1.3% [18-19), 37.0% [20-40), 48.4% [40-65), 13.4% [65-80)
Number of female	215 (54.2% of completed)
Highest level of education	29 P.S, 202 H.S , 137 H.E , 27 MSc , 2 Ph.D.
Highest level of education (Perc.)	7.3% P.S., 50.9% H.S. , 34.5% H.E , 6.8% M.Sc , 0.5% Ph.D.
Income	71 A, 95 B, 113 C, 63 D, 20 E, 35 F
Income (Perc)	17.9% A, 23.9% B, 28.5% C, 15.9% D, 5.0% E, 8.8% F
Shopping using car	0 a, 44 b, 108 c, 46 d, 179 e, 20 f
Shopping using car (Perc)	0.0% a, 11.1% b, 27.2% c, 11.6% d, 45.1% e, 5.0% f

Table 4.8: CBS Statistics (CBS, 2009)

Percentage of female	50.5%
Age -Classes (Perc)	35.5% [20-40), 49.0% [40-65), 15.4% [65-80)
Highest level of education (Perc.)	5.4% P.S., 55.1% H.S. , 32.2% H.E , 6.5% M.Sc , 0.6% Ph.D

Implementation Requirements

For the simulation of parking ,there are several basic requirements that should be met. The primary

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requirements for the implementation of simulation of parking have been described in detail by Young and Weng (2005) and have been briefly presented in Section 2.4.4. However, in order to fully implement the Parking Assignment Model some further requirements are important to be met.

As it has been clear parking is modelled in 3 behavioural levels. The strategic (pre-trip) the operation and the tactical. On the strategic level the parking search route for each individual is defined. On the operational level the "re-evaluation" takes place, while the tactical level includes the route choice and the search directions. The 3 levels shape the requirements for simulation:
Parking Search Route:
The simulation is required to be able to include routes with multiple visit points.

Information transfer:
The simulation is required to be able to include some type of infrastructure that can transfer information to individual actors such as Message Signs.

Decision Points:
The simulation should have points where the parking search route strategy should be re-evaluated based on the input from the network.

Route Derivation en-route:
During the simulation routes must be able to be derived.

Intersection direction choice:
A decision should be able to be taken every time a vehicle is reaching an intersection while searching for on-street parking.

Ability to represent Parking Facilities On-street and off-street parking facilities should be modelled, in such a way that would make it possible to replicate the on street parking procedure and the parking manoeuvring.

Given those requirements, it was chosen to use the ITS modeller as the simulation tool due to the fact that it qualified for most of the modules required for the implementation of the Parking Assignment Model.

IT'S Modeller
ITS modeller is a simulation tool, developed by TNO that would be able to cater the needs of simulating ITS applications (Figure 7.2). The major advantage of ITS modeller is that first of all it is designed in such a way that the programming of ITS applications can be done in a very robust way, with pre-defined modules to be offered. The fact that it is written in Java, an object-oriented programming language allows for modular programming with ITS modeller to offer many modules that can be used to model most ITS cases. A complete presentation of ITS modeller is not intended for this thesis however it is important to mention in this section the components that were used to make the parking modelling possible.

As most advanced Java programs ITS Modeller has a "core" that it is intended not to be modified and provides an interface that gives the opportunity to access the core of ITS Modeller in a safe way. The modules used focused on the modelling of actors behaviour (individuals) and the modelling of the infrastructure (Figure 7.3). The modules used and the programming are further presented in the following sections of this chapter for each specific case. As ITS Modeller is an advanced simulation tool kit includes several vehicle, vehicle acceleration, driving, lane choice, and car following models that can be modified according to the application.

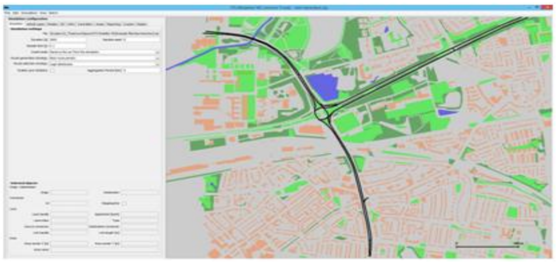

Figure 7.2: ITS modeller Graphical User Interface (GUI)

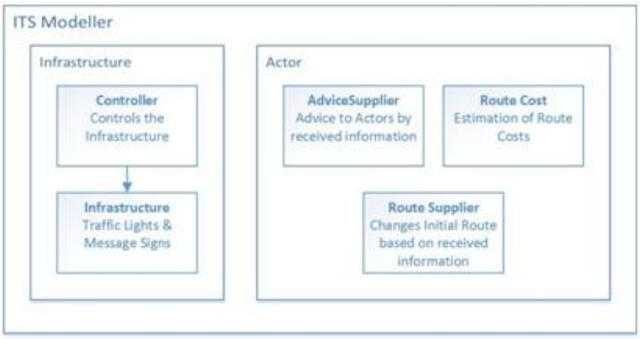

Figure 7.3: Modules used in ITS Modeller

Implementation Modules

The modelling of both, the reference and the Smart Parking application cases require a number of modules to be implemented in ITS modeller. Those modules constitute the basis for the simulation. In this section, the developed and implemented modules are presented for the parking facilities, the familiar users, the unfamiliar users and the Smart Parking Users (Smart Parkers). There are also other modules regarding the modelling of vehicles' movements and interaction with each other that were not developed, yet used. Those are also summarized in this section. Finally, some useful details on how those modules were programmed are presented.

Parking Choice Set

The size of the Assen city and the fact that there are 11 parking destinations lead to the decision to use one universal choice set including all 11 parking destinations for all parking users. In this context, all travellers heading to the city centre looking for parking, can visit all the 11 parking destination.

Parking Facilities

The parking facilities in ITS Modeller are represented in a very simple way using a traffic light, a traffic counter and a Message Sign (Figure 7.4). When a vehicle passes the traffic counter the load of the Parking facility is increased. The parking facility is programmed as a controller (Parking Controller) that controls the traffic light and the message sign while it collects information at every time- step from the traffic counter. The message sign transfers an information object from the controller to the actors. The traffic light turns red if the parking facility is full.

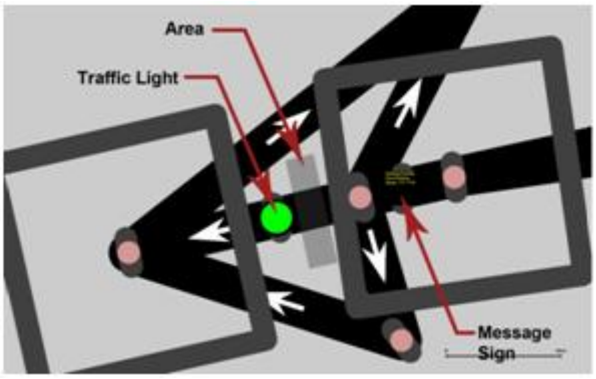

Figure 7.4: Off-street parking facility representation

Due to the fact that as described before familiar users are assumed to have information for the system's state and Smart Parkers receive information from the system for multiple parking destinations the introduction of a "Back Office" controller which plays the role of the parking management entity is programmed. The Back-Office Controller collects information from the Parking Controllers and makes it accessible to the familiar users via the Message Sign.

Finally, the departures of vehicles from any parking facility are events based on the arrival time of each vehicle to the parking facility and a random variable representing the duration of parking. When a departure is taking place the load of the parking facility is reduced and in case the traffic light was red it becomes again green.

Familiar Parking Users

The familiar users are programmed to be in line with the Parking Modelling Framework given the ITS modeller limitations described above. To begin with, in ITS modeller it is not possible to predefine routes with specific passing points that could serve as the parking destinations included in a parking search route. For this reason only the choice of the first parking destination is governed by the habitual pattern describing choices.

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The process starts by pre-defined Origin Destination pairs, representing the first parking destination to be visited, given the actual destination, in the context of the behaviour on the strategic level. The simplified version of the strategic parking search route model (initial parking destination preference) is used due to mainly time limitation.

When vehicles reach a parking destination that is full, they get information from the PGIs (tactical level) and they choose the next parking destination under the scheme of the Logit RUM-based behavioural model derived (see Chapter 4). The same process is followed until all familiar users find a parking destination. An example of the way a random familiar individual would react is presented in the Figure 7.5. The driver has chosen (pre-trip) to visit the parking destination closer to his/her destination (Parking Route). When arriving there, he/she finds out that it is full and decides to drive to another parking destination (Parking to Parking Route1). However the second parking to visit is also full so he/she decides to drive to a third parking destination (Parking to Parking Route 2). It is important to mention here that the unfamiliar users were assumed of not being aware of the existence of the other user classes –when applicable. In other words, familiar users decide, without taking into account the parking-related decisions of the Smart Parkers or the Unfamiliar users of the system.

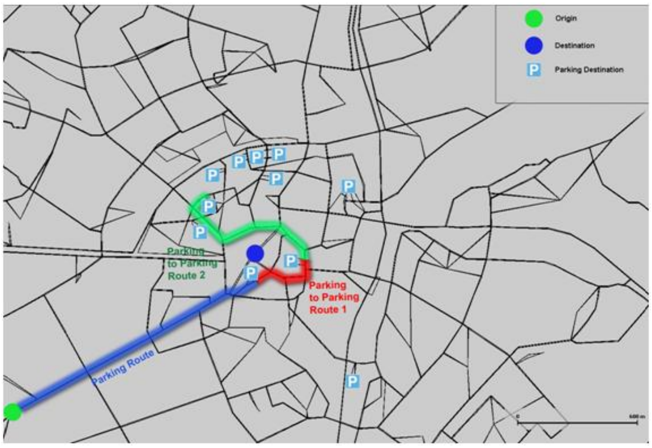

Figure 7.5: Routes followed by a random familiar user in ITS modeller

Unfamiliar Parking Users

As described in the behavioural research, the majority of the unfamiliar users choose to visit the initial destination, while others either get close to the initial destination and park or search for parking before trip. In this implementation unfamiliar users were directed to drive towards the initial destination. While driving, travellers are searching for a parking destination and if they find a parking destination they "store the location" and continue driving until they reach their destination. After they visit their destination they visit the stored location to park. In case travellers do not find a parking destination and they reach the destination, they choose a direction (north, south, west, east) and then follow a random predefined route towards this direction. During this route they again search for parking until they reach a point at the network which is located around 500 meters from the initial destination (applicable for the city of Assen). If they have reached this point they take a random predefined route back to their initial destination, while again searching for parking until they find a vacant parking spot. An example of a random unfamiliar user is presented in Figure 7.6. The predefined routes are produced based on a K-shortest path penalty algorithm, used in ITS modeller, with a high number of iterations (30). The driver drives to the initial destination without finding any parking on this route. Then he/she chooses to take a route to south, and when reaching a point where it is distant to the initial destination and he/she decides to go back.

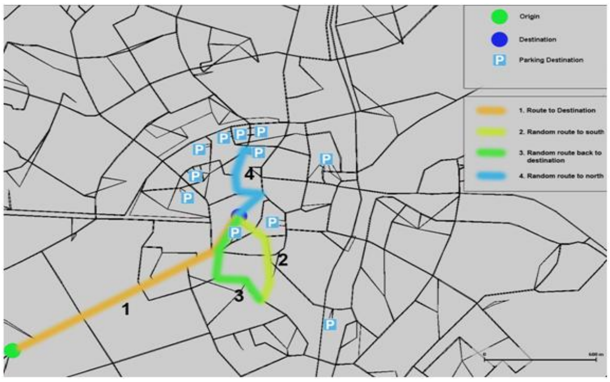

Figure 7.6: Routes followed by a random unfamiliar user in ITS modeller

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It is important to mention at this point that the unfamiliar user's module was only used for one destination in the city centre for users originating from several origins.

Smart Parking Users

The implementation of the smart parking users was based on the Smart Parking application developed for the Sensor City. Individuals receive information about the parking destinations via an application for a Smart phone replicated by a Message Sign that is controlled from the Back-Office controller containing information for all parking destinations at the area to be visited. Individuals decide to reserve a parking spot at a parking destination. At this point it is assumed that all drivers using the reservation system comply with the reserved parking spot. The choice of one of proposed parking destinations is modelled using the Logit RUM- based behavioural model derived (see Chapter 4), only for parking destinations which have available parking spots at the moment of the reservation. Given a chosen parking destination, the reservation procedure takes place by informing the Back-Office controller and the Parking controller involved to reserve the parking spot (which essentially means to increase the load of the parking destination by the parking controller). Individuals who get a reserved parking spot follow the shortest route to the destination. In case there is no available parking spot at any destination the same procedure is followed until a parking reservation is made.

Conclusions

This thesis presented the development of a simulation-based parking assignment model for the evaluation of Smart Parking applications.

Behavioural research was conducted, proposing a decision process model, that describes the choice for two user classes (familiar and unfamiliar parking users), on three behavioural levels (strategic, tactical and operations). A survey was conducted with 397 complete/stratified responses for the investigation of those decisions and several model structures were examined to derive the model that can best represent parking choices. The attribute set used in the experiment was based on those found in the literature, yet different, by combining the probability of finding a vacant parking spot and the search time, into the newly introduced attribute of the probability after some minutes of searching/waiting. All attributes investigated were found to be significant in the model structures examined, supporting this inclusion.

The two probabilities investigated (upon arrival and after some minutes of searching) allow for the connection of the parking system with the choice of individuals as they were defined using parking related stochastic characteristics such as the arrival rate and duration. For that reason, a novel probability model based on simulation is introduced to approximate the true probability experienced by individuals.

The parking decision process model and the MNL parking choice model are used for the parking assignment model concerning familiar users. The decisions are represented in all behavioural models and the modelling methodology is suggested. This methodology differs to the methodologies presented in the literature, as it is solely based on the utility function of the MNL model. A habitual pattern is assumed on the strategic level, and a novel parking search route consisting of sequential parking destinations to be visited is suggested. On the tactical level, the re-evaluation of the strategy is introduced, for the first time for parking, given an improvement margin. Finally, on the operational level, decisions concerning routes and on-street search decisions are included. The verification of the novel strategic search route show a realistic approach, in line with the theory related to them. A second user class, the unfamiliar users are introduced for the first time in parking modelling. They were modelled to have a diverse behaviour with some to search for information, and some drive to the destination and then start searching on the strategic level. On the tactical level for those without information concerning parking, a search process was defined in a random pattern of choosing direction and a random search, assumed to represent the lack of information.

The assignment framework was introduced in ITS modeller by coding the components for the evaluation of the Smart Parking reservation system developed in the Sensor City project and scenarios were investigated. The application of the framework shows the potential of using the Parking Assignment Model. It is found that it can be implemented in a simulation environment and is capable of representing the situation in a realistic way. On the other hand, is found that the results for the scenarios developed indicate that the reservation system can improve the traffic conditions and offer lower travel times for its users.

Both the reference cases and the scenario cases are found to yield realistic results concerning travel times and parking choices. Even the case of unfamiliar users (who were found to have increased travel time) seems to be realistic, taking into account the lack of parking related signs in the implementation. The improvements of average travel times (both total and individual-based) were found to be of rather small magnitude, which is expected, as it is in line with the magnitude of many ITS applications.

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