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Smart Parking

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ABSTRACT;

This research focuses on the derivation of an assignment model that can be used for the evaluation of Smart Parking ITS 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

1, 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. 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 . The main instrument for reducing the impact ofparking is the development of parking-related policies. Those balance the demand and supply for parking with the most prominent to be parking pricing . 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.

In the literature models describing the parking process are still in their infantry. Most of them are ad hoc models developed for a particular application or only deal with parking under specific -mostly stationary conditions that cannot apply for ITS applications. There are very limited parking simulation models, on mostly a theoretical level, which investigate

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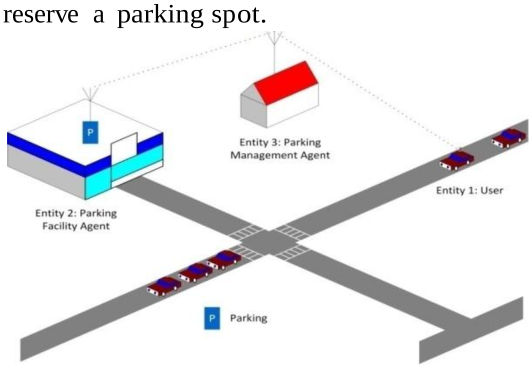
parking, without taking into account the behavioral characteristics in the assignment process. This leads to the conclusion that there can be an adequate model that would take into account the behavioral characteristics, for modeling Smart Parking applications.

Evaluation Approach

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.

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. 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.



Problem Definition, Objective & Research Questions

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,

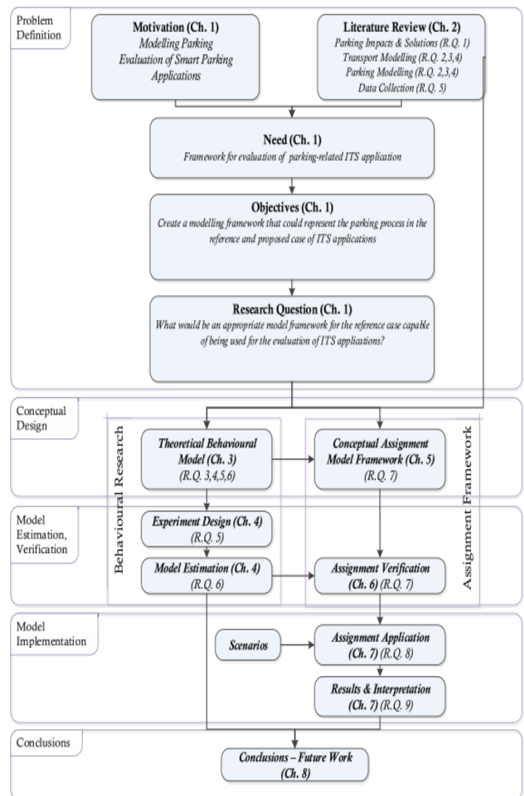


Figure 1.3: Research Framework

2, 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. 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

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(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. 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.

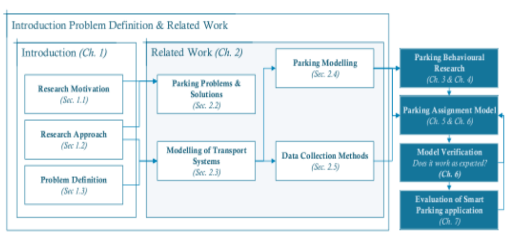


Figure 2.1: Chapter's components and connections

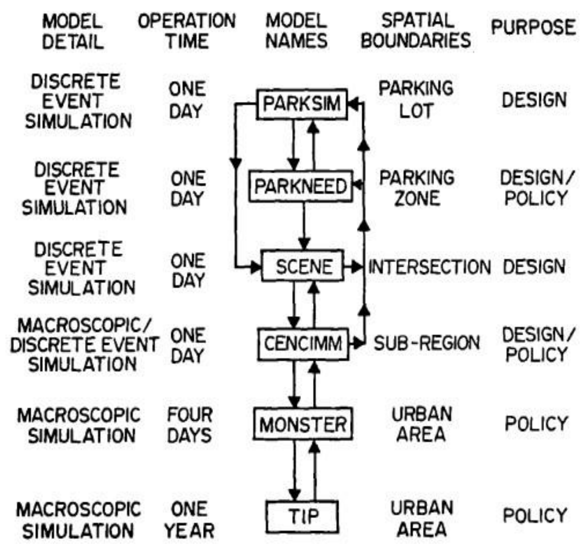
Modeling of Transportation Systems

The transport system can be defined as "a set of elements and interactions between them that produce demand for travel and the provision of transportation services to satisfy this demand. The representation of this system is approached by modeling the components of the system that seem to have a clear influence to the outcome. In the context of evaluating an ITS application the two main components to be explored are the modeling of the behavioral characteristics using mainly discrete choice models and the traffic assignment modeling.

Parking Modeling

There are several types of parking-related models with different purposes, such as design of a parking facility, optimization of parking entrances, or representation of interactions between users and parking.

The simplest and very common way of including parking in transport model is to include the costs of parking in the generalized cost function of travel and use it in the well known 4 step transport model. This kind of models does takes into account the parking as a transport component, but it fails to represent the real dynamics of parking. Generally, it does not give any indication for most of the aspects of parking choices except for the mode choice (if it is included) and the route choice



3, Theoretical Parking Behavior

The understanding of the decisions taken in the parking process, and how individuals decide upon them are crucial for the representation of the parking process. The definition of the parking decision process model and the discrete choice models help towards this direction, with the investigation of the attributes which shape those decisions and the way individuals evaluate the available alternatives to be required. In order

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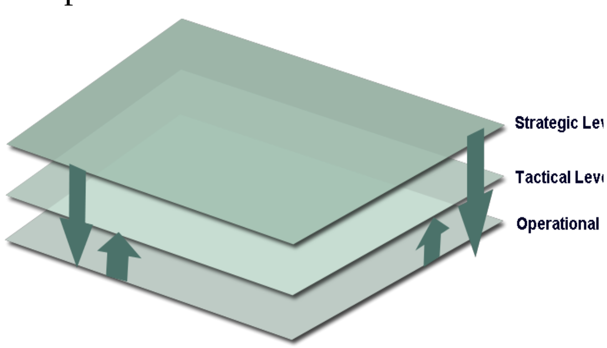
to fulfill those requirements there is a need to explicitly define and analyze the parking system (users, network), and the decisions behavioural levels. The behavioural research is going to be used as the basis for the parking assignment modeling framework.

The decisions are explored on a decision process level starting with pre-trip decisions and moving towards the decisions taken while individuals interact with traffic (on-trip). In order to have a clear structure of the decision process it is chosen to categorize decisions on a three-layer behavioural model. Different users of the network imply the definition of users classes.

Behavioural Concept

The interviews and the panel conducted showed that there is a distinct pattern of behaviour among familiar and unfamiliar users. For that reason the description of every model is based on that pattern.



Personal Information

The collection of the personal characteristics takes place for mainly two reasons. First of all, in order to examine the representative character of the sample against the population. Of course it is not possible to take into account all the socio-demographic attributes yet, it should at least include the characteristics that generally are important for the examined behavior. In this case the survey data collection is designed in a way to reduce the possibility of having a non representative sample. Second of all, it is rather common in models resulting from behavioural research surveys to include socio-demographic as part of the model structure due to their significance.

4, EXPERIMENT DESIGN AND MODEL ESTIMATION

The design of a survey and the analysis of the acquired information are both very important components of behavioural research. As the system describing the behavioural responses of individuals is complex, its identification and the investigation of the experimental designs were rather limited to some basic concepts of efficient designs.

The literature suggests that the most usual design for Stated Preference research is the orthogonal design. However, as it is indicated by Rose et al. (2008) even in case there is only an indication of the *priors*[1], designing a survey with efficient design techniques yields more information. This information can be described by the Fisher Information Matrix[2] with the highest information to result in lower variance described by the Cramer Rao Inequality[3] (given that some conditions on the estimators properties are met). The experiment design process does not take into account the application (which in this case is the prediction) with the

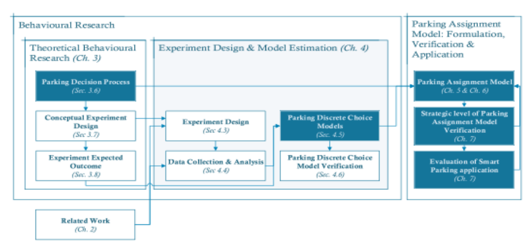


Figure 4.1: Chapter's components and connections

Experiment Design Process

The experimental design process for the familiar section (as conceptually designed in the previous chapter - Section 3.7) was initially implemented from data from the

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literature and compared to the orthogonal design. The comparison was made on the D-error estimator (the determinant of Variance Covariance Matrix). As expected, the orthogonal design was found to be ineffective with many scenarios to be governed by dominating alternatives. As such, the first round of the pilot study was introduced to have a clearer indication of the estimators. Afterwards, the design process continued with the derivation of the second round's design and was completed with the final design. All the experiment designs were produced using Ngene. The model structure chosen to use for the designs was the MNL model.

Parking Choice Models Estimation

On of the reasons for the realization of the behavioural research is the derivation of models that would be able to represent individual's choices concerning parking. For that reason both for familiar and unfamiliar users it was attempted to derive choice models.

Model Verification

Model verification is a tedious task in general. Although the models derived seem to behave as expected (with the costs to be negative and the utilities to be positive) and the estimation process did not resulted in general in little radius of fit or other negative diagnostics. Although the goodness of fit is presented for all models and is described by the likelihood ratio index (see Train, 2003, section 3.8), it was intended to further explore it, by comparing the predicted percentage of choosing one alternative to the actual percentage of people choosing the same alternative. It is important to keep in mind that as Train (2003) clearly indicates, this metric for the goodness of fit should not used due to the fact that it "misses the point of probabilities". In this case, a random choice situation was chosen, the utilities and the probabilities were calculated and compared to the actual choices of individuals. The resulted percentages are presented in Table 4.17 indicating a rather high goodness of fit.

5, PARKING ASSIGNMENT MODEL

This chapter presents the *Assignment Model* for familiar and Unfamiliar users, on all be-havioural levels. For each user class and behavioural level, the conceptual model is presented, followed by its formulation –when applicable. The Assignment Model is strongly connected to the Behavioural Research conducted and presented as it is used in the Assignment Model for prediction of individuals behaviour. The Parking Decision Process is used as reference for the modelling of the decisions and the discrete choice model is used to represent the way choices are made.

The discrete choice model on which the assignment models are practised is the Multinomial Logit model, derived in Section 4.5.2. The introduction of a more sophisticated model can take place rather easily although a simple model structure would allow for direct analysis of the results and verification.

The parking assignment model takes into account both traffic interactions, and parking inter- actions. In a sense, it could be described as a Dynamic Traffic Model with Parking, however, for consistency with the terminology used in parking modelling it is referred to as Parking Assignment Model.

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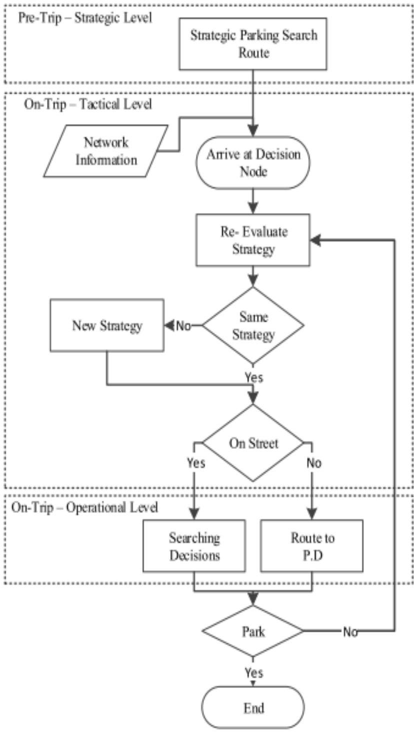

Figure 5.3: Familiar users modelling framework

Parking Assignment Model for Unfamiliar Users

The unfamiliar users were treated in a rather different way compared to familiar users due their lack of information concerning the parking situation. Given this special attribute, unfamiliar users are modelled under a random adaptive context presented in the following sections. The general idea on how unfamiliar users are modelled is presented

Parking Probability Model

In the conceptual behavioural design, it was introduced that a set of attributes to be investi- gated refer to the probabilities of finding a vacant parking spot (either upon arrival or after some minutes). The problem that directly arises is how probability is defined and how it is connected to characteristics of the parking destinations that can be observed. The goal in other words is to "translate" the probability of finding a vacant parking spot to measurable parking-related characteristics.

The probability of finding a vacant parking spot is related to the following parking-related characteristics:

1. The capacity of the parking destination
2. The number of occupied parking spots
3. The number of arriving vehicles
4. The number of departures

6, FAMILIAR STRATEGIC LEVEL MODEL VERIFICATION

The special character of the Strategic Parking Search Route model (SPSR) for familiar users requires the verification of the concept in some situations that would prove that it does work as expected. The other components of the Parking Assignment Model are verified and discussed, in the context of the application presented in Chapter 7. As described in Section 5.5.1 the strategic parking search route is a two level stochastic user equilibrium assignment. In the first level (*SUEr*), the travel times to the parking destinations are calculated. Those are used in the second level of the assignment (*SUEp*) to define the flows to the parking destinations. The assignment iterates until the travel times and the flows to the parking destination settle.

Due to the rather high complexity of the model it is chosen to go through a series of tests start- ing from rather simple situations and going towards more complex situation. Furthermore, it is chosen to start by testing the model for only the initial destination (initial destination preference model) and then apply the strategic parking search route.

Model Programming

The general concept is that the Parking Search Route Model –describing a habitual pattern– would be used as an input for simulation. The model was coded in MATLAB with the input to be in Extensible Markup Language (XML file) for the Road Network (will be

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referred to as *Network*) and transport demand (will be referred to as *OD pairs*). The output of the code is the parking search routes in a way that can be the input of a simulation program.

Verification Process

The verification process goes through a series of tests for the verification of the programming and modelling components of the parking search route assignment. The modules to read XML files and derive routes as well as the *SUEr* assignment were initially tested[1]. Afterwards, the SUEp component is examined, for both the initial destination preference and the strategic parking search route. In general, the complexity increases with the scenarios examined with the last scenario for the Initial Parking Destination Preference and the SPSR model to be implemented in a dynamic context for the Assen Network.

7, PARKING ASSIGNMENT MODEL APPLICATION

The Parking Assignment Model is –as described in Chapter 5– a package of modelling modules capable of simulating parking in an urban environment, for the representation of the existing situation (reference case) and for representing Smart Parking Applications as scenario cases. The suitability for evaluating Smart Parking applications lies on the behavioural representa- tion of the perception on the probability of finding a vacant parking spot, which is the basis of parking-related ITS applications. The strategic level of the parking assignment model have been verified in Chapter 6 ensuring only partially the applicability of the Parking Assignment Model. In this chapter the rest of the components are verified and the applicability of the model is evaluated based on an implementation in the context of the Sensor City project for the Smart Parking application.

Implementation Requirements

For the simulation of parking ,there are several basic requirements that should be met. The primary 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 (Section 5) 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

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 summarised in this section. Finally, some useful details on how those modules were programmed are presented.

8, 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

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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 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.

Recommendations & Future Work

In general, it is believed that the parking assignment framework is capable of evaluating parking related ITS applications and that the results of the implementation on the Smart Parking application are promising. In this section, recommendations are made in three direc- tions (Behavioural Research, Assignment Framework, Implementation & Smart Parking case). Those recommendations are considered as further steps for improving the components of this thesis with a strong focus on the further development of the parking assignment modelling framework for ITS applications.

Implementation & Smart Parking Case The implementation of the parking assignment modelling framework took place for evaluating the applicability of the model, verifying the simulation components and evaluating the Smart Parking application. The recommendations mainly focus on the full scale implementation of the model as well as the specific case of smart parking. Starting from the implementation, it is recommended to fully implement all the behavioural levels in order to investigate also, how the strategic parking search route model, the re-evaluation model and the on-street search model behave in a simulation environment. In order to accomplish this, the requirements described in Chapter 7 should be met. The implementation should include also some modules to store parking related and route choice related data that were not implemented due to time limitations. Given this data, more detailed analysis on the behaviour of the models can be achieved what would essentially result to a better verification of the model.

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