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EVALUATIONOFSMARTPARKINGAPPLICATIONS

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ABSTRACT

Developing an assignment model for assessing ITS Smart Parking applications is the primary goal of this study. There were three layers of behavioral analysis (Strategic, Operational, and Tactical), as well as two user classes, included in this study in order to better understand people's parking habits (Familiar and Unfamiliar users). Representation of the choices people have when they are asked to park their vehicle in a specific location. For the investigation of decisions for familiar and unfamiliar users, a Stated Preference experiment is carried out –designed utilizing efficient designs– and discrete choice models are constructed for familiar users. Parking Decision Process model and MNL Parking Discrete Choice model are used in the creation of a Parking Assignment Model for behavioral simulations for both user classes. Verification and testing of the Parking Assignment Model's components and applicability are conducted. As a final step, the Parking Assignment Model is used to gauge the success of Assen, Netherlands-based Sensor City's Smart Parking app. There was a significant reduction in travel time for both individuals and the overall population as a result of the Smart Parking application.

1.**INTRODUCTION**

Parking in cities has been a serious issue in the last few years. Information on parking issues is plentiful, with estimates ranging from 30 to 50 percent of the overall traffic volume in city centers at rush hour being accounted for by parking demand (Shoup,2006; Arnott and Inci, 2006). Every excursion in an urban location is capped off by the quest for a parking spot, which brings with it a slew of problems: "cruising" Loss of time, greater consumption of fossil fuels, traffic congestion, risk to others, and increased emissions are just a few of the consequences (Kaplan and Bekhor, 2011). In order to reduce the negative effects of parking, parking-related policies are the most effective. Parking price is the most prominent way to strike a balance between supply and demand for parking.

etal.,2006).However,asparking pricingpolicies reachtheirlimitsduetosocialandpoliticalreason s, theneedtodevelopnewsystemstoalleviatethe parkingimpacthasbecomeimperative.Lately, ITS and Smart Parking applications are being developed and need to be tested before they can be

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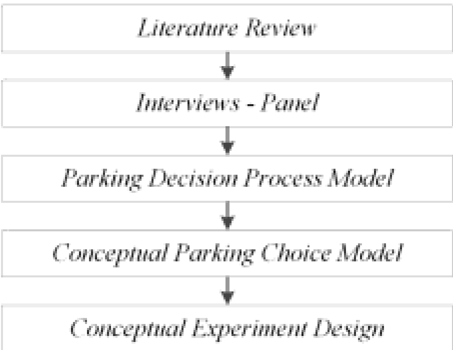
adopted on a widespread basis.Parking models in the literature are just beginning to take shape (Young, 2008; Lam et al., 2006). To a certain extent, they're all unique designs aimed at solving a particular problemproblem (Young et al., 1991) or are limited to a certain type of parking situation (mainly stationary; Lam et al., 2006) and hence cannot be used in conjunction with ITS (Mahmassani, 2001a). To date, there have been only a few number of parking simulation models that take into account the behavioural characteristics of the parking assignment process (Gallo et al., 2011; Guo et al., 2013; Benenson et al., 2008). As a result, a good model for Smart Parking applications may be found that takes into consideration the behavior features.

2. **THEORETICALPARKINGBEHAVIOR**

Processmodel&ChoicemodelDerivation Process

The conceptual design of the decision models included in the Parking Decision Process model, as well as the conceptual experiment design, are based on a



Derivationprocess

systematic process presentedThe need for a choice modelthatwouldaccommodatetherepresentation of someparking-relateddecisions,takingintoaccounttheinteractionwiththetransportsystemwas used as a guideline.The starting point of this processistheavailableliteratureonparking modeling.The models used to represent parking behavior, the user classes for which behavior was modeled, and the data collection methods were investigatedFurthermore,themodeledattributeswere identified and categorizedbased on theirfrequencyof appearance.

The process for the derivation of a conceptual decision process flow model includes interviews of 5 individualsand a panel of 4 students. The interview structure, the questionsasked and the participants characteristics arepresentedintheAppendixA. Basedon theresultsof the interviewsthepaneland theinputof thethesissupervisorsthedecisionprocessmodel was derived.

Thedecisionprocessmodelwasusedasthestarting point for thedefinitionof theconceptual choicemodel andas a consequenceof thecomponentsof the experiment.Thedefinitionof the experiment's componentsanditsprocessisreferredtoasexperimentdesign.

ParkingDecisionprocessmodel

hereisatwofoldreasoningbehindtheillustration of thedecisionprocessconcerningpark-ing:toset theguidelinesbasedonwhichthesurvey experimentisdesigned,andtoguide the parking assignment framework models derivation.More specifically, the decision process frameworkwas employedtodescribethedecisionstakenwhile choosingaparkingdestina-tionAsalready mentionedit is a corollary of the literature review, individual interviewsandpanelinterviews.

There are a number of qualities that can be used in defining a random traveler (decision maker) who wishes to drive to the city center and then a number of preferences for attributes that describe parking options that can be used in characterizing the parking choices. There is a significant difference between drivers who are familiar with the parking issue at their final destination and those who are not.

A parking search method can be chosen based on the previously given clusters of attributes. If a parking space is available at the destination, the traveler just parks and exits the system. There are two options if the initial location does not have a parking spot available: continue searching or re-evaluate the other options each group has available.

Finally, it should be mentioned that, in the context of this research, it is impossible to fully describe and explore all the choices on an equal level. It is because of these two flaws in the report that the assumptions will be clearly expressed as appropriate in the next sections.

Familiarusers

Many elements influence a traveler's decision-making when they are familiar with the system. Route selection and parking destination selection can be represented by a habitual pattern on the strategic level – before the journey is even started – depending on individual qualities, trip features, and of course, parking factors. In a nutshell, the notion is that acquainted travelers choose both route and destination in a way that maximizes or reduces utility (or decreases disutility) for both options. The finalized plan is organized in the form of a search route for strategic parking.

It's possible that the scenario at the destination isn't quite what you imagined. If you get at your destination and find that the parking lot is already full, you can either find out about the issue before you arrive, or you can simply interpret the traffic situation while driving. In this instance, they must decide whether or not to continue with their original approach or to change it. Continuing the tactic means they'll have to make a new decision. As a final tactical step, when looking for on-street parking, drivers outline their route in the parking destination area.

UnfamiliarUsers

Despite the fact that many newcomers begin their journeys by searching for information (maps/navigation devices) before setting off, there may be a more planned approach when it comes to parking. The unfamiliarity effect has a significant impact on the speed of searching, the logic of decisions, and the choices that people make. Because they have changed their parking destination based on the information they have obtained, it is claimed that those who conduct research can be treated as familiar users.

3.EXPERIMENTDESIGNANDMODEL ESTIMATION

This section's experimental design was initially based on literature data and then compared to an orthogonal one. On the basis of the D-error estimator, a comparison was made (the determinant of Variance Covariance Matrix). Because of the prevalence of dominant alternatives, the orthogonal design was deemed inefficient in many instances. It was for this reason that the first phase of the pilot research was launched. This was followed by the development of the second round's design and the completion of the final design. [*] Ngene was used to create all of the experiment designs. The MNL model was selected as the model structure to be used in the designs.

PilotStudy

TU Delft students and TU Delft and TNO staff participated in the first round of the pilot trials (second round). For the purposes of evaluating the questionnaire's complexity and making content-related changes, both were accompanied with feedback.

PilotStudyFirstround

The first round's design was created based on a combinationof theavailablepriorsfrom literature (0LPr).Thepriorswerebasedontheresearchers of Van der Waerden (2012); Axhausenand Polak(1991). Table A.2 and Table A.3 in Appendix A. show the Fisher information matrix and the characteristics and attribute-levels employed.

Because of the two studies being combined, the information that could be gathered was not at its maximum potential (the design was therefore sub-optimal). It's possible to fit more information into this design, though, than an orthogonal one.design (which yielded a higher number of dominant scenarios) and it was chosen to be implemented in the firstroundofthepilotstudywitha small sample.

After acquiring the answers from 11 respondents an MNLmodelwasestimatedusingBIO-

GEMEbasedontheirresponsesforthesecondround of thepilotstudy.Thismodelis presentedinthe TableA.4of AppendixA.Feedbackwasalso provided with most respon- dents indicating that the survey was rather demandingand large.The MNL modelestimatorsformthe1LPrestimators'setto beusedinthedesignof theexperiment,for the secondroundof thepilotstudy.Ithastobestated, thattheresultsofthismodel(basedonthe0LPr) canbeconsideredasbiased.Thereasonthisstands isduetothefactthatthemodelrepresentavery smallandbehaviourallyspecificsampleof international students who live in the Netherlands, having a drivers license and occasionally using a car. However, it is believed that it provides a better representationoftheestimatorsofthemodeland thatthe valuesoftheestimatorsareclosertothe vectoroftruevalues(θ0).Thisisbelieveddueto the fact that the 0LP r were normalized estimators' valuesofattributeswhichweresimilartothe attributes investigated.

PilotStudyFirstround

Based on the 0LP r priors, a 0LDes design is used in this second pilot research round. As a result of the first round's input and observations, some alterations were made to the design. People's impression of the distance between them and their destination was found to be indistinguishable between 500 and 100 meters (during discussions after filling out the questionnaire most respondents indicated that it does not make a difference to have to walk 500 or 100 meters). In addition, the distance from home was recalculated to more realistic automobile trip times, as cycling is more frequent in the Netherlands for such journeys. There is a table of values that were used in the design of 1LDes

Parkingrelatedattributes1LDesDesign

In Table A.5 of Appendix A, you'll find the Fisher information matrix for this particular plan. In comparison to the Fisher information matrix produced by the 0LDes design, the amount of information that can be gleaned is clear. With no dominant situations and a D-error of 0.10, this design was created. This time around, the questionnaires were sent out to a more diversified group of employees.ftheDelftUniversityofTechnologyandTNO.It

Price
Distancefrom Destination
TraveltimeParking Type Probability upon arrival Probability after4 minutes
Probabilityafter8

Attributes	Levels	Level Values

2 AC1.5/
2 AC2.5
2 100meters/700
2 meters
2 16min/24
2 min
2 On-Street / Off-Street
10%,

was filled outby 35 respondents.Itwas accompanied by feedbackfrom theparticipants.Thestatistics of those respondents are presentedin Table A.6 of AppendixA.

AnMNLmodelthatwasestimated,using BIOGEME as shown in Table 4.3. The results for the estimators are as expected with the expected results for price 1, walking distance + 2 minutes + 3 minutes + 4 minutes + 5 minutes + 6 minutes + 7 minutes + 8 minutes being negative and the expected access time + 3, access time + 3, on-street + 4, on-street + 5, on-street + 6, on-street + 7 minutes + 8 minutes + probability upon arrival + 5 + 6 + 6 + 7 + 8 minutes being positive.

On theestimators significance,some testswere run withalternativespecificconstants(ASC)and without,resultingininsignificantASCs.Apart fromtheMNLmodel,theresultsof thepilot surveyweretestedagainsttheMMNLmodel (mixedlogit)inordertotestfor heterogeneityin the population. It was found that the variancesof the parameters were not significant andthat theMNL modelperformedbetter thantheMMNL.

It has to be stated, that it is rather unsafe to draw conclusions based on this model due to thelownumber of participants and the fact that the sample is not representativeofthe(Dutch)population.Thismodel is only useful towardsthe directionofa more efficient designforthefinalsurvey.Theresultsforthe1LPrdesignwereonlyusedfortheactualsurveyof400

4. PARKINGASSIGNMENTMODEL

The Parking Decision Process and its components will be reviewed prior to the presentation of the parking assignment modeling framework and its components. The strategic, tactical, and operational levels of parking can all be articulated. The parking decision framework is designed for two user groups: the familiar and the unfamiliar (Section3.3).minutes 40%

Unfamiliar users have a strategy on searching or not information pre-tripas well as for the desired parking type. The operational level applies after reaching the destination (orwhen close to it)where a search directionischosen.Afterwards,theroutetowards thedirection chosenis definedon thetacticallevel and,incaseofon-streetparkingthelinkon intersection level.

Conceptualimplementationprocudure

It is proposed that the Parking Assignment Model be used in a computer simulation. Practical and methodological considerations are the key ones.

This thesis does not include the time or resources necessary to carry out the laborious task of implementing the Parking Assignment Model's components in a macroscopic dynamic stochastic user equilibrium assignment for both known and unknown users, and for all possible behavioral variations. Due to the dynamic nature of traffic information, such as parking occupancy, departures, and arrivals, steady-state models cannot adequately depict the exploration of ITS implementation and their impact size (see Section 2.3.2). Section 6.4.3's verification of the familiar strategic level shows that a 15-minute time period does not allow for a comprehension of possible re-routings.

Here, the ParkingAssignment model is developed in order to be implemented in two phases: Pre-trip and On-trip.Thepre-tripphaserepresentsthe strategicleveloftheparking decisionprocessandit isdevelopedforbeingtheinputofthesimulation. The on-tripphase is completely developed for being implementedin asimulationenvironment.

ParkingAssignmentModelForFamiliarUsers

Inthissection,adetaileddescriptiononhowthe familiarusersaremodelledisintendedforthethree

5.several facets of human behavior. Modeling familiar users is consistent with the decisions made in the familiar component of the Parking Decision Process model. On the strategic level, familiar users develop a parking search strategy (pre-trip). This method may need to be tweaked while traveling based on new information that is gleaned (operational level). Routes between parking locations are mapped, as well as off-street parking options for each intersection. An assignment modeling conte is used to depict this process. This section is meant to serve as an explanation of both the concept and the formulation.

6. FAMILIAR STRATEGIC LEVEL MODEL VERIFICATION

ModelProgramming

Parking Search Route Model (PSRM) would be utilized as an input for simulation, describing a regular pattern. Extensible Markup Language (XML) files representing the Road Network and transport demand were used to code the model in MATLAB (will be referred to as OD pairs). The programme generates parking search paths that can be used as input to a simulation program.

The pseudo-code ofthe program created for the verificationof the algorithm is presented In the beginning, the simulationfiles and the parking characteristics are inserted as input.All the stringsaretransformed tointegers,andtables arecreated.Withallthe requiredcomponents to be in a proper form, the route derivation proceduretakesplace forthe ODs insertedand for some null ODs in orderto have a more realisticrepresentation of the travel times to parking destinations. The route derivation outcome is an assignment map, for each time period,which is used for the SUErfor all ODs, for all periods.The output ofthe SUEr(travel times)is used as an inputof theSUEpassignmentwhichoutcomeistheparkin g searchroutesandtheirdemand.Thoseare again used in the SUErassignment in order to derive more accuratetravel times given the demand ofthe parking search routes.This takes place iteratively until it converges, given the dualitygap (or flow differences between iterations).

7. CONCLUSIONS

A simulation-based parking assignment model was developed in this thesis to evaluate Smart Parking applications.

Behavioral research was undertaken, which proposed a decision process model that depicts the option for two user groups (familiar and unfamiliar parking users) on three behavioral levels (strategic, tactical and operations). To further understand these choices, a survey of 397 people was administered, and the results were analyzed using various different model structures. To make the new attribute of probability after some minutes of searching or waiting, we employed a set of attributes based on those reported in the literature but different from those found in the experiments. To support this inclusion, all attributes were shown to be important in the model structures analyzed.

The two possible outcomes that were examined (upon arrival)and aftersome minutesof searching)allow for the connection of the parking system with the choice of individualsas they were defined using parking related stochastic characteristics such as the arrival rate and duration. For that reason, a novel probability model based on simulationis introduced to approximate the true probability experiencedbyindividuals.

For the parking assignment model including well-known users, we turn to the parking decision process model and the MNL parking choice model. All behavioral models include a representation of decisions, and a modeling approach is offered. The MNL model's utility function is the sole basis for this methodology, which differs from others offered in the literature. An established pattern is assumed at the strategic level, and an alternative search path is proposed, which includes a series of sequentially located parking lots. When there is room for improvement, the strategy for parking is reevaluated at the tactical level for the first time. Finally, on the operational level, judgments on route and on-street search decisions are taken into consideration. According to the hypothesis behind the new strategic search route, the results reveal a practical solution to the problem at hand. In parking modeling, a second user class, the unknown users, are introduced. Their behavior was simulated to be different, with some seeking for information while others drove to their destination and then began searching on a strategic level. To help those who had no prior knowledge of parking options, a search strategy based on random search patterns and direction selection was devised. The assignment framework was introduced in ITS modellerbycodingthecomponentsfor the evaluation of the SmartParkingreservation system developedin theSensorCityproject andscenarios were investigated.The application of the framework shows the potential of using the ParkingAssignment Model.It is found that it can be implemented in a simulationenvironmentandiscapableof representingthesituationinarealisticway.On the other hand,is is found that the results for the scenariosdevelopedindicatethat thereservation system can improve the traffic conditionsand offer lower traveltimesfor itsusers.8.Realistic results are obtained for both the reference and scenario scenarios in terms of travel times and parking options, as shown in Table 1. It appears that even the case of unfamiliar users (who were shown to have an increased journey time) is plausible, given the implementation's absence of parking-related indicators. Average journey durations (both total and individual-based) improved by a rather little amount, which is predicted given the size of many ITS applications.

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