Traveler Response to Information

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Preface

This thesis is the product of four and a half years of study. Years that I have thoroughly enjoyed: research is fun! And even more so, team research is fun. Various interactions with a number of fellow scholars have made the journey towards a PhD more stimulating than it could have possibly been, had I done the work in solitude. Please note, when going through this thesis, that these colleagues appear as co-authors of the various papers that form the Chapters of this book.

The majority of the research presented here is done at Delft University of Technology, Section of Transport Policy and Logistics' Organization. This research group is quite a special one. Its members combine an academic attitude with a remarkable interest in things 'other than academic'. This combination for me resulted in a very nice working environment. I would like to mention two colleagues in particular. Firstly, Eric Molin, my daily supervisor and the originator of the PITA-program that has fostered this PhD-research, has been a stimulating and very thorough sparring partner at various stages of this research. Besides that, he is also a great hiking partner, from the streets of Washington DC to the forrests of Oregon and Belgium. Secondly, Bert van Wee, my promotor, has been a continuous motivator from the moment he started supervising my PhD-research. I have greatly appreciated his 'can do' mentality, his quick mind, and his interest in my work and whereabouts. The fact that our research interests have from the start differed to some extent has never resulted in a lack of attention – on the contrary, Bert has repeatedly helped me find *my* way towards a successful completion of this PhD-journey.

One of the choices made in this regard has been the decision to visit Eindhoven University of Technology for one day a week, starting in the second year of my PhD-research. I immediately felt welcome in TUE's Urban Planning Group. In fact, being there became such a pleasure that, since last September, I work in Eindhoven on a full-time basis. Also within this group, two colleagues deserve some special attention here. Theo Arentze, my second daily supervisor, and Harry Timmermans, my second promotor, have both been an

inspiration. It is fair to say that some of the crucial ideas presented in this thesis have originated from discussions with them. Theo's creative conceptual thoughts on human behavior, and Harry's methodological rigor, have substantially helped shaping and refining my own ideas on traveler behavior modeling. I look forward very much to continue working with them and my other new colleagues!

Although Eindhoven is already slightly abroad for *Hollanders* like myself, my research interests have brought me a bit further as well: MIT's Intelligent Transportation Systems lab has provided a very fertile research environment during a four-month visit in Fall 2005. I have much enjoyed the hospitality of the Department of Civil and Environmental Engineering at large, and the ITS-lab members in specific. Furthermore, Boston is just a fantastic place to spend your Indian Summer! Two American scholars have been instrumental for me and my research during this period abroad. Joan Walker is not only a very nice person to interact with, she also has a superb knowledge of discrete choice-modeling. Moshe Ben-Akiva, head of the ITS-lab, has been crucial in enhancing my insight into the microeconometrics of traveler behavior. His classes at MIT and the numerous discussions with him and Joan were a treat.

Finally, I would like to acknowledge the members of the secretarial offices of the research groups I worked in or visited. At various crucial stages of this PhD-research, either in Delft, Eindhoven or Boston, I've benefited greatly from their help and support. Thank you!

Caspar Chorus

Eindhoven, January 2007

Content

Chapter 1: Introduction

1.1 Background and problem statements

Travel information has been with us for thousands of years, be it in the form of - to name a few - verbal communications between individuals, maps, or more recently transit time tables. These rather low-tech forms of travel information predominantly served to help people find their way as they traveled towards their destination. Since the late 1980s, technological advances in the gathering and synthesizing of transportation data and the presentation of information to travelers started to trigger visions of increasing capabilities of travel information services, along with an increasingly important role for such services in traveler decision making (e.g. Boyce, 1988; Arnott et al., 1991; Ben-Akiva et al., 1991; Mahmassani & Jayakrishnan, 1991; Polak & Jones, 1993). These visions gradually led to the introduction of the acronym ATIS for Advanced Traveler Information Services (e.g. Khattak et al., 1993a; Schofer et al., 1993; Adler & McNally, 1994). ATIS started out as systems that, based on observations of the current situation in the transport network in combination with historic data, provided car-drivers with travel time estimates, advice or route guidance, and transit-riders with up-to-date messages on delays of trains or buses. The information was provided to travelers through radio, variable message signs, telephone services and, starting in the mid-1990s, internet-sites. Over the years, these ATIS have become increasingly capable of providing travelers with reliable and relevant information, in times when the negative externalities of passenger transport, in terms of e.g. congestion, inaccessibility of urban areas, safety issues, utilization of fossil resources and environmental pollution, have become increasingly relevant.

These two factors in combination (increasing ATIS capabilities and increasing passenger transport externalities) generated substantial interest among transportation academics regarding traveler response to information, or the behavioral aspects of travel information.

This interest mainly concerned one of two lines of thought: firstly, there is a *marketing* point of view (e.g. Abdel-Aty et al., 1996, 2001; Polydoropoulou et al., 1997; Khattak et al., 2003; Molin & Timmermans, 2006) which is predominantly concerned with the potential of ATIS as a business case, either stand alone or as part of an effort to gain or retain customers for some transportation service, e.g. urban transit. A second and more dominant line of thought focused on ATIS as a potential tool for Travel Demand Management (TDM). This TDM or *transport policy* point of view[1] (e.g. van Berkum & van der Mede, 1991; Adler & McNally, 1994; Emmerink et al., 1995, 1996; Hato et al., 1999; Kenyon & Lyons, 2003; Jou et al., 2005) investigates the high expectations of travel information provision as a means to change traveler behavior in ways that are deemed beneficial to the transport system. Examples of such behavioral changes are a modal shift from car to transit and a more efficient use of the available road capacity due to route and departure time choice adaptations. At many levels of government, expectations concerning the potential of ATIS to help reach important transport policy-aims grew over the years, and remains high until today (e.g. Commission of the European Communities, 2001; Ministry of Transport, Public Works and Water Management, 2002; Federal Transit Administration, 2003; Department for Transport, 2004).

This interest in the behavioral aspects of travel information was fuelled further by a second wave of technological developments, in particular the increasing deployment of Geographic Information Systems (GIS) and the introduction and rapid market penetration of mobile telecommunication devices such as cell phones; together, these developments boosted the development of ATIS towards what some have called Intelligent Travel Information Services (Adler & Blue, 1998). These travel information services are generally envisaged to be able to provide a traveler at anytime, asked for and unasked for, with all the travel information that is relevant to her given her time and place in the multimodal transport network and her personal characteristics. Although currently, no existing travel information service truly meets these expectations, it seems plausible to assume that within five or at most ten years from now, these types of ATIS will have been successfully implemented. In the meantime, the currently available ATIS are getting increasingly more advanced. Driven by these recent advances in ATIS-functionality, as well as by ever increasing concerns with the externalities associated with transport, the interest in the potential of ATIS as a business case or as a means to change traveler behavior has steadily increased among transport academics, transportation and telecommunication companies and transport policy-makers. The cumulative result of this interest over the past 15 to 20 years is an abundant research body concerning travelers' response to information, providing a wide variety of valuable insights into the (potential) role of travel information in travel choice making.

However, in the author's opinion, the current state of the art in literature concerning traveler response to information suffers from two major drawbacks: firstly, research efforts have generally been very specific. Most research papers on the topic have been concerned with a particular type of information (service), a particular travel mode and a particular travel context and situation. For example, the majority of studies consider the effect of travel time information on car-drivers' in-trip adaptation of route-choices. Notwithstanding the obvious value of such studies, they fail to provide generic, integrative knowledge concerning the potential response to information among travelers. Secondly, a great majority of the research efforts into the behavioral aspects of travel information, especially the empirical ones, have focused on the manifest determinants of the response to travel information (such as trip purpose and socio-demographic variables) and easily interpretable functional forms (such as a linear relationship between on the one hand explanatory variables and on the other hand the

[1] Note that the distinction between *marketing* and *policy* is somewhat artificial: from a policy point of view, it might be considered that marketing ATIS or transit is part of the solution to traffic externalities.

utility of a particular response to information). Although such an approach is understandable as it may substantially reduce the complexity of analysis, it does not provide insights into the true behavioral mechanisms underlying traveler response to information (such as involving the dynamics of and interplay between decision styles, knowledge levels and perceptions of information reliability). Related to this, few advances have yet been made in the formal behavioral description of traveler decision making in the presence of knowledge limitations and information provision.

It is the author's opinion that this lack of an integrative, formal behavioral research perspective limits our longer term capability to reap the benefits of the ongoing technological advances described above. The following scientific problem statement can be derived from this argument, and provides the main underpinning of the research effort presented in the remainder of this thesis:

Due to the lack of an integrative, behavioral perspective, past work into traveler response to information suffers from a rapid decay of relevance and applicability, given the ongoing technological developments in the field of transportation and telecommunication.

Based on this scientific problem statement, a secondary policy-oriented problem statement can be formulated as follows:

The fact that, in the author's opinion, our current understanding of traveler response to information seriously lags behind our understanding of the technological advances that enable the development of ever more capable travel information services, implies the potential hazard of unrealistic expectations concerning the potential of travel information as a transport policy-instrument.

The following Section will proceed from here by deriving from these problem statements the research goals and questions that are addressed in this thesis. Section 1.3 goes through the contents of the thesis, and discusses each Chapter's contribution to the state-of-the-art in research into the behavioral aspects of travel information. Finally, Sections 1.4 and 1.5 describe and discuss the research scope in terms of the content and methodology, respectively, that has been adopted for the research presented here.

1.2 Research goals and research questions

Based on the argument presented above, this thesis predominantly focuses on increasing our understanding of the behavioral aspects of travel information, and on developing a behavioral perspective, in order to help prepare for the emerging and ongoing technological revolution towards highly sophisticated ATIS. The primary and most important research goal of this thesis can be stated as follows:

This thesis foremost aims to develop an integrative behavioral perspective on traveler response to information, and to use this perspective to derive integrative, generic and hence durable behavioral insights with respect to the role of travel information within traveler decision making in multimodal networks under conditions of incomplete knowledge.

Furthermore, this thesis will try to put into practice the most important of the behavioral insights to be derived. A secondary research goal can be stated as follows:

This thesis also aims to apply the derived behavioral insights in order to help enable the formulation of realistic expectations among transport policy-makers concerning the potential of travel information related policies.

Resulting from these research goals, the following first research question can be derived with respect to our primary research goal:

What are the behavioral determinants of the response to travel information among travelers that face incomplete knowledge in multimodal networks, and how can we coherently describe and analyze the mutual relations between these determinants?

The following second research question can be derived with respect to our secondary research goal:

What potential effects might be expected from travel information related transport policies?

1.3 Defining the scope of research: content

Clearly, the title “Traveler Response to Information” covers a potentially enormous research field. In order to make the research effort focused and feasible, the adopted scope of research content is specified along four dimensions, which are described here.

Firstly, it should be acknowledged that a very wide variety of types of travel information is currently available, or will be made available in the near future. In the different Chapters of this thesis, a variety of types of information and services will be discussed. Generally, the reader will see that whenever possible (e.g. in the developed theoretical frameworks) an abstract notion of *information* is adopted, in favor of investigating the use and effect of some particular *information service*. This abstract approach fits with the aim of deriving generic insights, rather than insights concerning the use and effects of specific information services. Throughout this thesis, we distinguish between two types of information that have been given special attention here: travel information for alternative generation (i.e. asking the service to provide formerly unknown alternatives) and alternative assessment (i.e. asking the service to provide estimates for the attributes of known alternatives). Secondly, it is obvious that longer term learning effects may play an important role in traveler response to information (e.g. van Berkum & van der Mede, 1991; Avineri & Prashker, 2003; Sun et al., 2005); individuals that repeatedly use particular travel alternatives and information services may learn over time, for example, about the transport network’s performance under different travel circumstances and the information service’s reliability. This study however, has adopted the time-horizon of one trip, instead of multiple trips. As such, the work presented here may be considered a building block for longer term learning oriented research. Thirdly, in this research the focus is predominantly on travelers’ choices for modes and routes. Cancellation and rescheduling of activities, choices for destination and departure time are not considered explicitly here, although most of the ideas and results that are presented here may prove helpful for the analysis of these and of other choice-dimensions. Fourthly and finally, as is increasingly acknowledged, it is useful to consider that traveler decision-making is dependent on the group (household or social network) within which the traveler functions (e.g. Zhang et al., 2005, Dugundji & Walker, 2005). Many types of group dependencies are currently being investigated in the traveler behavior research field, both theoretically and empirically.

Although the author feels that this interest in group decision-making is very much justified, it is also felt that for the role of travel information in group decision-making to be properly understood, a firm understanding is needed first at the individual level, which is the focus of this thesis.

1.4 Defining the scope of research: methodology

Reflecting that in traveler behavior research methodological standpoints are more often, and more heavily, debated among researchers than are research scopes in terms of contents, this Section on the methodological scope of the research is relatively detailed and extensive.

1.4.1 Applied research methods

It goes without saying that a wide variety of quantitative and qualitative research methods is potentially applicable and useful for answering the above formulated research questions. Furthermore, focusing on one particular research method will likely prohibit acquisition of the integrative knowledge that is deemed necessary here. That is why the research presented in this thesis has applied a number of research methods, including

- literature reviews;
- building, validation and application of formal behavioral models;
- statistical analyses of web survey and travel simulator data;
- estimation of behavioral models, based on travel simulator data.

In combination, these methods aim to provide a coherent and integrative answer to the formulated research questions. Notwithstanding this rather wide methodological scope, it is acknowledged that the work presented in this thesis has adopted some methodological perspectives, particularly concerning traveler decision making and data collection, in favor of other, also widely used and accepted, viewpoints. As perspectives on traveler decision-making and data-collection have been the topic of extensive debate in recent travel behavior research, we will provide arguments for the perspectives adopted in this thesis in a relatively detailed way. First, often used perspectives on traveler decision making and data-collection will be described briefly, after which it will be made clear which particular perspectives are adopted in this research, and why.

1.4.2 Perspectives on traveler decision making

Although many classifications of perspectives on traveler decision-making are possible, with varying degrees of detail, it can be argued that the following three perspectives together represent the bulk of research efforts in travel behavior modeling[2]:

[2] Note that another important class of traveler decision-making deals with the concept of habitual choice (e.g. Triandis, 1977), asserting that travelers are often found to base their choices for travel modes and routes not so much on a deliberate evaluation of alternatives, but rather on the execution of their habit (e.g. Verplanken, et al., 1997; Gärling, et al., 2001; Gärling & Axhausen, 2003). As information acquisition is found to be extremely limited in habitual choice behaviour (e.g. Aarts, et al., 1997), this thesis predominantly focuses on situations where travelers do make some sort of evaluation before actually choosing an alternative. However, this thesis' literature review Chapters do cover some important studies concerning habitual travel behavior.

a) Firstly, there is the perspective of individuals as (expected) utility-maximizing rational agents, which is termed the *standard model of microeconomics* (e.g. Samuelson, 1947). This perspective has proven to be very suitable for the quantitative analysis of traveler behavior, as is most convincingly demonstrated by the overwhelming success of discrete choice methods for travel demand analyses (e.g. McFadden, 1974; Ben-Akiva & Lerman, 1985; McFadden & Train, 2000; Train, 2003). The former two references mainly refer to the widespread MultiNomial Logit and Nested Logit models; the latter two refer to the Mixed Logit, or Logit Kernel, models which currently form the state-of-the-practice in econometrical travel behavior analyses. Over the last 30 years this microeconomics-based discrete choice perspective is without any doubt dominant in the field of traveler behavior research (e.g. McFadden, 2001). It should be noted that many attempts have recently been made in the travel behavior community to use advances in model estimation techniques and computational power in order to develop more flexible utility-maximization models with the aim of increasing their behavioral realism (e.g. Walker, 2001; Walker & Ben-Akiva, 2002). Parallel to this development, the travel behavior community has become increasingly interested in modeling travel choice under conditions of uncertainty. The bulk of these contributions (e.g. Noland & Small, 1995; Bates et al., 2001; Denant-Boèmont & Petiot, 2003; de Palma & Picard, 2005) is based on the powerful and intuitive generalization of utility theory towards conditions involving uncertainty: Expected Utility Theory (Von Neumann & Morgenstern, 1947).

b) In reaction to the often perceived as rather stringent behavioral assumptions behind the decision-making perspective described above, a class of theories has emerged in economics and psychology that is often grouped together under the name of *behavioral economics* (e.g. Simon, 1982; Kahneman, 2003). This theory asserts that individuals are prone to use simple heuristics or make mistakes when making choices, rather than faultlessly performing complex trade-offs and optimization procedures. Furthermore, they assert that economic models should reflect these so-called bounds to rationality in order to give accurate and meaningful accounts of economic phenomena such as the working of markets and the formation of equilibria[3]. Without the aim of being in any way complete, or drawing a strict line between them, two sub-categories are worth mentioning here in the context of traveler behavior modeling. Firstly, inspired by Herbert Simon's ideas of bounded rationality (Simon, 1955, 1978), a stream of travel behavior studies have adopted the concept of travelers that forego extensive evaluation of the choice situation at hand, and instead apply simplified heuristics in order to reach satisfactory decisions at low decision costs: so-called satisficing behavior (e.g. Foerster, 1978; Mahmassani & Chang, 1987; Lotan, 1995; Jou et al., 2005). Secondly, inspired by scholars such as Allais (1953), Ellsberg (1961) and Kahneman and Tversky (1979), a number of studies have pointed to the fact that individuals, when faced with choice-situations involving uncertainty, easily make 'mistakes' against the premises of Expected Utility Theory, and that notions such as anchoring, framing and probability weighing should be used when modeling their choice behavior. Since traveling is very much about dealing with uncertainty, our community is increasingly adopting such non-expected utility perspectives (e.g. Katsikopoulos et al., 2000, 2002; Avineri & Prashker, 2003; Arentze & Timmermans, 2005a). An interesting sub-class of these non-expected utility models aims to circumvent theoretical and

[3] A field that is very much related to that of behavioral economics is that of behavioral decision theory (e.g. Edwards, 1961; Tversky & Kahneman, 1974; Payne et al., 1993). Although it is impossible (and if it were possible, certainly outside the scope of this thesis) to draw a strict line between these two streams of literature, it might be said here that behavioral economics is rooted in behavioral decision theory, and has expanded its scope by also considering the impact of not fully rational decision makers on the workings of the economy.

empirical violations of the theory of expected utility maximization by framing decisions as the result of the minimization of regret, rather than the maximization of utility (e.g. Loomes and Sugden, 1982, 1983). The notion of regret is conceptualized as the emotion that is experienced when an alternative is chosen that turns out to be surpassed by another alternative that was, or could have been made, available at the time of choice. It is assumed that individuals anticipate the possibility of regret, and aim to minimize regret when choosing from alternatives. The concept of regret, although well known in such areas as behavioral economics, psychology and marketing (e.g. Simonson, 1992; Inman et al., 1997; Zeelenberg, 1999; Crawford et al., 2002; Hart, 2005), remains to the author's knowledge virtually non-existent in the travel behavior research domain. This is somewhat surprising, since many researchers would agree that traveling is perhaps more about the minimization of negative emotions/regret (e.g. avoiding being late, avoiding getting stuck in traffic or missing a bus, minimizing travel times), than the maximization of positive ones/utility.

c) Thirdly, *social psychology*'s attitude theory, and more specifically the Theory of Planned Behavior (Ajzen, 1991), has inspired a number of travel behavior studies (Gärling et al., 1998; Bamberg et al., 2003; Thøgersen, 2006). As Thøgersen (ibid.) states, these studies generally attempt to account for the psychological implications of behavioral constraints (real or imagined); three types of evaluations are distinguished that co-determine choice behavior, being the evaluation of expected outcomes, the assessment of social pressure and the assessment of whether or not the behavior can feasibly be carried out. This type of theory is less wide-spread in travel behavior research than the former two categories, although some interest has always existed.

In addition to less behaviorally oriented statistical analyses, this thesis has adopted several of the above mentioned perspectives on traveler choice behavior: utility maximization models as well as models of satisficing behavior are applied, in combination with the notion of regret-minimalization[4]. The main rationale behind this diversity is the following: in the author's opinion, adopting different decision making perspectives is a useful approach to find an integrative, robust and generic insight into the complex questions surrounding the role of information in traveler choice behavior. In other words, traveler decision making (under conditions of knowledge limitations and information provision), is a too complex and subtle phenomenon to be studied from one and the same perspective. This reasoning may be compared to visual inspection of human beings using both daylight and X-rays: both perspectives shed a different light on a complex subject, and together they provide a more complete picture of what is being inspected.

A second reason for this diversity is more pragmatic: whereas it is felt by the author that the notion of regret serves well for the creation of a coherent *theoretical* perspective on traveler response to knowledge limitations and information provision, its compatibility with *statistical model estimation* lags behind that of the (expected) utility maximization perspective. In an attempt to narrow this gap, this thesis does present, in one of the Epilogues, the development of a microeconometrical formulation of Regret-Theory, which enables the estimation of discrete-choice models in the context of multiattribute decision making and general choice sets. Notwithstanding the successful application of this model on our data, it does become clear that the developed framework is less suited for the estimation of choice models involving large choice sets, due to combinatorial explosion. This was expected to become

[4] Note that the *Theory of Planned Behavior* has not been adopted in this research as it was felt that it provided fewer possibilities to study in a structural way the role of information in decision making, in theory and empirically.

problematic in relation to the estimation of full-fledged behavioral models of traveler response to information, based on the travel simulator data collected for that aim. As a result, the notion of expected utility, rather than expected regret, has been adopted for the estimation of these more complex behavioral models.

1.4.3 Perspectives on data-collection

When considering the issue of data for travel behavior analysis, and in particular the analysis of travelers' choices for travel alternatives and/or information acquisition, it can be argued that there are three categories of data-types that together represent the bulk of the theoretical and empirical research efforts in this field[5]:

a) The first type of data is not collected, but rather *simulated*. One or more hypothetical travelers are simulated that have certain personality traits, such as preferences, decision styles, knowledge levels. By simulating the behavior of one or more of the created individuals, insights can be gained into the working of behavioral models at the individual level (e.g. Arentze & Timmermans, 2005b), or their implications at a network level (e.g. Levinson, 2003). Especially in the case of more complex behavioral models, numerical examples based on simulation are often deemed necessary to illustrate the workings and implications of these models and their underlying behavioral assumptions, provide face validity to them, or avenues for improvement. Due to the limited costs and high flexibility associated with creating, or simulating, data its use has been quite popular throughout the years, especially as a first step towards empirical model validation and estimation (e.g. Mahmassani & Jayakrishnan, 1991; Jha et al., 1998; Ettema et al., 2005).

b) The second category of data, often referred to as *Stated Preference (SP) data*, presents participants with hypothetical alternatives, and asks them to indicate which of the available alternatives they would choose in real life, or asks them to state their needs, willingness to pay for, or preferences for the alternatives. These experiments have varying levels of sophistication, ranging from paper-and-pencil SP-surveys (e.g. Jackson & Jucker, 1981; Polak & Jones, 1993, 1997; Khattak et al., 1993b; Wardman et al., 1997), to fully interactive computerized experiments in travel simulators (e.g. Chen & Mahmassani, 1993; Adler & McNally, 1994; Koutsopoulos et al., 1994; Bonsall & Palmer, 2004). The advantage of SP-methods for data-collection again lies in their low-cost, flexible and efficient nature; for example, it is possible, by carefully designing choice tasks, to control experimental conditions in such a way that variations in choices or preferences can be efficiently attributed to each of the explanatory variables being studied. Furthermore, the SP-approach enables the evaluation of the demand for products and services that are not yet available in the market at the time of the investigation. The most notable disadvantage of this method is its limited external validity: the analyst can simply never be sure that the observed hypothetical behavior resembles the behavior in real life travel situations. It is generally felt however, that the ongoing advances in making simulator environments more realistic travel choice environments, increase the external validity of the collected data.

[5] Recently, a fourth category of data-collection, applying techniques from experimental economics, has been introduced into the field of traveler behavior research and, although still very small, is worth mentioning here (Denant-Boèmont & Petiot, 2003). This approach involves rewarding individuals financially for 'good' choices, e.g. travel alternatives that turn out to have low travel times. Although the field of experimental economics itself is widely established, the application of experimental economical techniques in the field of traveler behavior research has been very limited until now, but is perhaps emerging.

c) The third category, *Revealed Preference (RP) data*, analyzes choices that are actually made, or behavior that is actually performed, by travelers in the real world; the data is mostly collected by asking travelers to report about the last trip made, or the travel information service most recently used. RP-data has a high external validity and is a widely used approach in economics in general, and travel behavior research in specific (e.g. Emmerink et al., 1996; Polydoropoulou & Ben-Akiva, 1998; Hato et al., 1999; Lam & Small, 2001; Chatterjee & McDonald, 2004). The two most notable disadvantages to the use of RP-data, when compared to SP-studies, are the following: firstly, as the level of experimental control is low, RP-data often suffers from little variation in, and collinearity among, explanatory factors; many observations are needed in order to obtain meaningful parameter estimates. Secondly, and this is of central importance to the study presented here, RP-data is simply unavailable concerning the use of transportation and information services that are not yet available to travelers in real life.

The study presented in this thesis makes use of all three categories of data, although our use of data on revealed choices is very limited. Firstly, numerical examples based on simulated travelers are used to study and illustrate, at the individual rather than at the network level, the workings of the developed formal models with respect to travel information acquisition and effect, and provide face validity to them. Also, simulation-based examples are used in order to derive policy implications concerning the potential of travel information as a transport-policy instrument in a mode-choice context. Secondly, a web survey is conducted, which focuses largely on testing hypotheses concerning the determinants of travelers' stated needs for travel information services. Following this, responses from the same web survey, but then to questions concerning revealed behavior, are used in order to validate SP data obtained from a developed multimodal travel simulator: it is investigated how SP-choices from the simulator correspond to participants' reported actual use of travel modes and travel information services. Finally, three empirical research efforts reported in this thesis are integrally based on the SP-data gathered in the simulator. Together, a fair coverage of possible data-collection methods is obtained, although it is felt that future research should try to obtain RP-data on travelers' use of highly functional ATIS-prototypes, as such RP-data has an unparalleled external validity.

1.5 Outline and contributions of this thesis

Before going through the Chapters that make up this thesis, it should first be noted here that most Chapters consists of a paper that has been published, is forthcoming, or has been submitted for publication in a scientific peer-reviewed journal or book. Intrinsically, this format leads to considerable overlap between some of the Chapters, especially regarding parts of their introductions and the description of data-collection efforts, although every attempt has been made to write each paper in such a way that enables the transition from one Chapter to another to be as smooth as possible. The reader is asked to also bear with the discrepancies in terms of terminology, notation and reference style in forthcoming Chapters. These reflect the preferences of the journals in which they have been or will be published, or have been submitted to. Spelling has been adjusted where necessary to US English. Reference style is made consistent throughout the thesis, as is heading-style. Footnotes and Sections are numbered throughout the thesis as a whole; Figures, Tables and Equations are numbered per Chapter.

The remainder of this thesis is split into three Parts: Part I, containing Chapters 2-6 and focusing on behavioral determinants of response to information; Part II, containing Chapters

7-9 and focusing on information provision as a transport policy instrument; and Part III, containing Chapters 10-12 and reflecting on the research done in Part I and II respectively. It should be noted here that the dominant perspective of this thesis, as formulated above, is a behavioral one: the policy-related Chapters (Part II) are therefore also rather behaviorally oriented. This is partly due to the author's background and interests, although another reason for this is that it is currently felt that an integrative behavioral insight is especially needed in the research field, also as a potential underpinning of transport policy. In other words, it is felt that at this stage an integrative behavioral insight into the determinants of traveler response to information is conditional to the formulation of realistic expectations concerning travel information-related transport policies. The outline of this thesis can be best understood, as is indicated visually in Figure 1, as an attempt to answer research question 1 (concerning the behavioral determinants of travel information use and effects), and research question 2 (concerning the potential role of travel information provision in transport policy), using a variety of research methods. Figure 1's columns represent the two research questions to be answered; its rows represent the applied research methods. The arrows imply a chronological order, not necessarily an input-output causation.

Part I: Behavioral determinants of response to travel information

Chapter 2 provides a literature review of past research efforts that are relevant for the study of the behavioral determinants of traveler response to information. It identifies, based on reviewed work on traveler decision making, how the acquisition of travel information is a function of the traveler's decision process. Subsequently, a conceptual framework is provided to explain the behavioral determinants of travel information use. Empirical insights concerning the determinants of travel information acquisition are then discussed in the light of this framework. The Chapter proceeds by discussing how travel information may influence a traveler's awareness of travel alternatives and her perception of their attributes; past work on this topic is reviewed and a conceptual framework of the iterative nature of the use and effects of travel information is derived. A number of knowledge gaps in the research field are identified.

Chapter 3 proceeds by formulating a formal mathematical model of the value of travel information for traveler decision making. Integrating notions of search theory and Bayesian perception updating into a regret-based framework of decision making under incomplete knowledge, it provides a representation of information value for so-called *maximizers* and *satisficers*. The model is geared towards understanding the use and effects of travel information for alternative generation (i.e. asking a service to provide formerly unknown alternatives) and alternative assessment (i.e. asking a service to provide estimates for the attributes of known alternatives). Numerical examples are presented that provide face validity to the models, as found relations between traveler knowledge levels and information reliability on the one hand, and information value on the other, are in line with intuition as well as empirical insights from the field of traveler response to information.

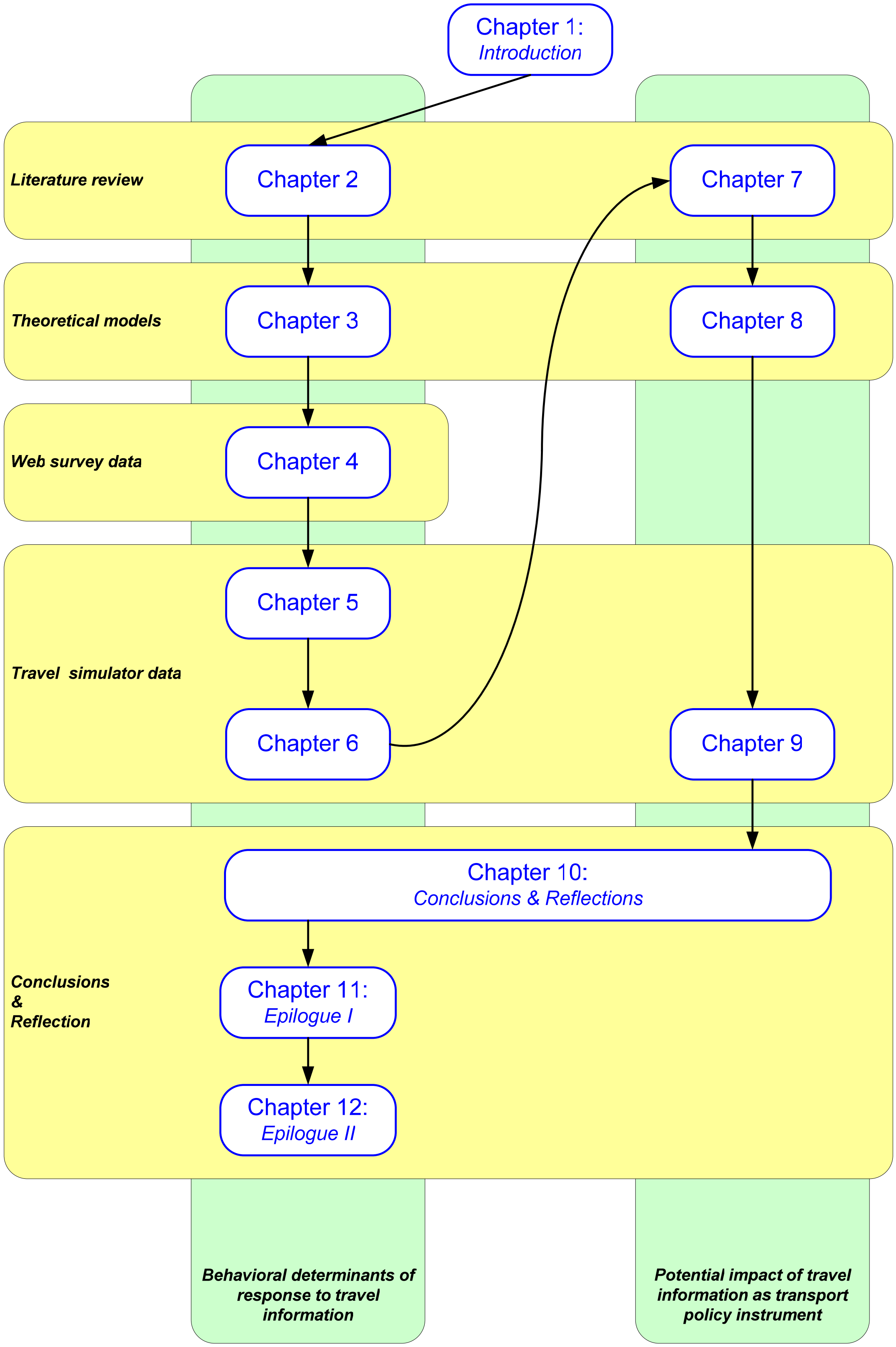

Figure 1: Overview of this thesis

Chapter 4 presents the statistical analysis of empirical data obtained through a web-survey. The survey focused on the behavioral determinants of travel information use among car-drivers and transit-users. More specifically, how travelers' knowledge levels play a mediating role between on the one hand manifest factors such as destination type and trip circumstances and on the other hand travelers' need for travel information is investigated. Subsequently, what kind of information is needed among travelers is identified, and in particular whether travelers exhibit a need for those types of information that are currently being developed and are likely to be implemented in the near future (e.g. personalized multimodal information), relative to more basic and widely available types of travel information. Differences in the determinants of knowledge levels and information needs between car-drivers and transit-users are highlighted and explained.

Chapter 5 presents a multimodal travel simulator with information provision[6]. The simulator is designed to empirically study traveler decision making in multimodal travel networks under conditions of limited knowledge and the provision of a variety of advanced types of travel information. Subsequently, an experiment is described where participants made trips in this simulator environment. Since the developed simulator's functionality differs from existing ones, especially in terms of the variety of travel information-types that is made available to participants, a validation effort is performed in order to investigate whether the obtained data forms a valid representation of travelers' behavior under similar conditions in real life. This validation effort is partly based on a statistical analysis of the observed information acquisition and travel choices, and partly on a comparison of the observed choices with revealed travel behavior as reported by the same participants in a web survey (the one described in Chapter 4).

Chapter 6 presents an expect-utility, discrete-choice based model of traveler response to information. It differs from existing approaches in three ways: firstly, instead of focusing on either the acquisition of information or the effect of received information on travel choices, this model describes the full sequence of possibly multiple information acquisitions, followed by a travel choice. Secondly, instead of modeling the utility of information acquisition in an ad-hoc fashion (e.g. as a linear function of attributes of the information service and the trip context), the utility of information acquisition is conceived in terms of the anticipated utility of the travel choice set after having received the information. Thirdly, instead of focusing on a specific type of knowledge limitation and a specific type of information, the response to a variety of information types is described, resulting from a variety of knowledge limitations. This model of travel information response is then estimated on data collected in the multimodal travel simulator-experiment with travel information provision (presented in Chapter 5). Estimation results provide face validity to the proposed modeling approach, and a number of new insights are gained with respect to the role of travel information in multimodal travel choice making.

Part II: Travel information provision as a transport policy instrument

Chapter 7 identifies, based on a review of literature, the potential effect that provided travel information might have on travelers' choices for traveler alternatives. In particular, how travel

[6] Note that Chapter 5, dealing with the development and validation of a travel simulator environment, in fact neither specifically focuses on behavioral dynamics nor policy-issues. It is grouped in Part I since the first Chapter that will apply the dataset collected through the simulator environment is Part I's Chapter 6.

information provision may help change travelers' behavior in ways that are beneficial to the performance of the transport network (e.g. in terms of congestion relief) is discussed. The role of travelers' preferences for travel alternatives and their attributes, their knowledge levels and perceptions of information quality, and the role of choice adaptation costs and information acquisition costs is identified through inspection of the abundant body of empirical literature on these topics.

Chapter 8 applies one of the formal regret-based models presented in Chapter 3, in order to study the potential effect of transit travel time information provision on the mode-choices of travelers that have an intrinsic preference to use their private car. Using numerical examples, the model is subsequently applied to identify and illustrate the existence of several barriers that may prohibit travel information acquisition among the considered group of travelers, as well as behavioral adaptation towards transit as a result of received information. Policy implications are derived from the obtained simulation results.

Chapter 9 statistically tests the validity of the often held expectation that the acquisition of travel information actually helps travelers make better choices. In order to do so, a measure of travel choice quality is proposed around the notion that a traveler's choice for an alternative (e.g. a mode-route combination), made under incomplete knowledge, is of a high quality if the traveler, given complete knowledge, would choose the same alternative. This conceptualization enables a choice theory-based assessment of choice quality along multiple attribute dimensions of travel alternatives. Using data from a Stated Choice experiment under conditions of complete knowledge and observed choices (made by the same individuals) from the travel simulator experiment, a Structural Equation Model is estimated, which identifies the effect of information on the quality of travel choices.

Part III: Conclusions & Reflection

Chapter 10 draws conclusions on the behavioral determinants of traveler response to information and their mutual relations. Subsequently, conclusions are drawn with respect to the potential impact of travel information as a transport policy instrument, and with respect to methodological issues.

Chapter 11, the first Epilogue, describes how Regret-Theory (RT) may be translated into an operational discrete choice model for multiattribute decision making within general choice sets. An RT-based model is developed as an alternative to mainstream random utility models, and subsequently applied on the data collected in the travel simulator experiment. Estimation results provide validity to the model, although it becomes clear that models developed within the well established Expected Utility paradigm are better suited for the study of choice from large choice sets.

Chapter 12, the second Epilogue, provides an account of promising research avenues in the field of traveler decision making under conditions of knowledge limitations and information provision. Substantive and methodological research agendas are presented.

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Chapter 2

Chorus, C.G., Molin, E.J.E., van Wee, G.P., 2006. Use and effects of Advanced Traveller Information Services (ATIS): a review of the literature. *Transport Reviews,* 26(2), pp. 127-149.

Abstract

Rapid technological developments in the field of personal communication services probe visions of a next generation in Advanced Traveler Information Services (ATIS). These technological developments provoke a renewed interest in the use and effect of such next generation ATIS among academia as well as practitioners. In order to better understand the potential use and effects of such next-generation ATIS, a thorough review is warranted of contemporary conceptual ideas and empirical findings on the use of travel information (services) and their effects on travelers' choices. This paper presents such a review and integrates behavioural determinants such as the role of decision strategies with manifest determinants such as trip contexts and socio-economic variables into a coherent framework of information acquisition and its effect on travelers' perceptions.

2.1 Introduction

Providing travelers with relevant information on travel options is generally acknowledged as having the potential to change their behaviour in ways that are beneficial to the efficiency of the use of the transport system (e.g. Koppelman & Pas, 1980; Kanninen, 1996). Services providing such information (ATIS) are widely available nowadays for travelers, and are becoming more advanced every year. Recently, rapid technological developments in mobile communications have provided a vision among telecommunication companies, transport agencies, governments and academia of a technological revolution in ATIS towards what can be called the next generation ATIS (e.g. Adler & Blue, 1998; TRAIL Research School, 2002). Such ATIS are envisaged to be able to provide at anytime a traveler with all the travel information, asked for and unasked for, that is relevant given her time and place in the multimodal transport network and her personal characteristics. Currently, policy makers in many western countries have high expectations of the potential effects of such information services on, for example, network efficiency (e.g. Commission of the European Communities, 2001a, b; Ministry of Transport, Public Works and Water Management, 2002; Transportation Research Board, 2004). These expectations provide an interesting momentum for research and development efforts aimed at designing this next-generation in ATIS as well as policy initiatives that aim at optimal use and effects of such ATIS.

This momentum provides opportunities for many players in the field of personal mobility and information provision. Firstly, public transport companies may consider the provision of next-generation ATIS as a means to retain or attract customers. A comparable argumentation goes for the automotive industry, where built-in information services become more and more common. Secondly, providers of personal telecommunication services in general or travel information in particular may find the development and implementation of next-generation ATIS an interesting business case, depending on the traveler's willingness to pay for these services. Thirdly, policy makers that in some way wish to induce changes in travelers' choices for departure times, routes and travel modes may hope that the introduction of next-generation ATIS will, more than current ATIS, cause such adaptations to occur. Finally, as academia has been greatly interested in the role of travel information and services in traveler decision making, it is expected that this interest will most certainly apply for next generation in travel information services. Central to all these perspectives, two categories of questions arise: What will be the level of use of next-generation ATIS? And what will be the effect of information provided through next-generation ATIS, once used, on a traveler's choices?

Although next-generation ATIS' functionality reaches beyond that of most currently available ATIS, a conscious interpretation of the abundant body of literature concerning ATIS use and effects that has been established over the last decade-and-a-half may provide an important first step in the understanding of its potential usage and effect. This body of literature takes the form of either empirical results, such as notable contributions by Polak & Jones (1993), Emmerink et al. (1996), Khattak et al. (1996), Polydoropoulou & Ben-Akiva (1998), Hato et al. (1999) and Denant-Boemont & Petiot (2003) or conceptual frameworks such as the ones presented in Bovy & Stern (1990), Ben-Akiva et al. (1991), Schofer et al. (1993), Walker & Ben-Akiva (1996) and Kenyon & Lyons (2003). Where the empirical work mostly focuses on the study of the use and effects of current information services given all sorts of manifest determinants such as trip purpose and socio-economic characteristics, the conceptual contributions predominantly take a rather behavioural perspective, identifying the role of latent determinants such as decision-styles and knowledge levels in the process of information use and effects. On the threshold of an area in which a new generation of travel information services is introduced, a review of academia's recent empirical and conceptual contributions to our understanding of travelers' decision-making in the presence of information is warranted, in order to learn lessons concerning the potential of future ATIS.

This paper presents such a review of both empirical and conceptual literature concerning the use and effects of travel information. It contributes to literature by integrating the conceptual and empirical findings of more than 15 years of research regarding ATIS use and effects and summarizing these in coherent frameworks that appear to be consistent with several dominant theories on traveler behaviour. Designers of next-generation ATIS as well as transport policy makers might apply some of these findings in order to derive technical or functional requirements of optimal services or to help them estimate the potential levels of use and effects of services that are being developed. Note, however, that this paper itself does not aim at presenting a state of the practice regarding technical development and implementation of next-generation ATIS and their prototypes, or at deriving implications for the design of ATIS or related transport policy: rather, a behavioural focus is adopted that aims at identifying important determinants of the levels of use and effects of next-generation ATIS in general.

Although throughout most of this paper the general term of travel choices has been applied, the focus is on literature regarding an important sub-group of travel choices: departure time-, route- and mode-choice. It is expected that, as well as these choices, next-generation ATIS might also have an impact on a traveler's destination choices and activity patterns, and that the framework developed here might assist in understanding those impacts. Furthermore, it should be noted that this paper has been concerned with day-to-day pre and in-trip information use and effects. The acquisition of next-generation ATIS as a device or service, however, would also be an interesting subject of research. Finally, it should be mentioned that the short-term, or direct effect of next-generation ATIS on a traveler's behaviour, is studied here. Through primary learning there may also be an indirect effect that may in the long term influence next-generation ATIS' use and effects. Such effects may be analyzed using extensions of the framework presented here.

The paper is organized as follows: Section 2.2 reviews theoretical and empirical literature concerning *information acquisition* among travelers and integrates them into a conceptual framework. Section 2.3 reviews studies concerning travelers' perception-updating as a direct *effect of travel information* and presents a framework that depicts travel information acquisition and effects as an iterative process. Section 2.4 draws conclusions and points towards further research efforts needed in order to more fully understand travel choice-making in the presence of next generation ATIS.

2.2 Information acquisition

We will focus here on predecisional acquisition of travel information, defined here as information acquisition that is performed before a travel choice is made, with the purpose of supporting the making of this travel choice. It is this type of information acquisition that is of most interest to policy makers, as the expected impact of acquired information for the purpose of making travel decisions is likely to be higher than that of information acquired for other purposes, such as post-decision information use: a traveler, after having decided to travel by train, may still need information in order to find out the exact time, and on what platform to board this train. Note that predecisional as such does not necessarily imply pre-trip. We will also distinguish here between active information acquisition (information search) and passive information acquisition (use of information provided). This way, two combinations of these forms of information acquisition may be identified: firstly, a traveler may first decide to search for information (active acquisition). After he has found it, he must subsequently decide whether or not to use the information he provided himself with (passive acquisition). Secondly, an information service may provide a traveler with information unasked for. A traveler must then only decide whether to use the information he is provided with (passive acquisition). Predecisional information acquisition can either aim at the generation of alternatives, i.e. adding alternatives to the traveler's choice set, or at assessing the alternatives that are already in her choice set. Understanding an individual's predecisional information acquisition therefore follows from understanding the strategy she uses to generate and assess alternatives: we will call this her decision strategy. Arguing the other way around, the decision strategy an individual has adopted is often manifested through her search for and use of available information. Note that the term decision strategy is used here with a somewhat different meaning than decision-making. The latter refers to the entire process that the individual follows when choosing between alternatives, while the former refers to the assumed goal of this process and the amount of effort that the individual puts into trying to achieve this goal. It is clear that, when discussing the acquisition of travel information, this must be done in the light of dominant theories of traveler decision strategies. We will therefore commence this Section by presenting an overview of theories that have proven to be useful and important in current travel demand literature (for a more extensive overview, see Gärling et al., 1998, Svenson, 1998 or Stern & Richardson, 2005), and by discussing the role of information acquisition in each one of them. Subsequently, empirical findings concerning actual information acquisition among travelers are presented and discussed. Together, this leads to the formation of a behavioural framework of travel information acquisition.

2.2.1 Dominant theories on travelers' decision strategies and information use

Maximization

The dominant perspective on travelers' decision strategies is that of microeconomic consumer theory (e.g. Samuelson, 1947). The individual is assumed to be an instrumentally rational agent that performs an exhaustive assessment of alternatives, exploring each alternative's relevant attributes and trading off the utilities derived from them. The decision strategy serves to generate a choice from a choice set for the alternative that provides the individual with a maximum pay-off. When choices are made under uncertainty, this pay-off is mostly defined though the concept of maximum expected utility (Von Neumann & Morgenstern, 1947), although other preference measures are also applicable. This view is often extended by including so-called transaction costs (Coase, 1937; 1960), representing the often intangible costs of decision-making and information acquisition preceding the actual moment of choice. Today practically every study on travel demand that does not explicitly adopt another perspective on decision-making, implicitly adopts principles of utility maximization. Note that this utility maximization framework only deals with the assessment of already available or specified alternatives and not with alternative generation. Often, it is simply assumed that the decision-maker knows all the alternatives he can choose from. Microeconomic search theory, however, applies the principles of utility maximization to the situation where an individual performs a sequential search for alternatives as well as an assessment of the alternatives generated, and can provide us with insights regarding this alternative generation process (e.g. Weibull, 1978; Richardson, 1982). In such a sequential search process, apart from transaction costs, the cost of rejecting the most recently searched-for alternative can also be included. Such costs may be traded off against the expected utility to be derived from the next found alternative. The alternatives found are mostly assumed to be subsequently assessed following the principles of utility maximization. Several notions of microeconomic search theory can be found in travel demand studies. For examples see Williams & Ortuzar (1982), Richardson (1982), Lerman & Mahmassani (1985), Swait & Ben-Akiva (1987), Polak &

Jones (1993), Ben-Akiva & Boccara (1995), Arentze & Timmermans (2005a, b). There is one important difference between the application of utility maximization principles for alternative assessment and for alternative generation: utility maximization for alternative assessment deals with choosing from alternatives, while its application on alternative generation in addition to this also deals with choosing from decision strategies (should one proceed or stop searching?). Choosing a search strategy by applying utility maximization principles, the individual may well end up with an alternative having sub-optimal utility because the costs of searching are also taken into account in his decision strategy. Utility maximization principles are thus applied at different levels.

Although the application of principles of utility maximization has provided many valuable contributions to the research on individual choice (e.g. McFadden, 1974), as well as travel choice (e.g. Ben-Akiva & Lerman, 1985), researchers in general agree that its assumption of trade-off and maximization behaviour may form a less realistic representation of the actual behavioural process the individual performs (e.g. Edwards, 1954, Simon, 1955, 1978a, 1978b; Kahneman & Tversky, 1979, 1992; Hargreaves Heap et al., 1992; McFadden, 1999). This agreement is shared with many researchers of travel demand (e.g. de Palma, 1998; Gärling & Young, 2001).

Satisficing

A dominant critique on the validity of utility maximization principles as a base for individual decision-making was formulated by Herbert Simon, introducing the perspective of bounded rationality (Simon, 1955, 1978a, 1978b). According to Simon, human beings cannot be assumed to have either the wish or the capability to perform extensive search processes and thoroughly assess the alternatives found. A perspective on decision strategies that does not make such strict assumptions is that of satisficing behaviour (Simon, 1955); the individual is assumed to be searching for the first alternative that is good enough, i.e. he has certain aspiration levels for relevant attributes of alternatives – these levels may change over time - and searches for an alternative that meets these standards (Olander, 1973). Bounded rationality is often called procedural rationality, representing the idea that most decision-making is performed using simple 'rules of thumb' (e.g. Hey 1982, Johnson & Raab, 2003). An essential consequence of this perspective is that choice between alternatives, and with this choice also the generation and assessment of alternatives, are generally not driven by a determination of the agent to use information in order to maximize some form of pay-off. Instead, a predecisional information search is performed to end up with an alternative of which relevant attributes meet the aspiration level set for that attribute. Notions of bounded rationality and satisficing behaviour can be found in several travel demand studies (e.g. Foerster, 1978; Mahmassani & Chang, 1987; Mahmassani & Jayakrishnan, 1991; Schofer et al., 1993; van Berkum & van der Mede, 1993; Emmerink et al., 1995, 1996, Gärling et al., 2002).

Habit Execution

As a third perspective, parallel to the ones describing decision-making as a more or less conscious process, it is often argued and shown that many of the choices individuals repeatedly make are a consequence of the execution of a habit (e.g. Triandis, 1977, Hodgson, 2004), being defined as a repetition of past behaviour without deliberating or forming an intention. Since no actual decision is made in the sense of generating and assessing alternatives, habitual behaviour is often not regarded as decision-making. Although the past behaviour on which habitual behaviour is based was an actual decision, and could well have been optimal when it was first performed, a sub-optimal situation may arise as changes concerning alternatives and situations are not observed by the individual, because he does not consciously makes his decisions. Predecisional information acquisition is virtually non-existent in habitual behaviour (Aarts et al., 1997, Verplanken et al., 1997). Ample recent empirical studies on travel demand have pointed towards the role of habitual travel behaviour in the making of travel choices, especially mode choices (e.g. Aarts et al., 1997, 1998; Aarts & Dijksterhuis, 2000; Fujii et al., 2001; Fujii & Kitamura, 2003; Fujii & Gärling, 2003; Schlich & Axhausen, 2003).

Effort-Accuracy Trade-off

From the field of behavioural decision theory a perspective on decision-making originated that is often seen as an extension of bounded rationality, but that in fact incorporates several perspectives on choice-behaviour: the individual is assumed to select a decision strategy based on an effort/accuracy framework (Payne et al., 1993, 1996). When choosing between alternatives, an individual first chooses a decision-strategy based on (Chu & Spires, 2003) a trade-off of both the perceived effort and perceived accuracy of different decision strategies 'available' to him. Often, making decisions based on a careful trade-off of utility derived from attributes of alternatives (i.e. compensatory strategies) is not the selected decision strategy, and non-compensatory strategies such as satisficing (Simon, 1955) or some variant of lexicographic choice[7] (Tversky, 1972) are performed instead. Only when there exists a need for and a possibility of achieving highly accurate choice-outcomes, will the costs of extensive search for and use of information be accepted by the decision-maker (see Huneke et al., 2004, for a study on the effects of accountability on information search). In other cases, it is more likely that decision strategies are used that are only boundedly rational, including less extensive information search and use. Furthermore, different individuals facing the same choice-situation may perform different strategies. In recent travel demand research, explicit notions of this framework are not very widespread (for examples of the application of this framework see e.g. Gärling et al., 1998, 2001, 2002; Svenson, 1998; Fujii & Gärling, 2003). Note that this effort-accuracy framework implicitly deals only with the assessment of already available or specified alternatives (Swait & Adamowicz, 2001) and not with alternative generation, while both these processes should be taken into account when studying decision-making and information acquisition (Smith, 1991; Posavac et al., 2003).

A central notion: predecisional information acquisition as a cost-benefit decision

In our opinion, all the theories above, although they differ widely in their description of choice strategies, have in common that the use of information, be it for alternative generation or assessment, is framed as a cost-benefit decision[8]. The costs of information acquisition are a function of price and usability of the information service and characteristics of the travel situation at hand. They may include a number of tangible and intangible costs, such as monetary costs, time (see Stern, 1999 for a study concerning travel choice-making under time pressure), effort, irritation, attention and the risk of foregoing any already found alternative (Simon, 1978a; Weibull, 1978; Shugan, 1980; Richardson, 1982). The benefits of information acquisition result from the fact that information may help a traveler achieve his goal, as manifested in the decision strategy he applies. For maximizers, benefits may thus lie in the

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[7] In a lexicographic choice, the performance of alternatives concerning their most important attribute is evaluated, and the alternative with the highest score is chosen.

[8] Framing elements of habitual behavior as a cost-benefit decision may appear somewhat counter-intuitive at first. However, it may be argued that when relevant past behavior exists, executing a habit is in a sense an economizing mode of decision-making as the costs of decision-making are practically non-existent (Gärling et al., 2001; Golledge, 2002; Gärling & Axhausen, 2003). Argued this way, habit may be regarded as an application in extremis of the cost-benefit perspective: given both unchanged situational factors and availability of alternative options, repeating successful past behavior without acquiring any information is very cost-effective.

potential of information to help them choose the alternative with maximum pay-off. Satisficers may derive benefits of information acquisition as it may help them choose a 'good enough' alternative. Habitual travelers may find some benefits in information when they want to have their habitual option confirmed in changing travel circumstances, although such will be not be the case very often. Obviously, this cost-benefit perspective is congruent with the general idea of an individual's trade-off of effort and accuracy.

Generally, information benefits are a function of the decision strategy followed by the individual together with his perceived knowledge level, the availability of attractive alternatives and the quality of the information service. More specifically, information is beneficial to the traveler only to the extent that he feels that his current knowledge is insufficient to make the right choice. Note here that two travelers with the same levels of knowledge but different decision strategies may have completely different perceptions of their lack of knowledge, as argued in Huneke et al., 2004. Further conditions for information acquisition to be perceived as beneficial are that the alternatives about which information is available are perceived as potentially attractive and that the service is perceived to be resourceful and delivers relevant and reliable messages. A number of studies in the field of travel demand analysis have, in one way or another, adopted the idea of information acquisition as a cost-benefit analysis (e.g. Ben-Akiva et al., 1991; Schofer et al., 1993; Polak & Jones, 1993; Bonsall, 2001; Yang & Meng, 2001; Golledge, 2002; Khattak et al., 2003; Denant-Boèmont & Petiot, 2003, Sun et al., 2005; Arentze & Timmermans, 2005b). Given this view on information acquisition, it appears very logical that travelers sometimes do not engage at all in a search for travel information in response to uncertainty they face, but rather use another tactic to deal with their lack of knowledge (Gemünden, 1985; Lipschitz & Strauss, 1997; Bonsall, 2004). For example, a traveler may decide to simply acknowledge his lack of knowledge when choosing, instead of trying to reduce it, by taking a guess and knowing he may guess 'wrong' (e.g. Johnson & Raab, 2003 for the case of alternative generation and Bonsall, 2004 for the case of alternative assessment). Also, he might decide to lower his aspiration level so that the unreliability of estimates or absence of attractive alternatives does not affect him, or apply a number of other tactics when confronted with a lack of knowledge.

In order to test and concretize the idea of information acquisition as a cost-benefits trade-off within the boundaries of a traveler’s decision strategy, in the following Sub-section it is considered against findings of studies that tried to identify manifest determinants of ATIS use.

2.2.2 Empirical findings on manifest determinants of ATIS use

Over the last 15 years, a number of studies have been trying to identify what kind of traveler would be relatively likely to search for and use travel information, in what kind of trip context and facing what kind of travel alternatives and information services. The focus of this literature is on a variety of ATIS, such as the internet, phone services including mobile and SMS, in-car guidance systems, Variable Message Signs etc. We will show that the insights generated from these empirical studies are fully consistent with the theoretical notions on information acquisition developed above. It is also argued that the identified manifest determinants of ATIS use are in fact determinants of the behavioural factors that really drive information acquisition.

Who uses ATIS?
What kind of traveler is relatively prone to acquire information? Literature on ATIS use in this regard mainly focuses on socio-economic characteristics. These characteristics of the

individual however, as can easily be seen, are nothing more than indicators or proxies for the actual, behavioural determining factors of ATIS use. The literature states that male, highly educated, high-income travelers (e.g. Petrella & Lappin, 2004) are more likely than others to use travel information, as well as professionals (Emmerink et al., 1996), as these appear to attach greater importance to making an accurate choice (Hato et al., 1999). Travelers that own mobile phones (Polydoropoulou & Ben-Akiva, 1998; Yim & Khattak, 2001) and are connected to and make use of the internet are relatively prone to use ATIS. These individuals can be expected to have more experience in handling information technology and therefore are likely to perceive less difficulty in using ATIS and to be more aware of the potential of ATIS, increasing its perceived usefulness. Regarding the awareness of ATIS-services (Goulias et al., 2004), it was found that professionals in general, higher income and younger persons are more likely to be aware of all kinds of ATIS, as are car-owners and owners of a bus pass. Chatterjee & McDonald (2004) however found that even messages on large Variable Message Signs (VMS) above highway routes may only achieve awareness rates among passing car-drivers of about 33%. Polak & Jones (1993) and Petrella & Lappin (2004) found that ATIS use may differ significantly across regions and countries, partly due to differences in transport systems. It has also been found that ATIS acquisition can be explained by attitudinal factors: individuals that can be characterized as control seekers and technologically savvy people are relatively aware of (Polydoropoulou & Ben-Akiva, 1998) and prone to use (Lappin, 2000) ATIS.

The influence of trip purpose and context

What trip purpose induces a predecisional search for and use of information? Commuter trips (Petrella & Lappin, 2004) and especially business trips (Emmerink et al., 1996; Hato et al., 1999) appear to induce the search for and use of ATIS, mainly because these are generally arrival time-sensitive trips (Polydoropulou & Ben-Akiva, 1998; Srinivisan et al., 1999). These insights show that trip purposes that cause a highly negative attitude towards uncertainty (lack of knowledge) induce a high willingness to engage in an information acquisition process. Expected congestion or expected volatility in travel times induces a search for and use of ATIS (Hato et al., 1999; Yim & Khattak, 2001; Targa et al., 2003; Petrella & Lappin, 2004). Traveling during peak hours in general also increased the likelihood of ATIS use (Peirce & Lappin, 2004). It has also been found that longer trips increase a traveler's need for travel information, pre- as well as in-trip (Emmerink et al., 1996; Lappin, 2000; Yim & Khattak, 2001, Targa et al., 2003). Furthermore, the expectation of bad weather during the trip causes an increase in ATIS use (Polydoropoulou & Ben-Akiva, 1998; Peirce & Lappin, 2004). These insights show that a traveler's willingness to engage in a predecisional information search indeed increases when the trip context induces a relatively high degree of perceived lack of knowledge regarding current characteristics of travel alternatives.

Travel alternatives and their characteristics

How does the perceived availability and quality of travel alternatives the traveler is aware of influence the search for and use of ATIS? Referring to the alternative the traveler plans to take, Polak & Jones (1993), Srinivisan et al. (1999) van der Horst & Ettema (2005) showed that travelers are more likely to search for information regarding alternatives they are aware of, prefer or often use, than for other alternatives. Secondly, Denant-Boèmont & Petiot (2003) and with them Peirce & Lappin (2004) van der Horst & Ettema (2005) noticed that the availability of viable travel alternatives to a planned alternative was crucial to predecisional information acquisition. However, Chatterjee & McDonald (2004) found that still about one-half of car-drivers found VMS information on incidents useful even though they considered that there were no alternative route options. It should be noted that this latter case does not concern pre-decisional information acquisition and therefore falls outside the scope of this paper. Taken together, these findings suggest that information is actively acquired mostly for those alternatives the traveler plans to use, and is actively acquired for other alternatives to the degree they are found viable or promising for the trip to be made.

Concerning the characteristics about which information might be acquired, it is recently found that besides travel time and travel costs, travelers are interested in many other, often less tangible characteristics of travel alternatives such as convenience, privacy and comfort (Hague Consulting Group, 1991; Steg et al., 2001; Thogersen, 2001; Ellaway et al., 2003; Bos et al., 2004; Steg, 2005; Anable & Gatersleben, 2005). Although it did not explicitly focus on information acquisition, this empirical literature does suggest that travelers might want ATIS to be able to provide them with information concerning such 'soft' characteristics of travel alternatives.

The influence of characteristics of the information service

Finally, what information service induces use? That is, how should an information service be designed in order to encourage use by travelers? In general, almost every study on ATIS use stresses the importance of information quality. More specifically, reliability, timeliness and coverage of the information provided is key to ATIS use (Polydoropulou & Ben-Akiva, 1998; Hato et al., 1999; Fayish & Jovanis, 2004). Also, travelers appear to have a need for personal (Adler & Blue, 1998) and multimodal information (Polak & Jones, 1993; Kenyon & Lyons, 2003). Just as is the case for all high-tech applications (Davis et al., 1989), easy accessibility and use of the information service and good graphical design also induce greater use of ATIS (e.g. Fayish & Jovanis, 2004)9. Concerning the issue of willingness to pay, literature generally states that there is, among travelers in general, a low willingness to pay for information provided through current advanced travel information services (e.g. Polydoropoulou et al., 1997; Khattak et al., 2003), and for PT-information among PT-users in specific (Vance & Balcombe, 1997; Neuherz et al., 2000; Molin & Chorus, 2004; Molin et al., 2005) as PT-users mostly feel that they have already paid for information provision by buying their ticket. From a business case perspective, this is a somewhat worrying finding. Nonetheless, these findings clearly state that the expected benefits of ATIS-use - as in the potential to improve the quality of choices - must outweigh the expected costs resulting from the high prices for information or difficulty using the information service, in order for the ATIS to be used.

It appears that the empirical findings on manifest determinants of information acquisition are fully compatible with the theoretical notions on behavioural drivers. Therefore, combining the theoretical ideas presented in Sub-section 2.3.1 with the empirical findings presented in Sub-section 2.3.2., a general framework of pre-decisional information acquisition may be constructed, which is done in Figure 1.

[9] It may be expected, although we know of no empirical evidence in that regard, that an important determinant of the usability of an information service (and therefore its effectiveness) is that it provides the traveler with information in his or her own language, especially in situations where complex information is provided, and time pressure plays a role.

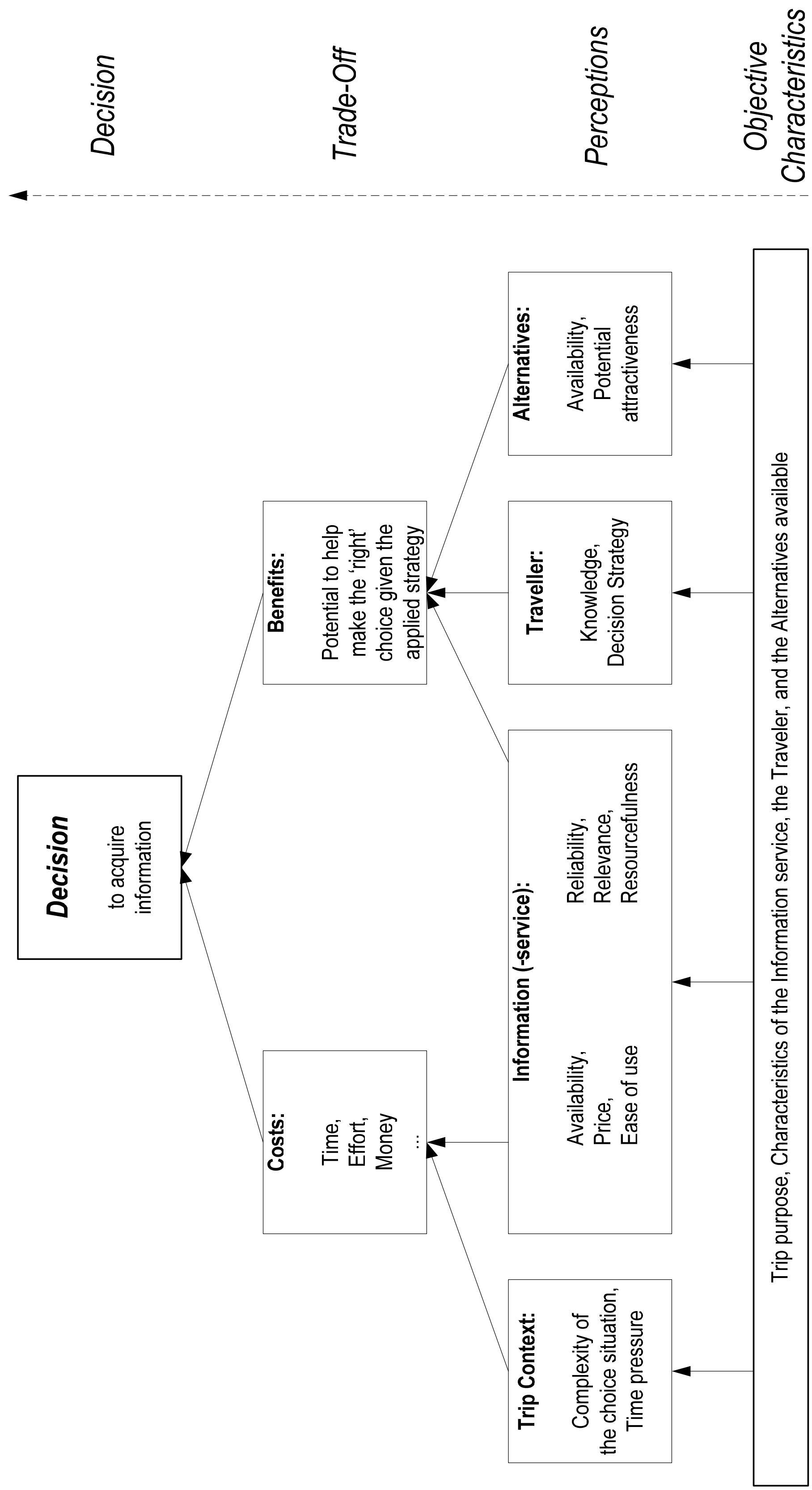

Figure 1: A framework on predecisional information acquisition

After having reviewed the contributions to literature in the field of information acquisition, we will now move our attention to an adjacent field of study, that of the effect of acquired information on travelers' perceptions.

2.3 Information effect

It is generally acknowledged that travelers base their choices on their perception of, or beliefs regarding, reality instead of on the objectively measurable reality itself (e.g. Recker & Golob, 1976; Koppelman & Pas, 1980; Ben-Akiva et al., 1998; Golledge, 2002; Bonsall et al., 2004). It is obvious that information will not change the objective reality, but rather may affect a traveler’s perception of this reality (e.g. Bovy & Stern, 1990; Ben-Akiva et al., 1991; Khattak et al., 1993). This Section will explore how travel information may update a traveler’s perceptions. When a traveler has decided to search for information and/or to use the information that he is provided with, the question arises as to how he will combine this information with already existing beliefs to create new beliefs. In other words, how may travel information update a traveler’s initial perceptions of travel alternatives? A first notion to be taken into account here is that perception updating occurs only to a certain extent: a traveler may be provided with information, either through his own active search, or because an information service has provided him with information unasked for. At that moment, he decides whether or not to use this information (i.e. passive information acquisition). This decision is not assumed to be a binary one: a traveler may subconsciously decide to pay attention to the information he is provided with to a certain extent, the decision itself determined by the traveler’s weighed expectations regarding the costs and benefits of information use (see above). The extent to which he decides to use the information forms an upper limit to the degree of updating that may possibly be achieved, based on the information provided. An upper limit, since also his mental processing ability and his perception of information unreliability may induce a further decrease in the degree to which perceptions are updated through information. There are two paths along which perceptions can be updated: firstly, information on travel possibilities may serve in the process of generation of travel alternatives by updating a traveler’s perception of availability (i.e. awareness) of travel alternatives, or in other words, his choice set. Secondly, information on travel costs may serve in the process of assessing the travel alternatives a traveler is aware of by updating his perception of characteristics of travel alternatives.

2.3.1 Awareness of travel alternatives and the effect of information

Usually, a traveler has several options to choose from when performing a trip. Different combinations of departure-time, route and travel mode may bring him from origin to destination within boundaries set regarding monetary costs, time and other constraints. For trips within urbanized regions, often having a dense multimodal transport system, the number of available travel options may even be very large (Ramming, 2002; Hoogendoorn-Lanser & van Nes, 2004). Nevertheless, a traveler is usually only aware of a handful of travel options, and only considers some of those alternatives when making a choice (Bovy & Stern, 1990; Fiorenzo-Catalano et al., 2003; Last & Manz, 2003). In the case of the existence and execution of a travel habit, often only one alternative is known and considered by the traveler (e.g. Aarts et al., 1997, 1998). Furthermore, knowledge, in the sense of the number of travel alternatives a traveler is aware of, may differ widely between individuals (Williams & Ortuzar, 1982; Cascetta & Papola, 2001). Recent studies have shown that it is therefore useful when analyzing travel demand to explicitly take into account a traveler's choice-set (e.g. Swait & Ben-Akiva, 1987; Thill, 1992; Ben-Akiva & Boccara, 1995; Swait, 2001; Ramming 2002; Hoogendoorn-Lanser & van Nes, 2004, Cantillo & Ortuzar; 2005). Cascetta & Papola (2001) suggest the behavioralistic idea of regarding a traveler's choice-set as having fuzzy boundaries: travel alternatives belong to the set of perceived available alternatives to some extent.

What might be the effect of the information that a traveler is provided with and decides to use? There seems to be, to the authors' knowledge, no empirical study that deals with the effect that ATIS may have on a traveler's perceptions and choices through generating travel alternatives and bringing them to the traveler's attention. This lack of empirical literature is quite surprising, given the potential impact of this type of information provision. However, it seems reasonable to assume that information might contribute to a traveler's awareness in two ways: firstly, an alternative can be brought to her attention that she was completely unaware of. In fuzzy terminology, the degree of membership of the alternative to the set of known alternatives is increased from zero to a value larger than zero. For example, a traveler might be told that she can reach her destination by intercity bus, while she was not aware that such a service existed for a given origin-destination pair. Secondly, information might inform the traveler in a more detailed way about an alternative he was already partly aware of, but did not know well enough to actually consider for choice. This is done by providing her with what might be called a 'user manual' for the alternative. That way, the degree of membership of that alternative to the set of known alternatives is increased from a non-zero value to a larger value. For example, a traveler that knew of the existence of an intercity bus-service, but did not know where to find the nearest bus stop, might be told where she can find that stop, making the intercity bus a more viable member of her choice set.

2.3.2 Perceived characteristics of travel alternatives and the effect of information

Travel demand literature, as well as more generic microeconomic literature, has provided convincing evidence that an individual's perceptions of characteristics of alternatives might differ greatly from the actual values of those characteristics (e.g. Mc Fadden, 1999, 2001; Zhao & Harata, 2001; Lyons, 2001; Li, 2003; Avineri & Prashker, 2003a, b; Bonsall et al., 2004). Mostly, individuals overestimate positive features of chosen alternatives compared to non-chosen alternatives. van den Steen (2004) argues that this can not only be explained through psychological insights (such as cognitive dissonance (Festinger, 1957)), but that it is also highly consistent with micro-economic theory: as alternatives that are overestimated in terms of the utility that may be derived from them are more attractive on average than those that are underestimated, the overestimated ones are per definition more likely to be chosen. Furthermore, just like awareness, perceptions of characteristics appear to differ widely across the population of travelers (e.g. Jha et al., 1998; Bonsall et al., 2004). Together with the facts that perceptions of reality are forceful drivers of choices and that information may affect these perceptions rather than reality itself, this makes the formation and adaptation of perceptions a non-neglectable issue to be dealt with in the analysis of choice behaviour, especially under conditions of uncertainty (Delavande, 2003; Manski, 2004) and the presence of information.

In studies on ATIS use and effects however, attribute perception updating is generally not treated explicitly as a distinctive step in the decision-making process. Rather, the effect of ATIS on travelers' perceptions of travel times is studied, either indirectly through observing choice adaptation (e.g. Adler & McNally, 1994; Lotan, 1995; Jou et al., 2003; Bogers et al., 2005), or theoretically using simulated data (e.g. van Berkum & van der Mede, 1993; Emmerink et al., 1995; Jha et al., 1998; Ettema et al., 2004; Chen & Mahmassani, 2004; Sun, et al., 2005) or from a network-perspective, where categories of informed an uninformed travelers are created (e.g. Levinson, 2003; Lo & Szeto, 2004; de Palma & Picard, 2005). A notable exception is a study by Zhao & Harata (2001), who found that travelers' perceptions of actual travel times under conditions of provision of travel times by ATIS may be represented by a linear function of the ATIS' message, with positive intercept and beta. This indicates that travelers do not completely rely on messages received, but rather use them in a conservative updating process. In the absence of other relevant empirical literature on the topic, the remainder of this Sub-section reviews studies on the updating of perceptions through travel information mainly from a theoretical approach. Although the main focus of recent theoretical studies on perception updating have focused on the updating of perceived travel times, most of the basic ideas and gained insights are applicable to a number of characteristics of travel alternatives (costs, number of interchanges, departure times, etc.). These perceptions can be argued to be stochastic variables, as the individual has limited confidence in his estimates regarding the characteristics of travel alternatives. However, most theory concerning the updating of travelers' perceptions treats them as deterministic variables, applying views consistent with information integration theory (e.g. Anderson, 1981; Einhorn & Hogarth, 1981). For example, Horowitz (1984) and Ben-Akiva et al. (1991) consider perception updating as a process of weighed averaging of initial perceptions and a new experience/the uptake of travel information. Such a view, although it has provided valuable insights regarding information potential (see for examples Adler et al., 1993; van Berkum & van der Mede, 1993; Emmerink et al., 1995), remains incomplete by not reflecting the stochastic nature of perceptions.

A perspective that does treat perceptions as stochastic variables is that of the decision-maker as a Bayesian updater (Raiffa & Schlaifer, 1961; Edwards et al., 1963): an individual has a prior perception of a characteristic, represented by a probability distribution. Using Bayes' rule, he uses new information to update this prior distribution into a posterior distribution that becomes his updated perception. The degree to which the prior perception is updated depends on the individual's perceived unreliability of his initial estimates and the perceived reliability of the new information. Recently, this perspective has been adopted in activity-travel studies. First suggested by Kaysi (1991) as a potentially fruitful perspective to analyze travelers' updating of travel time-perceptions, Bayesian travel-time perception updating was empirically introduced by Jha et al. (1998) and Chen & Mahmassani (2004). The updating of the attributes of travel destinations using a Bayesian Belief Network was introduced by Arentze & Timmermans (2005a, b). As the attributes of a destination represent the possible activities that can be performed at that destination, this latter application can also be seen as the updating or extension of choice-sets. It should be mentioned here that the assumption of the individual being a Bayesian updater, although extensively used in micro-economics, is found to have limited behavioural validity in some situations, due to the assumed high degree of information processing capability, in particular an individual's way of dealing with conditional probabilities (e.g. Phillips & Edwards, 1966; Tversky & Kahneman, 1974; El-Gamal & Grether, 1995; Avineri & Prashker, 2003b). However, we feel that the application of Bayes' law of conditional probabilities concerning variables that may be represented as continuous, rather than discrete, stochasts reduces to such elegant and intuitive formulations that these may provide behavioural realistic representations of human behaviour. It may therefore be expected that notions of Bayesian updating will better represent the effect that travel information may have on a traveler's perceptions of characteristics of travel alternatives than treating these perceptions as deterministic variables.

2.3.3 Information acquisition and perception updating as an iterative process

As discussed above, travel information may increase a traveler's awareness of alternatives by introducing them to the traveler or by explaining them. Also, it may alter a traveler's perception of the characteristics of travel alternatives. Next to these two main updating mechanisms, travel information potentially has two secondary impacts on a traveler's perceptions: firstly, it may influence a traveler's perception of the trip context, more specifically his perception of the complexity of the choice-situation, as good information may explain and compare travel alternatives, and present them in a format that is understandable. Such a re-formatting of the choice-situation may substantially reduce its complexity in the eyes of a traveler, especially in the case where a traveler faces a dense multimodal transport network[10]. Secondly, travel information may influence a traveler's perception of the degree of incompleteness of his knowledge by providing him with travel alternatives and estimates of their characteristics.

Given these four mechanisms, it can be seen that the acquisition of travel information may lead to further information acquisition: firstly, alternatives that are brought to the attention of a traveler might be evaluated as promising, which will increase the perceived benefits of further information acquisition concerning their characteristics. Secondly, the updating of perceptions regarding the characteristics of those alternatives that the traveler was aware of might make these alternatives more (or less) promising in the eyes of the traveler. This change in the degrees to which a traveler finds alternatives promising also influences the benefits she may expect to derive from further information search concerning their and other alternatives' attributes. Thirdly, as good information might reduce the complexity of the choice-situation a traveler perceives, the expected costs of further information acquisition will decrease. Such might for example be the case when a complex multimodal network is reduced by an information service to two attractive alternatives. Fourthly, relevant and reliable travel information will reduce the incompleteness of knowledge a traveler perceives, reducing the benefits he expects to derive from repeated predecisional information acquisition. These four mechanisms together determine whether additional predecisional information will be acquired.

Given these ideas, the following iterative decision-scheme can be presented for a traveler's acquisition of travel information (see Figure 2): facing a travel situation, a traveler forms perceptions of the trip context, the information services available, her own knowledge and the availability and characteristics of travel alternatives. Based on these perceptions, she subsequently forms expectations regarding the costs and benefits of predecisional information acquisition in order to decide whether or not to engage in predecisional information search or use. If she decides to do so, the information might lead to an updating of perceptions. As discussed above, this update may possibly trigger a repeated search for or use of information. This loop continues until the moment where a traveler finds that, based on her expectations of costs and benefits of information acquisition, further information acquisition will not be beneficial to her. At that moment, she will make her choice for a travel alternative, choosing from the alternatives she is aware of, based on their perceived characteristics and using the type of evaluation mechanisms that fit the decision-making strategy she has adopted.

[10] On the other hand, the introduction of new alternatives may also increase a traveler's perceived complexity of the situation.

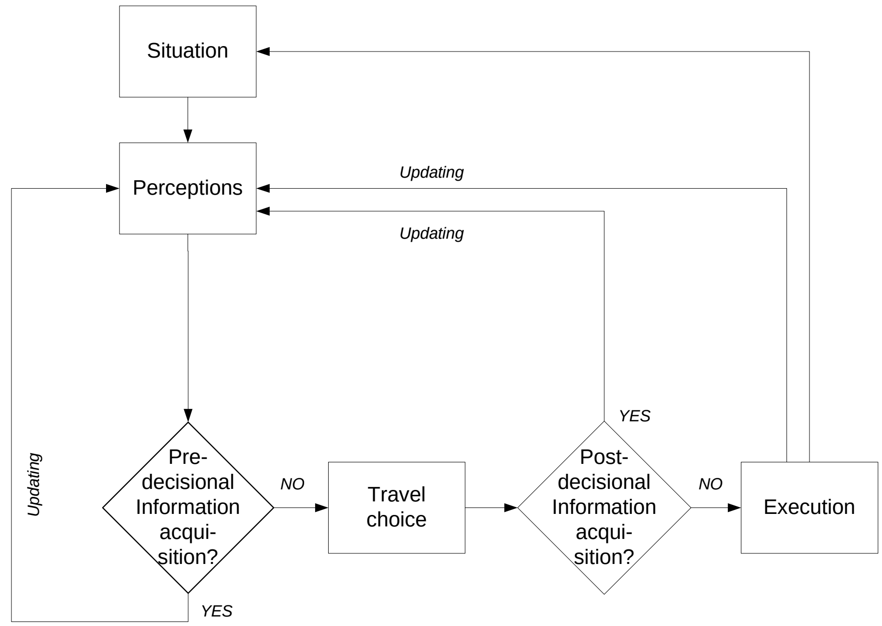

Figure 2: Information acquisition and effect in iteration

Between the moment of making the travel choice and executing the choice, additional information might be acquired, called here post-decisional information acquisition. This information may serve to help the traveler execute his choice or plan his activity schedule. Take for example the situation where a traveler that has decided to go by train needs to know on what platform his train is on, or the situation where a traveler that has decided to go by car may want to estimate his travel time in order to tell his family at what time he will be home and whether or not he will have time to do shopping on his way home. At least theoretically, the information provided to a traveler after he has made his choice might again update his perceptions in such a way that he subsequently feels the need to engage in a predecisional information search or even to change his choice. After this potential loop is iterated until the moment where no pre- or post-decisional information is needed by the traveler, he will execute his choice. From that moment on, the transport system may show its dynamic nature, e.g. by the occurrence of unexpected delays or congestion. Also, a traveler's perception of travel alternatives may alter as he for example notices underway that the road he is on is blocked. These changes in the transport system or in a traveler's perceptions potentially lead to a new process of predecisional information acquisition.

2.4 Conclusions

This paper signals the development of a next generation in ATIS potentially resulting in mobile, multimodal, dynamic, and personal travel information services. It is argued that a review of current conceptual frameworks and empirical findings regarding information use and effects is warranted to gain insights in the potential use and effects of this next generation ATIS. This paper presents such a review, and may therefore provide insights concerning the determinants of optimal levels of use and effects of next-generation ATIS for ATIS designers and transport policy makers.

Based on a review of general theories of individual decision-making and information acquisition, first a framework is developed that can be used to explain the acquisition of travel information. This framework regards predecisional information acquisition as a direct derivative of the decision-strategy a traveler uses, which makes the framework consistent with a multitude of perspectives on travel behaviour. It states that the decision to acquire information is based on a traveler's weighed expectations of costs (in terms of among other things time, effort and money) and benefits (in terms of the information's potential to help the traveler make the 'right' choice given his strategy) of acquiring the information.

A review of empirical literature concerning ATIS use makes concrete this theoretical notion of information acquisition as a cost-benefit decision. Several interesting findings concerning the manifest determinants of ATIS use are identified: concerning socio-demographics, there appears to be a consensus that male, highly educated, high income, professional travelers that frequently use internet and mobile phones are particularly likely to engage in information acquisition using all sorts of ATIS. Concerning trip purpose and context it appears that, consistent with intuition, business trips and commuter trips and arrival-time sensitive trips in general induce higher usage levels of ATIS. The variability in the performance of travel alternatives, due to for example peak traffic, bad weather or long trip duration also positively affects a traveler's inclination to use ATIS. Literature is also in agreement on the suggestion that travelers are particularly using ATIS to be informed about their favored mode of transport. On the other hand, the availability of viable travel alternatives other than the preferred mode also has a positive effect on ATIS use. There is indirect empirical evidence that travelers wish to be informed not only about travel times and costs of alternatives, but also about more 'soft' characteristics such as convenience, comfort and privacy. Besides all this, there is consensus in empirical literature that travelers use ATIS to the extent that they perceive them to deliver reliable, resourceful and relevant information. There does exist a clear need for multimodal, personalized ATIS-applications. However, willingness to pay for travel information is generally found to be very low and also the usability of ATIS plays an important role, which signals that travelers are generally willing to only bear very little costs in terms of effort, time and money in order to receive travel information through ATIS. Finally, it is argued that all these empirical findings are fully consistent with the idea of information acquisition as a cost-benefit decision: the manifest determinants are in fact nothing more than proxies for the true, behavioural determinants of information acquisition through ATIS.

This paper also presents a review of literature on the potential effect of travel information on travelers' choices. It is argued how, once acquired, information may update a traveler's perceptions of travel alternatives: it may make a traveler aware of alternatives and their true characteristics. Information acquisition and perception updating appears to be an iterative process. Eventually, travel information may, through the updating of perceptions, influence a traveler's choice-behaviour. Due to the scarcity of empirical literature on the topic of the effect of travel information on travelers' perceptions of alternatives, the developed framework on information effect is based only on theoretical work.

Based on the literature review performed, several knowledge gaps can be identified: firstly, it appears that there is a need for theoretical and empirical studies and research tools that investigate the behavioural, rather than the manifest, determinants of information acquisition under uncertainty. For example, a rigorous mathematical formalization of conceptual ideas regarding travelers' acquisition of information may help increase our understanding of the complex behavioural mechanisms that drive this process. Such mathematical representations are recently developed by Chorus et al. (2005, 2006a), Arentze & Timmermans (2005a, b) and Sun et al. (2005). Furthermore, concerning the direct effect of information on the updating of travelers' perceptions a serious lack of empirical knowledge exists. Insights on this issue are however critical in order to fully understand in what ways travel information may effect a traveler’s choices for departure time, routes and modes. The authors acknowledge the need for empirical data concerning the behavioural mechanisms behind information acquisition and perception updating in general and are currently obtaining such data through the application of advanced survey instruments, such as the travel simulator laboratories presented by Hoogendoorn (2003) and Chorus et al. (2006b), that facilitate interactive choice-experiments in a controlled but realistic transport network. It is expected that data derived from such experiments will help gain some of the insights so badly needed in order to fully understand the potential of next-generation ATIS.

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Chapter 3

Chorus, C.G., Arentze, T.A., Molin, E.J.E., Timmermans, H.J.P., van Wee, G.P., 2006. The value of travel information: decision-strategy specific conceptualizations and numerical examples. *Transportation Research Part B*, 40(6), pp. 504-519. Copyright © *Elsevier B.V.* [11]

Abstract

Behavioral models of the perceived value of travel information are developed that take into account satisficing as well as maximizing behavior, and are suitable for the evaluation of information acquisition for alternative generation as well as assessment. This is done by integrating notions of search theory and Bayesian perception updating into a utilitarian framework of information value. In order to clarify the important mechanisms behind these formulations, and provide some first face validity to the applied approaches, numerical examples are developed that simulate the value of information for different knowledge levels of the individual, and for different levels of reliability of the information service. The examples indeed provide preliminary confidence, as occurring trends appear to be consistent with intuition and empirical literature.

[11] We have corrected a notational typo in Equations (14) and (22). Also, we have corrected a mistake in Footnote 15, by changing the word ‘alternative’ into the word ‘attribute’.

3.1 Introduction

Ever since the introduction of Advanced Traveler Information Services (ATIS, referring to traffic information services as well as Public Transport information services), there has been substantial interest in understanding the intensity and nature of their usage among travelers. Questions examined include: what kind of travelers are likely to use ATIS and in what type of travel situation? What kind of ATIS are likely to induce high usage levels? What is travelers' willingness to pay for travel information? Since the early 1990s, many empirical studies have been performed that provide some valuable insights into the use of ATIS by identifying ATIS-prone segments of the traveling population, trip purposes and contexts and also identifying what characteristics successful ATIS should have (e.g., Polak & Jones, 1993; Emmerink, et al., 1996; Polydoropoulou & Ben-Akiva, 1998; Hato, et al., 1999; Kenyon & Lyons, 2003; Pierce & Lappin, 2004; Molin & Chorus, 2004). Several conceptual frameworks have been developed that describe travelers' acquisition of information provided through ATIS (e.g., Bovy & Stern, 1990; Ben-Akiva, et al., 1991; Khattak, et al., 1993; Schofer, et al., 1993; Denant-Boemont & Petiot, 2003). Predominantly, these frameworks describe the acquisition or gathering of travel information as a cost-benefit decision: a traveler will only use an ATIS when he feels that the perceived benefits of doing so outweigh the perceived costs. Within these cost-benefit frameworks, there is consensus about the perceived costs of ATIS use: next to monetary costs, investments in terms of time, effort and attention should also be taken into account. The perceived benefits of ATIS use, however, are often defined in fairly loose terms such as 'helping the traveler to make better choices', 'reduce the uncertainty a traveler faces'. These vague definitions have led to rather ill-structured approaches to identifying the determinants of these perceived information benefits, or perceived information value. It is generally acknowledged that the value of travel information increases with increasing reliability and relevance of the information, increasing variability of the travel conditions and the availability of viable travel alternatives. However, few models currently exist that try to link these determinants unambiguously to the concept of perceived information value for travel choice behavior. It can be argued however, that the ex-ante evaluation of ATIS' use and effects, as well as transport policies that include the provision of travel information, should rely on unambiguous models of travelers' information acquisition processes, based themselves on solid definitions of perceived information value and its determinants. Preferably, the perceived value of information should be defined in terms of the utility to be derived from travel alternatives about which information is acquired, as is done in Arentze & Timmermans (2005a) and Chorus et al. (2005).

This paper develops a possible approach to such a rigorous definition of perceived information value, and the modeling of its determinants. It contributes to the literature in two ways. First, unlike previous attempts, it takes into account the value of information both from an alternative generation perspective as well as from an alternative assessment perspective. The *alternative generation* perspective refers to the exploration of previously unknown alternatives. The *alternative assessment* perspective refers to the estimation of actual characteristics of known alternatives. Both terms will be defined more extensively in the next Section. Second, we make the concept of perceived information value presented here decision strategy specific, based either on notions of satisficing or maximizing behavior of the individual. The role of information acquisition is not embedded here in longer term learning processes, although the ideas presented here can be used as elements in such an approach. The paper mostly deals with choices for routes and travel modes. Nevertheless, information acquisition for other travel choices, such as choices for departure times and destinations can also be modeled using the concepts presented here. The paper is structured as follows: Section

3.2 starts with a literature review on relevant past research efforts. Section 3.3 introduces the mathematical formulation of the concept of expected regret, on which the notion of information value is based. Sections 3.4 and 3.5 use this formulation to derive expressions for perceived information value acquired with the aim of alternative generation, respectively assessment. Section 3.6 presents numerical examples that aim to clarify and provide some face validity for the introduced concepts. Finally, conclusions are drawn concerning the usability of these concepts for the development of behaviorally realistic models of travel information acquisition.

3.2 Travel information acquisition: a review and introduction of concepts

This Section reviews literature concerning the acquisition of information for assessment and generation of alternatives, and does so from both a maximizing and satisficing perspective.

3.2.1 Information acquisition for assessment and generation of alternatives

A traveler who is planning or executing a trip may face a choice from several travel alternatives (combinations of modes, routes, departure times). Assume first the ideal case of a traveler having complete knowledge, implying that she is aware of every alternative available to her, and of every exact characteristic of those alternatives. Her decision process now involves a choice under full certainty. Although this base case is quite suitable as an implicit assumption for travel demand models, it can hardly be said to be a realistic account of actual traveler behavior in real life situations. A first possible deviation from this ideal case is the situation where a traveler knows that she is not aware of all the travel alternatives that are available to her. A number of travel demand studies have explicitly taken into account limited awareness by modeling travelers' subjective choice sets (e.g., Swait & Ben-Akiva, 1987; Thill, 1992; Ben-Akiva & Boccara, 1995; Cascetta & Papola, 2001; Swait, 2001; Ramming, 2002; Fiorenzo-Catalano, et al., 2003; Hoogendoorn-Lanser & van Nes, 2004). The decision process of such a traveler may now include information acquisition with the aim of alternative *generation*. Through acquiring information, she expects to be provided with routes, destinations or modal options that were formerly unknown to her. In other words, she expects the information service to reveal the existence of previously unknown alternatives. Models that explicitly take into account the value of this type of information acquisition are often referred to as search models. Several examples can be found of such approaches in a travel demand context (e.g. Weibull, 1978; Richardson, 1982; Williams & Ortuzar, 1982; Lerman & Mahmassani, 1985; Arentze & Timmermans, 2005a, 2005b). Earlier work in this area tends to be rather normative in nature, whereas more recent work is more behaviorally oriented. A second possible deviation from the ideal base case would assume that the traveler has incomplete knowledge concerning the *characteristics* of known alternatives, i.e., the alternatives in her choice set. A wide body of travel demand models deal with choices based on this type of incomplete knowledge by using concepts of expected utility theory (Von Neumann & Morgenstern, 1947), prospect theory (Kahneman & Tversky, 1979, 1992) or, to a lesser extent, Regret-Theory (Loomes and Sugden, 1982, 1983). Other approaches used involve the inclusion of travel time variation terms or notions of schedule delay (Noland & Small, 1995) in the utility function. Examples of traveler decision making under this type of uncertainty can be found in Ouwersloot et al. (1997), Bonsall (2001, 2004), Lam & Small (2001), Rietveld et al. (2001), Bates et al. (2001), Levinson (2003) and Avineri & Prashker (2003a, b). Given such a deviation from the ideal base case, the decision process of a traveler may include possible information acquisition with the aim of alternative *assessment*. Through acquiring information she expects to be provided with estimates for characteristics of several alternative travel options. Several studies of travel information explicitly focus on its value for alternative assessment (e.g., Hato et al., 1999; Denant-Boemont & Petiot, 2003; Chorus et al., 2005, Sun et al., 2005).

It can be argued that the level of knowledge of a traveler nowadays, especially given the density and variability of current multimodal transport networks, should be represented by taking into account both these two deviations from complete knowledge because she can not be expected to either know all alternative mode-route combinations or the precise characteristics of these alternatives at the moment she faces a choice (Bonsall, 2004). Following this argument, a model of travel information acquisition should take into account the value of information acquisition for alternative generation *and* alternative assessment.

3.2.2 Different decision strategies and their relevance for information acquisition

A wide variety of normative and descriptive decision strategies for individuals in general, and travelers in specific, have been proposed and studied in psychology, decision theory, micro-economics and travel demand modeling. Seemingly, the most important opposing views on an individual's decision strategies are those of maximizing and satisficing strategies, where maximizing refers to finding and choosing the best alternative available and satisficing refers to finding and choosing a good enough alternative[12]. We will discuss briefly here how information acquisition is referred to in these opposing views of decision making. Maximizing strategies treat information acquisition as a step that can be taken in order to maximize the expected payoff of the choice being made, taking into account all sorts of costs of information acquisition. Examples of such approaches to information acquisition can be found in Weibull (1979), Richardson (1982) and Arentze & Timmermans (2005), all four referring to alternative generation and in Stigler (1961), Raiffa & Schlaiffer (1961), Denant-Boemont & Petiot (2003) and Sun et al. (2005), all three referring to alternative assessment. A parallel approach to the acquisition of information during the decision process is based on the notion that individuals look for and choose alternatives that are good enough, rather than the best possible. This satisficing approach, introduced by Simon (1955), states that information will only be acquired (or in his own words: gathered) in order to find an alternative that is good enough, or meets the individual's aspiration level. Examples of this approach to information acquisition can be found in Simon (1955, 1978a, b), Olander (1973) and again in Weibull (1979). Next to these two opposing views, a perspective has been developed stating that maximizing and satisficing behavior may both be valid and realistic decision strategies for different individuals facing the same contexts, or for one and the same individual facing different contexts. This approach assumes that individuals choose to adopt a decision strategy based on an effort/accuracy framework (Payne, et al., 1993, 1996). For example, the choice for a residence location may be assumed to follow notions of maximizing strategies, whereas everyday route choices might be made more along the lines of satisficing strategies. This would mean that measures for perceived information value should take into account both satisficing and maximizing travelers or contexts.

[12] Note that another important class of traveler decision-making deals with the concept of habitual choice (e.g. Triandis, 1977); travelers are often found to base their choices for travel modes and routes not so much on a deliberate evaluation of alternatives, but rather on the execution of their habit (e.g. Verplanken, et al., 1997; Gärling, et al., 2001; Gärling & Axhausen, 2003). As information acquisition is found to be extremely limited in habitual choice behaviour (e.g. Aarts, et al., 1997), this paper focuses on information acquisition in situations where travelers do make some sort of evaluation before actually choosing an alternative.

3.2.3 Towards the concept of perceived information value

Given that we wish to adopt one framework in order to analyze information acquisition that aims for alternative generation and assessment, from a maximizing and a satisficing perspective, how should we conceptualize the notion of information value? Assuming that a traveler knows that she is not *omniscient*, she by definition knows that when choosing an alternative, she might fail to attain the goals she has set. Should the individual follow a satisficing decision strategy, she knows that incomplete knowledge may cause her to choose an alternative that will turn out to be *not satisfactory*. Should the individual on the other hand follow a maximizing strategy, she knows that incomplete knowledge may cause her to choose an alternative that will turn out to be *not the best alternative available*. In both cases, the individual will have some expectations beforehand concerning the degree of failure and the probability of failure. Following the essence of the argument by Loomes & Sugden (1982, page 808)[13] let us assume now that the individual's choice, whether she is a satisficer or a maximizer, is driven by the expectation and anticipation of regret. Under full certainty, the amount of regret can be conceptualized as a function of the magnitude of failure to attain a goal. Under conditions of uncertainty, we conceptualize expected regret as a function of the product of both the probability and magnitude of failure to achieve the goal set through the adopted decision strategy, integrated over the probability density function of possible perceived failures. Given this assumption, it becomes possible to treat maximizing and satisficing behavior as both representable by one and the same concept: minimization of expected regret. That is: given her decision strategy, the individual is assumed to choose the alternative that minimizes the amount of expected regret she perceives to feel after having executed her choice[14]. The perceived value of information can then be defined as the perceived potential of the information to reduce the expected regret that is induced in a choice situation. Such a transformation can take place by either generating alternatives that were unknown to the traveler, or by assessing the characteristics of alternatives she is already aware of. We do not propose the concept of expected regret in any way as a superior, or more realistic representation of decision making under uncertainty compared to established approaches such as expected utility maximization or satisficing behavior. Rather, the concept of expected regret is applied because it makes possible the representation of both maximizing as well as satisficing behavior from within a common perspective.

3.3 Decision strategy-specific formulations of expected regret

[13] But not adopting the entire regret-rejoice framework presented in the remainder of that paper.

[14] Note that, following the original idea of satisficing behavior (Simon, 1955), there is a cognitive advantage to being a satisficer instead of being a maximizer. When viewed from this paper's perspective of choice under conditions of uncertainty based on notions of expected regret, this advantage is somewhat more subtle and somewhat less substantive, than is often the case in formulations of satisficing behavior under full certainty. That is, from our perspective, satisficers do need to evaluate a compensatory measure of utility per alternative for every possible state of the world, just as is the case for maximizers. This means that in the evaluation phase, there is no cognitive advantage to being a satisficer. However, after this is done the two decision strategies proceed in very different ways, and the cognitive advantage of being a satisficer becomes clear. In our formulation, a maximizing individual may experience regret as she compares the utility of some alternative for some state of the world *with the utilities of every other alternative for that state of the world*, whereas a satisficing individual may experience regret as she compares the utility of some alternative for some state of the world, *with her aspiration level*. This comparison-stage is thus much less complicated for satisficers than for maximizers, especially when large choice sets are involved. The straightforward comparison stage therefore induces a clear cognitive advantage for satisficers over maximizers.

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For simplicity of presentation, some assumptions have to be made before starting the mathematical derivation of the concepts discussed in Section 3.2. As the measures for expected regret and perceived information value that are developed here imply the evaluation of integrals, an increase in alternatives and characteristics taken into account will rapidly increase the number of integrals appearing in the expressions, which would decrease their readability. Therefore, and without any loss of generality, the following Sections will use a highly simplified travel situation to derive the formulations. A traveler facing a trip knows two alternative ways of getting to his destination (e.g. two routes by car) and is aware of the fact that there is one other option he does not know (e.g., a public transport service). He evaluates the alternatives on one characteristic only (e.g., travel time).

3.3.1 Some basic notions and general derivations

Suppose that a traveler facing a choice situation has a set S of two known travel alternatives Y_i and Y_j, such as different combinations of routes, departure times or travel modes:

$$S = \{Y_i, Y_j\} \tag{1}$$

Each of these travel alternatives can be thought of as being a bundle of attributes, or in the present case, as being nothing more than one attribute X_i or X_j:

$$Y_i = \{X_i\},\ Y_j = \{X_j\} \tag{2}$$

The traveler now may experience two types of incomplete knowledge: firstly, he might be aware of the fact that he does not know all the alternatives (e.g. mode-route combinations) that are available in the universal set V, being the total solution space of logical alternatives given the current state of the transport network. In other words, he perceives the universal set V as consisting of both the set S of known alternatives Y_i and Y_j and its complement $\overline{S}$ of unknown alternatives. Note that the term *unknown* here does not refer to not exactly knowing the characteristics of an alternative, but rather not being aware of the existence of an alternative. That is why, as will be seen in Sub-section 3.3.2, a traveler does not have the possibility to choose an unknown alternative. As soon as he is aware of the existence of the alternative, although he might not think he has reliable ideas about the alternative's travel times etc, the alternative becomes known in the terminology of this paper. In the present case, set $\overline{S}$ consists of only one unknown alternative Z:

$$V = S + \overline{S} \tag{3}$$

$$\overline{S} = \{Z\} \tag{4}$$

Secondly, the traveler might know that his estimates of the characteristics of those alternatives he knows of are imprecise. His perception X_i^p of attribute X_i may therefore be represented by a random continuous variable, having a distribution $f_i^p(x_i)$. Note that these perceptions may also be represented as discrete variables, which would not change the general argument made here. Throughout this paper, the normal distribution will be adopted to this aim, although many other distributions may prove suitable for the arguments made:

$$X_i^p \sim f_i^p(x_i) = N(\hat{x}_i^p, \sigma_i^p) \tag{5}$$

These perceptions are characterized by a mean $\hat{x}_i^p$ and a standard deviation σ_i^p. The mean represents the traveler's 'best guess' for a certain characteristic, the standard deviation represents the perceived unreliability of that estimate[15]. The utility of a particular state of a perceived alternative can now be expressed as $u(x_i)$.

3.3.2 Expected regret under satisficing and maximizing

As defined in Section 3.2, a satisficer that is confronted with perceived incomplete knowledge of the characteristics of alternatives known to him faces expected regret, as he is not certain whether an alternative Y_i under consideration will turn out to be good enough. More precisely, the expected regret induced by choosing Y_i may be formulated as the sum of the possible realizations of states for which the realized utility of that alternative is lower than the traveler's aspiration level, weighed by the probability of occurrence of these states and the difference between realized and aspired utility. Note that this and all forthcoming measures of expected regret are expressed in terms of the utility of the alternatives that are under consideration:

$$ER_{Sat}(Y_i) = \int_{-\infty}^{+\infty} \left[\gamma_i \cdot \left(u_{aspiration} - u(x_i)\right)\right] \cdot f_i^p(x_i)\, dx_i \tag{6}$$

where[16]: $\gamma_i = \begin{cases} 1 \Leftrightarrow u_{aspiration} > u(x_i) \\ 0 \Leftrightarrow u_{aspiration} \le u(x_1) \end{cases}$

As the traveler is assumed to choose the alternative which induces the lowest level of expected regret, the following notation represents the expected regret that is induced by a choice situation:

$$ER_{Sat} = \min_{k=i,j}\left(ER_{Sat}(Y_k)\right) \tag{7}$$

A maximizer that is confronted with perceived incomplete knowledge about the characteristics of the alternatives known to him and the availability of alternatives unknown to him, faces an expected regret as he is not certain that a considered alternative Y_i will turn out to be the best alternative in the universal set. Specifying this latter aspect, he knows that 1) another alternative *known to him* might turn out to be better than the alternative under consideration, and that 2) there might be an alternative that is *unknown to him* that turns out to be better. The difficulty in conceptualizing this second issue is that it mentions unknown

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[15] Should the more realistic case of alternative evaluation based on more than one attribute be discussed, and given that the alternative Y_i is defined as a bundle of its relevant characteristics X_{im}, this leads to the definition of a perception of this alternative Y_i^p as a joint density function representing the traveler's joint perception of all relevant characteristics of the alternative: $Y_i^p \sim f_i^p(x_{i1}, x_{i2}, ..., x_{im}, ...)$.

[16] The notion of γ_i will be used throughout this paper, with varying indices, to denote a possible violation of an aspiration level.

alternatives and the utility that may be derived from them. By definition the traveler is unaware of any unknown alternatives or their characteristics, so there is no way of determining exactly what utility levels he may perceive that could possibly be derived from them. However, it can be assumed that a traveler would conceive the value of the relevant characteristic X_Z of the unknown alternative (e.g. an unknown route's travel time), as being drawn from some probability distribution - meaning in the present case that he conceives the unknown alternative itself as being drawn from this distribution[17]. However, the traveler cannot be assumed to have any best estimate, as is the case in his perception of known alternatives. This should be reflected in the flatness (or breadth of spread around the mean) of the applied distribution. A uniform distribution[18] on some interval $[a,b]$ suits this condition, and will be used throughout this paper to represent a traveler's incompleteness of knowledge concerning unknown alternatives:

$$X_Z \sim f_Z(x_Z) = U(a,b) \tag{8}$$

Rather than assuming that the traveler will have ideas concerning the values of the end-points of this distribution themselves, it may be assumed that he has some ideas of the probability α that the value x_Z of the given characteristic of the unknown alternative Z will be higher than the traveler's best estimate $\hat{x}_i$ of this characteristic for one of the known alternatives, e.g. Y_i. For example, the traveler may have some ideas about the probability that the unknown route will have a higher travel time than any particular known route. The traveler may also be assumed to have some expectation δ of the difference in value of the characteristic between the unknown alternative and this known alternative. By simultaneously solving $\alpha = (b - \hat{x}_i)/(b-a)$ and $\delta = (b+a)/2 - \hat{x}_i$, the end-points of the interval that represents the unknown alternative Z can be written in terms of $\hat{x}_i$, α and δ:

$$a = 2 \cdot (\hat{x}_i + \delta) - b \tag{9}$$

$$b = \frac{2\alpha \cdot (\delta + \hat{x}_i) - \hat{x}_i}{2\alpha - 1} \tag{10}$$

Take for example, the situation where a traveler's best estimate for a known route's travel time is 30 minutes, and he would say that the unknown route has a 95% chance of having a higher travel time. When his best guess for the difference between the two is 8 minutes (that is, the unknown route takes 8 minutes longer), the end-points of the interval that reflects his guess for the unknown route's travel time are $[29,47]$ minutes. Note that, depending on the sign of utility function that maps the values of characteristics on utility levels, α and δ are indicators of the traveler's perception of his own resourcefulness, i.e. the quality of the alternatives he knows of, relative to the quality of unknown alternatives. For example, given a

[17] A somewhat similar conceptualization, made on the utility level however, can be found in Richardson (1982).

[18] Note the subtle difference between the interpretation of the distributions describing on the one hand the traveler's perception of a known alternative Y_i^p and his notion of the unknown alternative Z. The former refers to the fact that the traveler knows that the dynamic nature of the transport network may lead to a deviation from the traveler's best estimate for a characteristic. The latter distribution also refers to the fact that the traveler has no best estimate for this characteristic in the first place: the estimates themselves are distributed as well. A normal distribution with a very large standard deviation might also be suiTable for representing the perception of unknown alternatives.

positive utility-mapping, low values for α and negative values for δ signal high perceived quality of the known alternatives, or equivalently, low perceived quality of unknown alternatives.

Given these conceptualizations, the regret a maximizing traveler expects to be induced by choosing alternative Y_i can now be formulated as the sum of possible realizations of states for which the realized utility of a considered alternative Y_i is lower than that of the other known alternative Y_j or the unknown alternative Z, weighed by the probability of occurrence of these states of known and unknown alternatives and the difference between the realized levels of utility.

$$\begin{aligned} ER_{Max}(Y_i) = & \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\left[\gamma_{ij}\cdot\left(u(x_j)-u(x_i)\right)\right]\cdot f_j^p(x_j) f_i^p(x_i)\,dx_j dx_i + \\ & \int_a^b\int_{-\infty}^{+\infty}\left[\gamma_{iZ}\cdot\left(u(x_Z)-u(x_i)\right)\right]\cdot f_Z(x_Z) f_i^p(x_i)\,dx_Z dx_i \end{aligned} \tag{11}$$

where[19]: $\gamma_{ij} = \begin{cases} 1 \Leftrightarrow u(x_j) > u(x_i) \\ 0 \Leftrightarrow u(x_j) \le u(x_i) \end{cases}$ and $\gamma_{iZ} = \begin{cases} 1 \Leftrightarrow u(x_Z) > u(x_i) \\ 0 \Leftrightarrow u(x_Z) \le u(x_i) \end{cases}$

As the traveler is assumed to choose the alternative which induces the lowest level of expected regret, the following represents the expected regret induced by a choice situation:

$$ER_{Max} = \min_{k=i,j}\left(ER_{Max}(Y_k)\right) \tag{12}$$

This Section has presented mathematical formulations of the decision strategy-specific concept of expected regret. Based on these formulations, the next Section will derive decision strategy-specific formulations for the perceived value of information acquisition.

3.4 Perceived information value for alternative generation

This Section focuses on information that is acquired with the aim of generating alternatives that are currently unknown to the traveler, i.e. with the aim of adding alternatives to one's choice set. Firstly, we discuss the message that is expected to be received when the information service is asked to generate an alternative. Secondly, we look at what the expected effect may be of having received a particular message in terms of a reduction in expected regret.

3.4.1 What message is expected to be received?

It is assumed here, that the information service will always provide the traveler with the unknown alternative, although in reality less sophisticated services may also generate an alternative the traveler is already aware of. The format of the message to be received can be

[19] The notion γ_{ij} will be used throughout this paper, with varying indices, to denote the situation where the utility of the alternative represented by the first index is surpassed by the utility of the other alternative.

denoted as: $X_Z = x_Z^I$, where x_Z^I is the service's estimate for the value of the only relevant characteristic X_Z of the formerly unknown alternative Z. Should the information service be perceived as to provide completely reliable estimates of the characteristic, the perceived process of the generation of unknown alternatives may be regarded as the making of a random draw from the probability distribution $f_Z(x_Z) = U(a,b)$, giving $X_Z^I \sim f_Z(x_Z) = U(a,b)$. However, as for example future and unforeseen events in the transport system may lead to deviations from the information service's estimates for the actual values of characteristics (e.g. estimated travel times for some route), received messages may be perceived as unreliable. This perceived unreliability can be represented by assuming that a traveler thinks that, conditional to the occurrence of an actual value of a characteristic x_Z, the information service will provide him with a message $X_Z = x_Z^I$ that is drawn from a normal distribution having the actual value as mean, and having a standard deviation that represents the traveler's perception of the information service's unreliability:

$$x_Z^I \big| x_Z \sim N(x_Z, \sigma_Z^I) \tag{13}$$

A traveler may also perceive the information service to have a structural bias from the actual value, e.g. structurally underestimate the travel time by 10 minutes. Such a perceived structural bias can be represented by adding a constant τ to the mean of the normal distribution that was given in expression (13). Given this perception of partial unreliability of the information service, the probability function that reflects the traveler's beliefs concerning what messages may be received, can be denoted as:

$$X_Z^I \sim f_Z^I(x_Z) = \int_a^b f\left(x_Z^I \big| x_Z\right) \cdot f(x_Z)\, dx_Z \tag{14}$$

Although in this paper it is assumed that the traveler is only aware of the existence of one unknown alternative, the issue of multiple unknown alternatives will be briefly discussed here as well, because this generalization is not trivial from the perspective of message receiving. As the service is asked to generate one of multiple unknown alternatives, it becomes important to what extent the service is perceived to be capable of selecting the best one of the unknown alternatives available. The traveler's perception of the service's capability in this regard can be denoted as perceived resourcefulness. This resourcefulness can be formulated by assuming that the information service is perceived to draw values only from the top $(1-\lambda)\cdot 100\%$ of the distribution $X_Z \sim f_Z(x_Z) = U(a,b)$, which leads to the following distribution representing the alternative generation process, given full reliability of the service:

$$X_Z^I \sim f_Z^I\left(x_Z^I\right) = U\left(a^I, b\right) \tag{15}$$

where a^I can be obtained by solving $1-\lambda = \dfrac{b-a^I}{b-a}$, which leads to:

$$a^I = a + \lambda \cdot (b-a) \tag{16}$$

A resourcefulness of $\lambda = 0$ refers to the extreme case of very low resourcefulness, as $a^I = a$: asking the service to generate an alternative is nothing more than making a random draw from the set of unknown alternatives. A resourcefulness of $\lambda \approx 1$ refers to a service that is perceived to always generate the most attractive unknown alternative, as $a^I = b$. In the following, again the situation of one unknown alternative is assumed.

3.4.2 The effect of a received message in terms of reduction in expected regret

After having received a particular message in the form of $X_Z = x_Z^I$, the unknown alternative becomes known, and therefore available to be chosen. However, as the traveler may perceive the information service as being not fully reliable, the fact that an alternative is generated by the information service does not mean that the traveler knows that he has gained complete knowledge over its relevant characteristic. He now does have a best estimate $\hat{x}_Z = x_Z^I$ for this alternative's characteristic, and he perceives this best estimate as partly reliable, which is reflected through the standard deviation σ_Z^I. The traveler's perception of alternative Z's characteristic X_Z has thus changed from the flat uniform distribution $X_Z \sim f_Z(x_Z) = U(a,b)$, representing a mere guess, into the more skewed normal distribution $X_Z^p \sim f_Z^p(x_Z) = N(x_Z^I, \sigma_Z^I)$, representing a best estimate and a deviation. Based on the above discussions on what messages may be expected to be received when asking an information service to generate an alternative, and on what may be the expected effect of such a received message in terms of the formation of a perception of the alternative, the expected regret remaining after having asked the information service to generate an unknown alternative can now be formulated. For every message that one may expect to be generated by the information service, weighed by the probability of occurring $f_Z^I(x_Z)$, a perception $f_Z^p(x_Z)$ is formed, taking into account the traveler's beliefs about the level of reliability of the information service. This perception is subsequently compared to the traveler's initial perception of the alternatives he already knew. A satisficing traveler will now evaluate whether his perception of the newly generated alternative Z induces an expected regret against *the aspiration level* that is lower than that of the formerly known alternatives. If so, the generated alternative will be chosen and the overall expected regret induced in the choice situation (ER_{Sat}^{Gen}) diminishes.

$$ER_{Sat}(Z) = \int_{-\infty}^{+\infty} \left[\gamma_Z \cdot \left(u_{aspiration} - u(x_Z)\right)\right] \cdot f_Z^p(x_Z)\, dx_Z \tag{17}$$

$$ER_{Sat}^{Gen} = \int_{a}^{b} \left[\min\left\{ER_{Sat}(Y_i), ER_{Sat}(Y_j), ER_{Sat}(Y_z)\right\}\right] \cdot f_Z^I(x_Z)\, dx_Z \tag{18}$$

A maximizing traveler will evaluate whether the perception of the newly generated alternative induces an expected regret given his perception of *the other alternatives*, that is lower than that of the formerly known alternatives. If so, the generated alternative is chosen and the overall expected regret induced by the choice situation (ER_{Max}^{Gen}) diminishes. Also when the generated alternative appears relatively unattractive and is therefore not chosen, a reduction in expected regret is possible as the traveler now perceives that the chosen alternative has a lower chance of being surpassed in quality by other alternatives available in the transport system.

$$ER_{Max}^{Gen} = \int_a^b \left[\min_{k=i,j,Z} \left(\sum_{l \in \{i,j,Z\} \neq k} \int_{-\infty}^{+\infty} \int \left[\gamma_{kl} \left(u(x_l) - u(x_k) \right) \right] f_l^p(x_l) f_k^p(x_k) dx_l dx_k \right) \right] f_Z^I(x_Z) dx_Z$$

(19)

This leads to the following formulations for the perceived value of information acquisition that aims to generate alternatives in a satisficing (20) and a maximizing (21) context:

$$PIV_{Sat}^{Gen} = ER_{Sat} - ER_{Sat}^{Gen} \tag{20}$$

$$PIV_{Max}^{Gen} = ER_{Max} - ER_{Max}^{Gen} \tag{21}$$

3.5 Perceived information value for alternative assessment

This Section focuses on the value of information concerning a specific characteristic of an alternative that is already known to the traveler.

3.5.1 What message is expected to be received?

At first, it may seem somewhat strange to assume that a traveler that is uncertain about the actual value of a characteristic, does have expectations concerning what message to receive when asking an information service for an estimate: if a traveler knows what messages to expect when acquiring information, why should he make the effort to acquire the information at all? It should be noted however, that it is meant here that the traveler has *some* expectations concerning the information to be received, based on his initial perceptions concerning the value of the characteristic, reflected in $X_i^p \sim f_i^p(x_i)$ and the perceived unreliability of the information service, reflected in $f(x_i^I | x_i) \sim N(x_i, \sigma_i^I)$. Formally, we can express the travelers expectations concerning messages in the form of $x_i = x_i^I$ to be received regarding alternative Y_i's characteristic X_i as follows:

$$X_i^I \sim f_i^I(x_i) = \int_{-\infty}^{+\infty} f(x_i^I | x_i^p) \cdot f(x_i^p) dx_i^p \tag{22}$$

3.5.2 The effect of a received message in terms of reduction in expected regret

When a traveler receives a message from the information service, he uses it to update his earlier perception into a new one. While doing so, he must deal with the fact that both his initial perception concerning the alternative, as well as the message received, are only partly reliable –this is reflected in σ_i^p and σ_i^I respectively. An updating mechanism that takes into account these two sources of unreliability, is that of Bayesian perception updating, where probabilities are updated using Bayes' law. A widely used concept throughout psychological research (e.g., Edwards et al., 1963; Phillips and Edwards, 1966), Bayes' law has been recently adopted in travel demand contexts to explain updating processes concerning for example unreliable travel-time estimates (Kaysi, 1991; Chen & Mahmassani, 2004; Arentze

& Timmermans, 2005a; Chorus et al., 2005a). Under the assumption of a normally distributed[20] initial perception of both the characteristic X_i^p as well as messages received X_i^I, we can, applying Bayes' law for continuous variables (see Edwards, et al., 1963), derive the traveler's updated perception X_i^u as follows:

$$X_i^u \sim f_i^u(x_i) = N(\hat{x}_i^u, \sigma_i^u) \tag{23}$$

where:

$$\hat{x}_i^u = \left(\frac{1}{\sigma_i^p}\right)^2 \cdot \hat{x}_i^p + \left(\frac{1}{\sigma_i^I}\right)^2 \cdot x_i^I \Bigg/ \left(\frac{1}{\sigma_i^p}\right)^2 + \left(\frac{1}{\sigma_i^I}\right)^2 \tag{24}$$

$$\sigma_i^u = \sqrt{\left({\sigma_i^p}^2 \cdot {\sigma_i^I}^2\right) / \left({\sigma_i^p}^2 + {\sigma_i^I}^2\right)} \tag{25}$$

Note that, completely in line with intuition, the more reliable the information service is believed to be (i.e. the lower is σ_i^I), the more the updated perception resembles the message that is received through the information service. Note also that the more reliable the information is believed to be, the more confidence the traveler will have in his updated perceptions (reflected in a lower σ_i^u). These notions are key to the reduction in expected regret that may occur through acquiring information.

It is important to note here that the expected regret, under either satisficing or maximizing contexts, of the alternative for which information is acquired may be influenced by a received message in several ways. First, due to the message received, the traveler's best estimate for an alternative's characteristic may be altered, which directly leads to an increase or a decrease in expected regret that may be induced by the alternative (take for example the traveler who finds out that the travel time of a route he is considering is twice the normal travel time, due to an incident). Secondly, as the confidence in his estimate for some alternative's characteristic increases due to the reception of a message, or in other words as the spread of the perception of an alternative decreases, the lower tail of the distribution reflecting this perception is less likely to interfere with aspiration levels or the utility distributions of less attractive alternatives, in both cases decreasing expected regret. Thirdly, it may be possible that, even if the new information does not result in a changed decision, the traveler attaches a disutility to uncertainty per se (depending on his or her risk attitude). A reduction in uncertainty caused by receiving a message then indirectly results in an increase in perceived utility, decreasing the probability of interference of the alternative with aspiration levels or less attractive alternatives. Next to these three aspects that refer to the expected regret of the alternative a message is received for, the expected regret of an entire choice situation may be diminished by receiving an estimate for some characteristic, as the traveler is given the possibility to capitalize on the improved accuracy of his choice: even the perspective of possibly receiving a disappointing message may reduce the regret that is expected to remain

[20] This assumption is often made, and often criticized for being a less valid representation of perceptions from a behavioural point of view (e.g., Bonsall, 2001). However, the assumption is non-critical for the argument made here, and is only made for reasons of simplicity: the normal distribution can be replaced by other distributions, as long as these are conjugate priors, i.e. priors that are conjugate to the distribution representing the perceived unreliability of the information service.

in the choice situation, as the traveler knows that, based on the received message, he has the possibility to not choose the alternative for which the disappointing message was received. Based on the above conceptualization of what messages may be expected to be received when asking an information service for an estimate for the characteristic of a known alternative Y_i, and of what may be the expected effect of such a received message in terms of perception updating, the expected regret that is perceived to remain after having asked the information service for an estimate concerning this characteristic for Y_i can now be formulated. For every message that may be expected to be received through the information service, weighed by the probability of receiving $f_i^I(x_i)$, an updated perception $f_i^u(x_i)$ is formed using Bayes' rule, taking into account the traveler's beliefs about the level of reliability of his initial estimate and that of the information service. This updated perception is subsequently used to re-evaluate the choice situation. A satisficer's expectations of regret may now be formulated as follows:

$$ER_{Sat}^{Assess}(Y_i) = \int_{-\infty}^{+\infty} \left[\gamma_i \cdot \left(u_{aspiration} - u(x_i)\right)\right] \cdot f_i^u(x_i)\, dx_i \tag{26}$$

$$ER_{Sat}^{Assess} = \int_{-\infty}^{+\infty} \left[\min\left\{ \underset{Y_i}{ER_{Sat}^{Assess}}, \underset{Y_j}{ER_{Sat}} \right\}\right] \cdot f_i^I(x_i)\, dx_i \tag{27}$$

A maximizer's expectations of regret induced by a choice situation may be formulated as follows:

$$ER_{Max}^{Assess} = \int_{-\infty}^{+\infty} \left[\min \left\{ \begin{array}{l} \left(\begin{array}{l} \int_{-\infty} \int^{+\infty} \left[\gamma_{ij}\left(u(x_j) - u(x_i)\right)\right] f_j^p(x_j) f_i^u(x_i)\, dx_j dx_i + \\ \int_a^b \int_{-\infty}^{+\infty} \left[\gamma_{iZ}\left(u(x_Z) - u(x_i)\right)\right] f_Z(x_Z) f_i^u(x_i)\, dx_Z dx_i \end{array} \right), \\ \left(\begin{array}{l} \int_{-\infty} \int^{+\infty} \left[\gamma_{ji}\left(u(x_i) - u(x_j)\right)\right] f_i^u(x_i) f_j^p(x_j)\, dx_i dx_j + \\ \int_a^b \int_{-\infty}^{+\infty} \left[\gamma_{jZ}\left(u(x_Z) - u(x_i)\right)\right] f_Z(x_Z) f_j^p(x_j)\, dx_Z dx_j \end{array} \right) \end{array} \right\} \right] f_i^I(x_i)\, dx_i$$

(28)

This leads to the following formulations for the perceived value of information aiming to assess alternatives in a satisficing (29) and a maximizing (30) context:

$$PIV_{Sat}^{Assess} = ER_{Sat} - ER_{Sat}^{Assess} \tag{29}$$

$$PIV_{Max}^{Assess} = ER_{Max} - ER_{Max}^{Assess} \tag{30}$$

Now that all mathematical derivations are made, let us briefly refer back to the claim made at the beginning of Section 3.3, where is mentioned that the derivations made may be straightforwardly extended for the case of multiple known and unknown alternatives and multiple uncertain characteristics that are to be evaluated. Apart from the issue of information service resourcefulness, addressed in Equations (15) and (16), all the derivations are valid for the case of more complicated travel situations. Also the situation where an information service might present a traveler with multiple options at the same time may be formulated based on the concepts introduced here. However, for more complicated messages, e.g. those that involve giving advice to travelers, new derivation should be made. These might well be based on the formulations presented here. Furthermore, it may be expected that the computation of measures for expected regret and information value in travel situations involving multiple alternatives and characteristics potentially leads to difficulties in numerical evaluation, due to the possibility of combinatorial explosion.

3.6 Numerical examples

In order to further clarify the workings of these derivations and provide some initial validity to them, numerical examples are presented and discussed in this Section. An arbitrary and highly simplified travel situation will serve as a base case for the numerical examples provided (see Figure 1): a car-driver knows of two routes that may take him to his destination, evaluating them on travel times only. He heard of the existence of a third route, though he does not know it and therefore cannot choose it, in the sense explained in Sub-section 3.3.1. His best estimate for the first route's travel time is 55 minutes and he attaches an unreliability to this estimate, in the sense that he perceives the route's travel time as being normally distributed with mean 55 minutes and standard deviation 8 minutes. Equivalently, he perceives the second route's travel time as being drawn from a normal distribution with mean 70 minutes and a standard deviation of 8 minutes. He perceives the travel time of the unknown route to be drawn from $U[40,70]$, i.e. he believes that on average the unknown route is just as good as the best of his two known routes. He attaches a negative utility of one unit per minute travel time. He has an appointment starting 60 minutes from now, and thus any alternative with a utility higher than –60 is perceived as being good enough, should he be a satisficer (i.e. his aspiration level is set at –60). Furthermore, the traveler may acquire information concerning the generation of unknown alternatives, or the assessment of route 1's travel time, and he attaches an unreliability to messages received from the information service, represented by a standard deviation of 2 minutes.

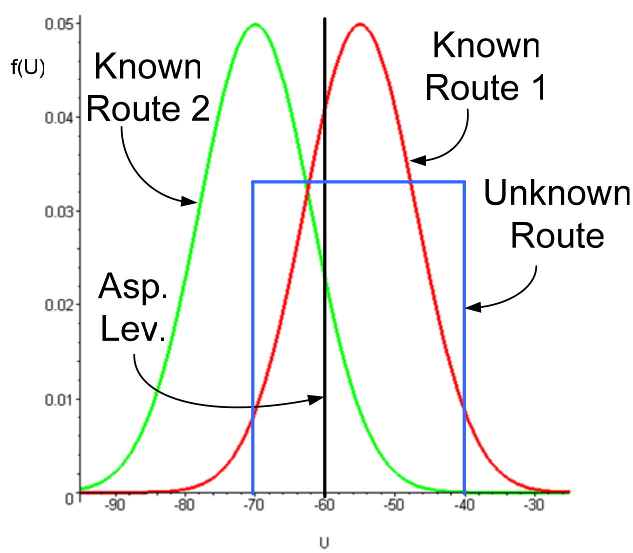

Figure 1: The base-case travel situation

Using expression (6), it can be computed[21] that in this base-case situation, a satisficer would experience an expected regret of 1.2 utils when choosing route 1, and 10.1 utils when choosing route 2. It can be seen using expression (11) that a maximizer would experience an expected regret of 5.0 utils when choosing route 1, and 30.9 utils when choosing route 2. Both types of choice-makers would therefore choose route 1 over route 2, given the settings of this base-case.

Figure 2 shows the effect of a traveler's knowledge concerning the existence of unknown alternatives in the transport system on his perception of information value for alternative generation[22]. That is, expressions (20) and (21) are evaluated for different end-point values of the uniform interval from which the traveler thinks the unknown route's travel time might be drawn. As stated in expressions (9) and (10), the traveler's perception of these end-point values is an indicator of his perception of the relative quality of the alternatives he does know of compared to those he is not aware of. Starting with the interval $TT \sim U[40,55]$, meaning that the traveler thinks that the unknown route is probably faster than the fastest one he knows of and that the mean travel time difference is 7.5 minutes, the upper bound of the interval is varied with stepsize 5 until the base-case value of 70 minutes is reached. Two main points may be drawn from this example: firstly, it appears that for both satisficers and maximizers, an increasing end-point of the interval from which travel times for unknown alternatives is drawn causes a decrease in the perceived value of generating an alternative from that distribution. Clearly, this result is logical and consistent with literature (Denant-Boèmont & Petiot, 2003; Peirce & Lappin, 2004) as information concerning unknown travel alternatives becomes less valuable as the expected values of the alternatives becomes less attractive in the eyes of the traveler. Secondly, maximizers appear to perceive the information as being more valuable than satisficers with the same preferences for routes and travel times. This results from the fact that among maximizers, the existence of viable alternatives unknown to them by definition adds to their expected regret (see expression (11)), which is not the case for satisficers. A maximizer will therefore accept higher 'costs' in order to reduce the number of unknown alternatives than a satisficer, who will only do so to the extent that he perceives known alternatives as being unsatisfactory.

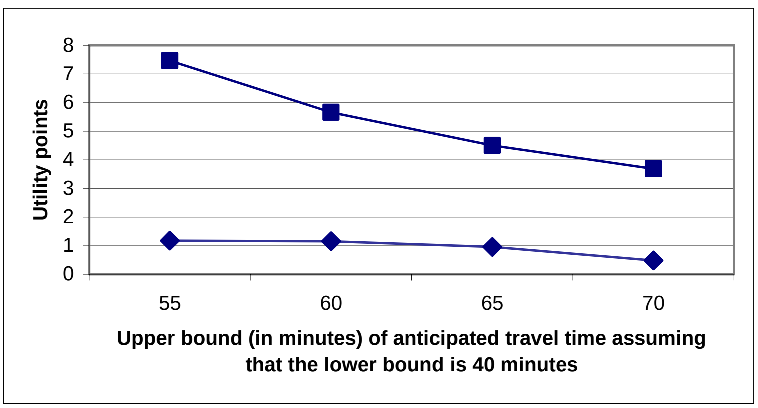

Figure 2: Impact of perceived quality of unknown alternatives on information value

[21] All integrals that are evaluated for computations in this Section are evaluated through simulation using each time 150 draws from their respective probability density functions.

[22] Like is also the case in Figures 3 and 4, the square dots represent computed values of information for maximizers, whereas the diamond dots refer to corresponding values for satisficers.

Figure 3 shows the effect of a traveler's knowledge concerning the characteristics of known alternatives (in this case travel times for different routes) on his perception of information value for alternative assessment. That is, expressions (29) and (30) are evaluated for the different levels of unreliability the traveler attaches to his own estimates for route 1's travel time, operationalized through varying the standard deviation belonging to his estimates from 2 (high perceived reliability) to 8. In line with intuition and literature (Hato et al., 1999; Yim & Khattak, 2001; Targa et al., 2003; Petrella & Lappin, 2004), increasing knowledge, or equivalently a decreasing volatility in the transport network, leads to decreasing information value. Note the difference between satisficers and maximizers: for satisficers, the information value becomes practically zero when one perceives his own knowledge as being very reliable. In that case, given the estimated mean travel time of 55 minutes, the traveler will experience very little expected regret. A maximizer however, will also in this case experience expected regret, as the possibility remains of route 2 or 3 (the unknown route) being more attractive.

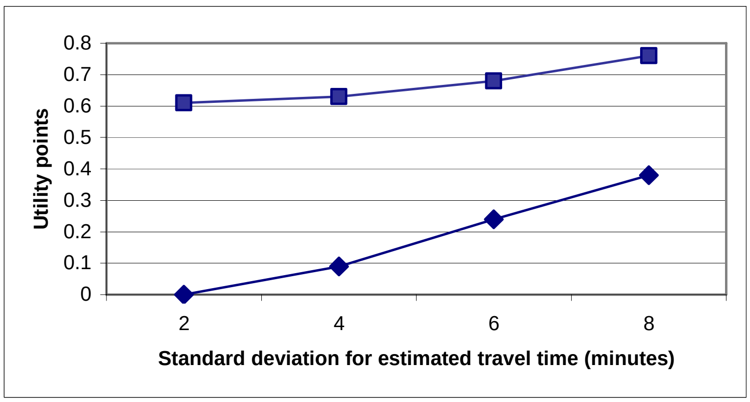

Figure 3: Impact of perceived knowledge for known alternatives on information value

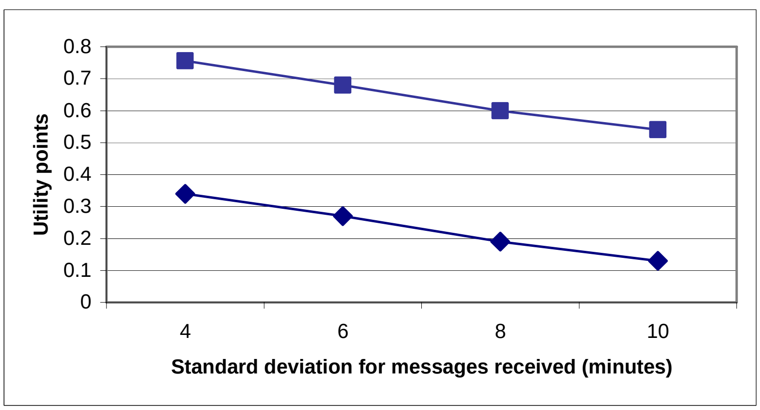

Figure 4: Impact of perceived info unreliability for known alternatives on info value

The third and last example deals with the issue of information service reliability. Figure 4 presents the impact that increasing information service unreliability (or increasing standard deviation that a traveler puts on the message received by this service) has on his perception of information value, this standard deviation varying from 4 to 10. Obviously, and again in congruence with literature (Polydoropoulou & Ben-Akiva, 1998; Hato, et al., 1999), the value of acquiring information from a service rapidly decreases once the traveler believes that the messages to be received are unreliable.

3.7 Conclusions

This paper presented the derivation of conceptual and mathematical models of the value of travel information. Applying notions of search-theory and Bayesian updating of perception, and integrating these in a utilitarian framework, measures for the perceived information value are developed that are consistent with both satisficing and maximizing choice-behavior. The models explicitly take into account both information acquisition that aims at generating new alternatives, as well as information acquisition aimed at assessing alternatives that are already known to the traveler. In order to clarify some important mechanisms behind these formulations, and at the same time provide some first face validity to the approach, numerical examples are presented that simulate the perceived value of information for different knowledge levels of the individual, and for different levels of reliability of the information service. The examples indeed provide preliminary confidence, as occurring trends are consistent with intuition and empirical literature.

Nevertheless, extensive empirical validation of the presented models is warranted. Such validation will be performed in the near future: using an interactive travel environment, empirical experiments have been performed concerning travelers' information acquisition behavior under uncertainty in multimodal networks (Chorus et al., 2006). The data obtained through these experiments will be used for validation efforts concerning the proposed measures of information value in short term. should this validation give positive results, the models of information value presented here can be used in several ways in order to help understand some of the subtle and complex behavioral mechanisms that drive travelers' acquisition of travel information and its effect on their choice-behavior. Firstly, as is done in this paper for a simplified example using synthetic data, the measures of information value can be applied to predict trends in the use of information services. Relative changes in perceived information value and ATIS use, based on changes in the characteristics of the information service, the travel situation, characteristics of the travel alternatives available and the traveler himself can be directly simulated using the measures developed here. Secondly, these measures, in combination with empirical choice data on ATIS use, can be used to estimate parameters defining the trade-off travelers make between the value and costs of information acquisition. Enriched with these parameters, these measures can now give predictions of ATIS use (e.g. in the form of market shares), and changes in ATIS use due to changes in all sorts of explanatory variables.

Note that although the approach taken in this paper towards travel information is rather general, the value of several forms of travel information may not be directly derived using the expressions presented here. This goes especially for the case of information services that provide advice concerning what route to take, or services that provide a number of messages (estimates or either complete alternatives) simultaneously. Furthermore, it should be noted that the present framework does not attempt to describe the value of information when information acquisition is embedded in longer term learning processes. However, we do feel that the measures of perceived information value developed here can be used as building blocks in such more complex applications, and in the core of many different model applications in the field of travelers' use of information and information services in general. These models are envisaged to be more realistic from a behavioral point of view than models currently used, and therefore to be more able to ex-ante evaluate the market potential of ATIS.

This might lead to a wiser allocation of investments in travel information technology and potential improvements in transport policies that include the provision of travel information.

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Chapter 4

Chorus, C.G., Molin, E.J.E., Arentze, T.A., Timmermans, H.J.P., van Wee, G.P., 2007. Travelers' need for information in traffic and transit: results from a websurvey. *Submitted for publication.* [23]

Abstract

This paper investigates (determinants of) travelers' needs concerning travel information, based on a web survey filled out by 488 individuals. It aims at narrowing down three identified gaps in empirical literature available on this topic. Firstly, instead of focusing on the influence of manifest factors on travelers' need for information, such as trip circumstances, this paper addresses the role of behavioral factors, in specific travelers' perception of their own knowledge levels. Secondly, instead of focusing only on currently available types of travel information, such as information on travel time and cost, this paper also discusses travelers' need for a number of more advanced types of travel information, such as personalized early warning functions. Thirdly, instead of focusing on travel by car or transit, this study considers travelers by both modes simultaneously, and makes comparisons between these two groups. A number of new empirical findings is reported.

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4.1 Introduction

Providing travelers with relevant information on travel options is generally acknowledged as having the potential to change their behavior in ways that are beneficial to the efficiency of the use of the transport system (e.g. Koppelman & Pas, 1980; Kanninen, 1996, European Commission, 2001a, b; Dutch Ministry of Transport, 2002; Transportation Research Board, 2004). Services providing such information (Advanced Traveler Information Services or ATIS) are widely available nowadays for travelers, and are becoming more advanced every year. Recently, rapid technological developments in mobile communications have provided a vision among telecommunication companies, transport agencies, governments and academia of a technological revolution in ATIS towards what can be called the next generation ATIS (e.g. Adler & Blue, 1998; TRAIL Research School, 2002). This next generation ATIS will eventually be able to provide at anytime a traveler with all the personalized travel information, asked for and unasked for, that is relevant to her given her time and place in the multimodal transport network and her personal characteristics and preferences. This vision of ever more advanced travel information services provides opportunities for many players in the field of personal mobility and information provision, including public transport companies and the automotive industry, providers of personal telecommunication services and also policy makers that in some way wish to induce changes in travelers' choices for departure times, routes and travel modes. A necessary condition for these opportunities to be fulfilled, is that travelers use the information that might eventually be provided to them. Therefore it is no surprise that over the last 15 years an abundant empirical literature concerning (determinants of) travelers' need for and use of travel information has been established, which has produced a number of interesting insights. We will briefly present some of these insights here (see Chorus et al., 2006a for an overview of this literature).

A significant number of findings relate to the influence of socioeconomic factors: literature states that male, highly educated, high-income travellers (e.g. Petrella & Lappin, 2004) are more likely than others to use travel information, as well as professionals (Emmerink et al., 1996), as these appear to attach greater importance to making an accurate choice (Hato et al., 1999). Travellers that own mobile phones (Polydoropoulou & Ben-Akiva, 1998; Yim et al., 2002) and are connected to and make use of the internet are relatively prone to use ATIS. Polak & Jones (1993) and Petrella & Lappin (2004) found that ATIS use may differ significantly across regions and countries, partly due to differences in transport systems. Also, insights have been gained into the role of trip circumstances: expected congestion or expected volatility in travel times induces a search for and use of ATIS (Hato et al., 1999; Yim et al., 2002; Targa et al., 2003; Petrella & Lappin, 2004). Travelling during peak hours in general also increased the likelihood of ATIS use (Peirce & Lappin, 2004). It has also been found that longer trips increase a traveller's need for travel information, pre- as well as in-trip (Emmerink et al., 1996; Lappin, 2000; Yim et al., 2002, Targa et al., 2003). Furthermore, the expectation of bad weather during the trip causes an increase in ATIS use (Polydoropoulou & Ben-Akiva, 1998; Peirce & Lappin, 2004). Concerning the influence of trip purposes on information needs, it was found that commuter trips (Petrella & Lappin, 2004) and especially business trips (Emmerink et al., 1996; Hato et al., 1999) appear to induce the search for and use of ATIS, mainly because these are generally arrival time-sensitive trips (Polydoropulou & Ben-Akiva, 1998; Srinivisan et al., 1999).

Although this existing body of empirical literature concerning travelers' need for and use of information has obviously presented numerous interesting results, we feel that it has so far not adequately addressed three important issues. Firstly, existing studies have predominantly focused on the role of manifest factors on information needs, rather than addressing underlying behavioral factors (notable exceptions are Bonsall & Parry (1990) and Denant-Boemont & Petiot (2003)). With manifest factors we refer to all factors that are non-behavioral. Behavioral factors are conceptualized here as factors that directly relate to travelers' emotion or cognition. Examples of the former are trip purpose, weather conditions, whether or not a destination has been visited before, age, education level, etc. Examples of the latter are decision styles, knowledge levels, learning, habit formation, etc. As Chorus et al. (2006a) show, manifest factors are often used by travel demand researchers in their analysis as proxies for behavioral factors. The relatively scarce *empirical* interest in the role of behavioral factors is somewhat surprising, given the apparent *theoretical* interest how these factors shape traveler response to information (e.g. Ben-Akiva et al., 1991; Schofer et al., 1993; Arentze & Timmermans, 2005a; Chorus et al., 2006b). Secondly, the large majority of empirical work on the topic of need for and use of information (a notable exception being Kenyon & Lyons (2003)) has dealt with currently available information (services), rather than travelers' need for types of information that are not yet, but perhaps will soon be, available to them. Probably, this is due to the fact that reliable data is far more readily available for the former than for the latter types of information. Thirdly, existing empirical work has focused on either the need for information among car-drivers or among transit users instead of simultaneously studying and comparing the two groups with respect to their needs for travel information.

This paper aims at narrowing down to some extent these three identified gaps in the literature by presenting the results of an empirical study. More specifically, it aims at providing answers to the following three questions: i) What is the role of travelers' level of perceived knowledge in the formation of their travel information needs in general? ii) What are travelers' needs for several basic and more advanced types of travel information in specific? iii) Do the answers to questions i) and ii) differ between travelers that predominantly travel by car and those that use public transport? A web survey filled out by 488 inhabitants of The Netherlands is used for data-collection.

The following scope of research is adopted: firstly, we confine ourselves to the analysis of two distinct forms of knowledge: reliability of estimates of attributes of travel alternatives (such as a route's travel time), and resourcefulness in terms of being aware of many routes towards a destination for a given mode. It should be noted here, that transportation researchers increasingly (at least from a theoretical viewpoint) acknowledge that a variety of other knowledge dimensions may play important roles in shaping traveler response to information, as is most convincingly conceptualized through the notions of spatial cognition and mental maps (e.g. Arentze & Timmermans, 2005b; Hannes et al., 2006). Secondly, we confine ourselves here to the study of non-professional travelers. It may be expected, and is also empirically established (see e.g. Bogers & van Zuylen, 2004) that professional travelers have their own distinct ways of responding to knowledge limitations and the provision of information. Thirdly, this study focuses on the identification of behavioral relationships, rather than the policy implications that may be derived from interpreting these relationships, although we will point at policy issues where these are particularly relevant and intuitive. It is our opinion that a deeper behavioral understanding of traveler response to information is necessary for an increase in insight into policy issues such as the provision of travel information as a travel demand management tool – also when policy implications cannot be directly derived from the results of behavioral analyses.

The outline of the remainder of this paper is as follows: Section 4.2 provides a presentation of the data-collection effort. Section 4.3 proceeds by analyzing the relationships between on the one hand manifest variables such as trip circumstances and destination familiarity and on the other hand travelers' knowledge levels. Subsequently, it is studied how knowledge levels themselves may determine travelers' general need for travel information. Where Section 4.3 treats travelers' need for information as a general, rather abstract notion, Section 4.4 discusses the need for specific types of information, ranging from basic to more advanced types of information. Conclusions are presented in Section 4.5.

4.2. The web-survey and its respondents

4.2.1 Overview of the contents of the web-survey

The web-survey's questions were framed into 4 categories. Category 1 concerned socioeconomic characteristics and current travel behavior. Category 2 referred to participants' actual use of, and stated need for, travel information (services) under varying travel conditions and destination familiarity. Category 3 focused on participants' perceptions of their knowledge levels concerning different travel modes given varying trip conditions and levels of destination familiarity. Category 4 concerned perceptions of quality of travel information (services). Most questions were phrased as propositions: answers indicated agreement on a 1-5 scale. The survey took about 20 minutes to fill in, on average. The web survey (in Dutch) can be obtained through contacting the first author.

4.2.2 Recruitment process and response group characteristics

Participants were recruited in 3 ways: an email list was used that was obtained for a recent web survey on activity-travel decision making, containing 226 email addresses. Together with this, an email was sent to 115 relations of the first author. Every one of these addressees could win a gift check of 25 euro by filling in the questionnaire, or by sending the link to at least three others that subsequently filled in the web-survey. Given the possibility of participants to send through the web-survey to others, a meaningful response rate estimate could not be obtained. Together, this resulted in 218 filled in surveys. Next to this, 270 individuals that were recruited through newspaper advertisements for a broader route choice experiment filled in the survey as part of this experiment (the experiment in total took 2 hours, and paid 27.5 euro). Participants were told in the advertisement (or email) that the data-collection effort was part of a research program aimed at identifying travelers' needs for travel information and at gaining insight into the potential of information to increase the reliability of traffic and public transport. No reference to specific types of information were made. All together, 488 filled in web surveys were collected. Throughout the recruitment process it was made clear that participants were expected to have some experience with both car and transit traveling, although no actual screening was done. Table 1 provides response group characteristics.

Based on these characteristics, it can be said that as far as sociodemographics (gender, age, education level, main out-of-home activity) are concerned, the sample has reached a rather high level of heterogeneity. However, representativeness with respect to the Dutch population as a whole is not tested, leading to at least three potential sampling biases. Firstly, it appears reasonable to expect that our sample contains a higher fraction of computer literates than does the Dutch population as a whole. As Arentze et al. (2005) indicate, this is likely to imply an under representation of elderly, and to some extent, women. Furthermore, it is clear that our sample is not representative in terms of travel behavior; particularly, they are likely to be far less captive with respect to either car or transit than the average traveler, which is a direct result from our framing of the experiment as concerning travel behavior in both traffic and public transport. Although the full implications of this bias are not directly clear, it does seem reasonable to assume that habitual or captive travelers are strongly underrepresented in the sample. Finally, also as a direct result from our sampling method, people interested in travel information services are likely to be overrepresented in our sample. These potential sampling biases should be kept in mind when interpreting the analyses performed in the remainder of this paper.

Table 1: response group characteristics (N = 488)

Variable	***Frequency %***	***Cumulative %***
Gender		
female	44	44
male	56	100
Age		
< 25	30	30
25 > age < 40	37	67
40 > age < 65	29	96
65 > age < 91	4	100
Completed education		
lower education	1	1
secondary school	50	51
higher education	49	100
Main out-of-home activity		
paid work	52	52
education	35	87
other	13	100
Drivers' license		
yes	92	92
no	8	100
Car availability		
always	49	49
usually	15	64
sometimes	20	84
less than sometimes	16	100
Public Transport (transit) season ticket		
some form of	57	57
none	43	100
Mode usually used for main out-of-home activity		
car	48	48
transit	52	100

4.2.3 Operationalization of concepts

Forthcoming analyses will refer to the concepts of *perceived knowledge levels*, *perceived information needs* and the distinction of *car-drivers* versus *transit-users*. Table 2 indicates how we operationalized these concepts in the web survey. Note that for the categories of perceived knowledge and perceived travel information need, a very large number of questions was asked, in order to able to retrieve answers that were specific for a variety of trip circumstances and types of information. Due to space limitations, we list in Table 2 only a sample of those questions as representative examples.

Table 2: An operationalization of concepts

Behavioral Construct	***Behavioral Sub-construct***	***Operationalization (examples)***	***Scale***
Perceived knowledge	*perceived reliability*	"My own judgment under normal conditions in terms of travel-times is ..." "My own judgment under peak hour conditions in terms of travel-times is ..." "My own judgment in terms of travel-costs is ..."	Very unreliable- Very reliable (1-5)
	perceived resourcefulness	"When driving my car towards a frequently visited destination, I usually know several alternative routes to the one I travel on" "When traveling with transit towards a destination never visited before, I usually know several alternative travel possibilities by transit"	Very much disagree- Very much agree (1-5)
Need for travel information	*need for travel information in general*	"I strongly need travel information under normal conditions, for trips towards frequently visited destinations" "I strongly need travel information during peak hours, for trips towards destinations never visited before"	Very much disagree- Very much agree (1-5)
	need for specific types of travel information	"I strongly need travel information concerning travel- (arrival-) and departure-times, for trips towards frequently visited destinations " "I strongly need a travel information service that updates me about disturbances in the transport system on its own initiative, for trips towards destinations never visited before "	Very much disagree- Very much agree (1-5)
Car-driver or transit-user?		" What travel mode do you usually use to travel towards your main out-of-home activity?”	Car Transit

We distinguish between two types of knowledge: *perceived resourcefulness* refers to a traveler's perceived awareness of viable routes; *perceived reliability* refers to a traveler's perceived confidence in his or her estimates for characteristics of known alternatives (Bonsall, 2004; Chorus et al., 2006a). Both these two perceptions may thus be seen as to represent a travelers' metaknowledge. We distinguished between travelers by car and transit-users based on travelers' most-used mode for their main out-of-home activity. Note that obviously, this is not to say that those who indicate to mostly travel by car in the context of their main out-of-home activity are in fact always car-drivers and hence never travel by public transport. Rather the categorization is based on a tendency to use car instead of transit. When in the following, we refer to car-drivers or transit-users, this nuance should be kept in mind.

Statements of perceived reliability regarding travel times have been obtained for specific trip circumstances (normal, peak hour, accident, …), while statements of perceived reliability regarding travel costs and other characteristics as well as statements of perceived resourcefulness have been obtained with no reference to the circumstances under which the trip is made. Statements of perceived resourcefulness have been obtained for both destinations never visited before as well as destinations frequently visited, while statements of perceived reliability have only been obtained for frequently visited destinations. The decision to not obtain circumstance- and destination-specific statements for every type of knowledge and information need followed from the notion that arised during small-scale testing, that the presence of an abundance of questions whose formulation only slightly differs from one another was experienced by participants as quite annoying. Note that the survey was not designed in order to obtain multiple measurements for a limited number of behavioral constructs. Rather, it was designed to obtain single measurements on a multitude of constructs, enabling an analyses of a wide range of potentially interesting issues related to the topic of information need. A disadvantage of this approach, as can be seen in some of the forthcoming analyses, is that the reduction of power of measurements it entails has lead to relatively weak estimates of the relationships between some of the factors studied.

4.3 The role of knowledge in the formation of information needs

This Section investigates the role of knowledge in the formation of a traveler's need for information. Before describing the results of the analyses, note that based on the obtained data, basically two different approaches are possible: one that first estimates the determinants of knowledge levels and subsequently the determines the effect of knowledge on information need, and one that estimates all effects simultaneously (e.g. through Structural Equation Modeling). Because in this paper we want to systematically discuss each of the relationships in depth, and also because the wide variety in levels of the input variables would necessitate a very large number of structural equations to be presented in case of simultaneous estimation, we have decided here to model all effects separately, one at the time. Note that, due to the way the questions of the web survey are formulated, no correlation exists between the different independent variables of forthcoming analyses, which allows us to analyze their effects on dependent variables through a series of separate analyses, rather than through one integrative analysis. We start this Section by identifying the relationships between a number of manifest factors and travelers' knowledge levels. Subsequently, it is analyzed how knowledge levels themselves may co-determine a traveler's need for information. Note that all reported statistical tests in the remainder of this paper are t-tests, unless reported otherwise. Independent sample t-tests are used when differences between car and transit-users are studied; paired sample t-tests are applied for investigating differences between answers on different survey-questions within one group. All reported levels of significance are two-tailed.

4.3.1 Relationships between manifest factors and travelers' knowledge

Perceived resourcefulness

It may be expected that travelers feel more resourceful when they engage in trips towards frequently visited destinations, compared to destinations they never have visited before. As is summarized in Table 3, this hypothesized difference between destinations frequently visited and destinations never visited before indeed exists and is highly significant for both the group of car-drivers as well as the group of transit-users. Note that car-drivers appear to consider themselves as more resourceful with respect to their usual mode of transport than do transit-users, in the context of destinations frequently visited (4.23 versus 3.90, p = .000). This is not surprising, given that there are in general more routes available for car-drivers than there are for transit-users. Concerning trips towards destinations never visited before, there is no significant difference between the two groups (2.44 versus 2.63, p = .058), signaling that for those trips, route availability plays a less important role than does route knowledge: both car-drivers and transit users perceive themselves as less knowledgeable for trips towards new destinations.

After having discussed the differences in perceived resourcefulness between car-drivers and transit-users *with respect to their usual mode of transport*, let us now briefly look into their perceptions of resourcefulness for *other than their usual modes*. That is, car-drivers were asked how resourceful they considered themselves when using transit and vice versa. First note here that in our sample, both participating car-drivers and transit-users have substantial experience in using the other than their usual mode (transit-users on average use their car 2.78 times per week, and car-drivers use transit for 2.29 times per week). It appears that transit-users perceive themselves as far more resourceful when making car trips than vice-versa, when frequently visited destinations are concerned (3.73 for transit-users versus 2.83 for car-drivers, the difference being highly significant (p = .000)). The same applies, although for a lesser extent, to trips towards new destinations (2.23 versus 2.06, p = .083).

Table 3: Relationships between destination familiarity on perceived resourcefulness

Destination	**Car-drivers**			**Transit-users**		
	Car	*Transit*	*sig. difference*	*Car*	*Transit*	*sig. difference*
Frequently visited	4.23	2.83	*.000*	3.73	3.90	*.070*
First time visit	2.44	2.06	*.000*	2.23	2.63	*.000*
sig. difference	*.000*	*.000*	-	*.000*	*.000*	-

Perceived reliability

Moving our attention towards the issue of travelers' perceived reliability of their estimates for characteristics of travel alternatives, we first focus briefly on differences between travelers' perceptions of reliability of estimates for travel times, travel costs and other relevant characteristics for trips towards frequently visited destinations. Subsequently, we will study more extensively the relationship between trip destination familiarity and trip circumstances such as weather conditions, occurrence of accidents etc on the one hand and travelers' perceptions of (travel time) estimates on the other. Participants were asked how reliable they thought their estimates were for travel times under normal conditions, for travel costs (in terms of tariff for transit-users and gasoline and parking fees for car-drivers) and for comfort-related aspects (seat probability for transit-users and parking possibilities at destination for car-drivers). It appears, as can be seen in Table 4, that travelers in general feel that reliability of their estimates for travel times is higher than for travel costs (4.16 versus 3.75, the difference being highly significant (p = .000)), and that their travel costs estimates are perceived as more reliable than their estimates for comfort related aspects (3.75 versus 3.48 (p = .000)). Note that here, as in forthcoming Tables where variables are arranged in order with respect to their magnitude, we do not statistically analyze the order itself, unless indicated otherwise.

Table 4: Perceived reliability concerning different trip-characteristics

Characteristic	Travelers (with respect to usual mode of transport)	Car-drivers (with respect to Car)	Transit-users (with respect to transit)	sig. difference (car – transit)
Travel time	4.16	4.27	4.07	*.003*
Travel costs	3.75	3.64	3.86	*.012*
Other characteristics	3.48	3.48	3.48	*.930*

Moreover, car-drivers appear to have a higher confidence than transit-users in their travel time estimates whereas transit-users appear to have higher perceptions of reliability for cost-aspects. The former of these two findings is rather interesting, as transit-trip times are time-table based, which allows travelers at least to learn the transit-corporation's estimate of trip duration, which estimates should be quite reliable under normal conditions. The latter finding is perfectly intuitive, as transit-trips are charged explicit fees, while car-drivers' fuel expenditures are not incurred explicitly on a trip-basis and parking fees differ widely across city-regions and time of day.

Participants were furthermore asked to state how reliable they thought their estimates for trip characteristics in general are for trips towards frequently visited destinations, compared to trips toward destinations that are visited for the first time (we did not ask them directly about their perceptions of reliability for these first-time destinations). This question was asked in a non mode-specific context. Mean score equaled 3.85 on a scale from 1 (very unreliable) to 5 (very reliable). As the difference of this score with the average value of 3 -representing *no difference in perceived reliability* between the two destination types- is highly significant (a one-sample t-test reported p = .000), it can be concluded that, as would be expected, travelers find themselves relatively knowledgeable in terms of reliability for trip characteristics concerning trips towards frequently visited destinations.

Moving our attention towards the relationship between trip circumstances and destination familiarity on the one hand and perceived reliability of travel time estimates in specific on the other, it is expected that trips towards frequently visited destinations will induce a higher degree of perceived reliability than do trips towards new destinations. Also, it is expected that perceived reliability will be highest in normal conditions, and also higher for recurrent congestion or delays when compared to incidental congestion or delays. Finally, a positive relationship is expected between the general usage levels for a particular mode and perceived reliability of time estimates for that mode. Starting with the issue of trip circumstances, participants were asked to score their perception of reliability for their travel time estimates under normal conditions, versus under peak-hour conditions, during diversions, bad weather conditions, the occurrence of accidents and when a transfer towards or within transit has to be made (see Table 5).

Table 5: Relationships between trip circumstances and perceived reliability of travel time estimates

Circumstance	Car-drivers (with respect to car)	sig. difference with 'normal'	Transit-users (with respect to transit)	sig. difference with 'normal'
normal cond.	4.27	-	4.07	-
bad weather	3.31	*.000*	3.45	*.000*
transfer	3.04	*.000*	3.45	*.000*
peak hour	2.89	*.000*	3.42	*.000*
diversion	2.84	*.000*	2.45	*.000*
accident	2.21	*.000*	1.90	*.000*

Note that most of these conditions, like 'bad weather', are intrinsically ambiguous: there obviously is a difference between a rainy day and a sever snow storm. For reasons of space limitations (we did not want to ask our participants to many questions) we decided to sue the rather aggregated categorization as displayed in Table 5. However, the potential ambiguity should be kept in mind by the reader when interpreting the found results. For transit-users and car-drivers alike, the relationship between accidents and the perception of travel time reliability appeared to be particularly large. Also the relationship between occurrence of diversions and traveling in peak hour or bad weather conditions, or the need for transfers and perceived knowledge appeared to be substantial. Comparing these two groups of travelers, it is interesting to see that there is a stronger negative relationship between accidents and diversions (incidental disruptions) and perceptions of travel time reliability for transit-users than for car-drivers. However, the opposite is the case for more recurrent circumstances such as weather and peak hour conditions, which usually do not really influence transit-travel time variability. In order to obtain a measure for the relationship between on the one hand the order of the impact of trip circumstances on perceived reliability among car-drivers, and on the other hand the order of the impact of trip circumstances among transit-users, we computed Kendall's tau on the observed means given in Table 5. Kendall's tau is a non-parametric rank-correlation measure that has an input the order of values for two or more different variables and which output lies between -1 (strong negative rank-correlation) and 1 (strong positive rank-correlation). We found a Kendall's tau of .966 (p = .007), signaling that there is a strong positive relationship between the order of trip circumstances' impact on car-drivers' and transit-users' observed mean knowledge levels. Furthermore, participants were asked about their perception of reliability of travel time estimates for the other than their usual mode. Just as was the case for perceived resourcefulness, again it appears that transit-users are far more confident in their estimates for travel time by car (3.77) than the other way around (3.29): the difference is highly significant (p = .000). This again is a signal of car-drivers' limited knowledge concerning transit.

Finally, the relationships between usage levels of different modes and perceived knowledge in terms of reliability of estimates will be investigated. When correlating perceived reliability of travel times under the circumstances displayed in Table 5 for frequently visited destinations among car-drivers and transit-users with the number of times their usual mode is used per week, only one significant effect at the 0.05 level is observable: there is a positive correlation between car-drivers' perceptions of travel time reliability during peak hour increases and the number of times they use their car per week (coefficient =.177, p = .008). The lack of effects of other experience-related factors can be seen as an indication that learning under normal conditions takes place very soon for often visited destinations, and very little for incidental disruptions in the network.

4.3.2 The influence of travelers' knowledge levels on their need for information

Where sub-Section 4.3.1 has shown how manifest factors influence travelers' perceived knowledge levels, this sub-Section proceeds by investigating how these perceived knowledge levels co-determine travelers' need for information *in general* with respect to their usual mode of travel (the words 'in general' imply that we did not ask respondents what type of information they needed. For analyses concerning the need for *specific* information types, please be referred to Section 4.4).

Starting with knowledge in terms of perceived resourcefulness, it is expected that the correlation between travelers' need for information (under normal conditions) and their perceived resourcefulness is negative. In other words, it is hypothesized that the more resourceful a traveler thinks she is, the less she will need information (under normal conditions). Indeed, this correlation appeared negative and significant (-.167, p = .000) for trips towards destinations visited for the first time, signaling that for these trips information needs among travelers are partly triggered by their perceived lack of resourcefulness. However, the found correlation is not particularly strong, and for trips towards frequently visited destinations, the correlation is not significant at any reasonable level (p = .341).

Moving our attention towards knowledge in terms of perceived reliability of travel related estimates, also negative correlations are expected: it is hypothesized that the more reliable a traveler thinks her estimates for travel times, costs, etc are, the less she will need information. We expect these relations to hold for a number of trip circumstances. Note that we only have data on reliability perceptions for frequently visited destinations. Starting with perceived reliability of travel time estimates, indeed significant negative correlations[24] are found between perceived reliability of ones own travel time knowledge on the one hand, and information need on the other hand. For normal conditions, correlation equals -.091 (p = .049); for peak hour travel, correlation equals -.138 (p = .003); for bad weather conditions correlation equals -.187 (p = .000) and for incident conditions -.150 (p = .001). Note that, due to the way the questions of the web survey are formulated, no correlation exists between the different conditions, which allows us to analyze their effects through a series of bivariate analyses. Found correlations signal that information needs among travelers are partly triggered by their perceived lack of knowledge in terms of the reliability of their travel time estimates. However, these correlations are by no means substantial, and for other than time-

[24] A more conservative approach to investigate these relationships would be to consider the used Likert-schales as being ordinal measurements, rather than measurements at the interval level. Then, Spearman's rho would be the appropriate correlation measure. Found values using Spearman's rho for computing the above mentioned relations (in the order in which they are presented there: -.121 (p = .008); -.142 (p = .002); -.180 (p = .000); -.188 (p = .000)) present roughly the same picture concerning the relation between perceived reliability of travel related estimates and need for information.

related attributes (such as travel costs), found relations are non-significant, although of the expected sign. It should be noted here that knowledge levels concerning other than time-related attributes were only available for at a non-trip circumstances specific level, so that measurement errors may have slightly suppressed the actual importance of these aspects. Notwithstanding this, it is fair to say that, looking at the found correlations, perceived knowledge limitations appear to be certainly not the only factors determining information needs. They appear to play a significant, rather than a substantial role.

4.4 Specifying the need for information

Where Section 4.3 addressed information in a very general way, this Section discusses travelers' need for a variety of specific types of information. It is investigated how travelers' needs for these different types of travel information may differ between car-drivers and transit-users, and may vary across different levels of destination familiarity, see Table 6.

Table 6: Need for specific types of information

Information type	Frequently visited destination	Destination never visited before	sig. difference
early warning function in case of disturbances	3.85	4.08	*.000*
full trip assistance	3.54	4.03	*.000*
time-related information	3.46	4.54	*.000*
personalized information	3.38	3.89	*.000*
location-specific information	2.98	3.43	*.000*
multimodal information	2.92	3.63	*.000*
cost-related information	2.78	3.85	*.000*
information on other than time- and cost-related aspects	2.75	3.57	*.000*

Participants were asked to state, with respect to their most-used mode, their need for a range of information types, encompassing ‘basic’ types of information (in the sense that many of the currently available information services provide such information.) as well as a number of more advanced types of information. No reference was made to the trip circumstances. Before interpreting found results, we show how the more advanced types of information were presented in the questionnaire: firstly, respondents were presented a three sentence introduction mentioning that travel information services are likely to become more and more intelligent over the next few years, gaining increasingly sophisticated functionalities. Then, specific types of relatively advanced travel information were presented in specific, see Table 6: ‘early warning function’ was specified as ‘an information service which, on its own initiative, keeps me updated on possible disturbances during my trip’; ‘full trip guidance’ was specified as ‘an information service which is capable of assisting me from the beginning until the end of a trip, also in case of incidental circumstances in the traffic or transit network'; 'personalized information' was specified as 'an information service which takes into account your personal preferences concerning modes, routes, departure times'; 'location-specific information' was specified as 'an information service which is always aware of my location in the transportation network'; 'multimodal information' was specified as 'an information service which covers car and transit within one single system'.

As might be expected, based on intuition as well as our earlier analyses, each type of information is needed more for trips towards destinations never visited before than for trips towards frequently visited destinations. Kendall's tau was calculated, based on the means reported in Table 6, in order to derive the strength of the relationship between the order of need for specific types of information for frequently visited destinations and ones never visited before. Kendall's tau was found to equal .571 ($p = .048$), signaling a modest and significant positive relationship between the order of observed mean information needs for frequently visited destinations and destinations visited for the first time. Besides this, it is worth mentioning here, with respect to the more advanced types of information, that especially those types of information that promise to make traveling 'easier' are needed (such as early warning functions, trip guidance), rather than information types that facilitate advanced search possibilities (such as multimodal information). When distinguishing between car-drivers and transit-users, some interesting differences between the two categories appear (see Table 7).

Table 7: Need for specific types of information

Information type	**Car frequently visited dest.**	**Transit frequently visited dest.**	**sig. diff.**	**Car destinations not visited before**	**Transit destinations not visited before**	**sig. diff.**
early warning	3.91	3.82	*.422*	4.15	4.04	*.284*
full trip assistance	3.60	3.49	*.308*	4.07	4.01	*.527*
time-related info	3.61	3.33	*.013*	4.43	4.64	*.004*
personalized info	3.44	3.34	*.219*	3.95	3.84	*.272*
location-specific info	3.10	2.87	*.038*	3.49	3.39	*.382*
multimodal info	3.10	2.74	*.001*	3.77	3.51	*.031*
cost-related info	2.93	2.66	*.017*	3.84	3.86	*.891*
Info on other than time and cost	3.00	2.53	*.000*	3.88	3.28	*.000*

Firstly, car-drivers appear to have a significantly higher (stated) need than transit-users for time-related aspects for frequently visited destinations, whereas transit-users are more in need for time-related information concerning trips towards destinations never visited before. It thus appears that the supply-oriented nature of transit induces a relatively high lack of knowledge for trips towards new destinations, for example due to the fact that departure times may be unknown to the traveler (which is obviously not the case for car-drivers). Secondly, it appears that car-drivers do exhibit a reasonable, and significantly higher need for multimodal information than do transit-users, for both destinations frequently visited and new destinations. Although this result does signal the potential of travel information for inducing a modal shift towards transit, it should be noted that car-drivers may relatively easily (pre- or in-trip) switch between car and transit, when compared to transit-users, who are often mode-captive as they have no car at their disposal. Thirdly, it can be seen that in general, car-drivers appear to be more in need for travel information than are transit users, especially for trips towards frequently visited destinations.

In conclusion, we applied Kendall’s tau on the means reported in Table 7 in order to shed light on the relationship between the orders for information needs between car-drivers and transit-users, and between different destination types for these two groups. Comparing the order of information needs between car-drivers and transit-users for destinations frequently visited we found a Kendall’s tau of .764 ($p = .009$). For destinations never visited before, it equaled .714 ($p = .013$). Together this signals that there is a rather strong relationship between the order of observed mean type-specific information needs between car-drivers and transit-users, and that this relationship holds for destinations never visited before, as well as destinations frequently visited. Applying Kendall’s tau on the relationship between the types of destination for car-drivers only, we found a measure of .618 ($p = .034$). For transit-users, this measure equaled .500 ($p = .083$), implying that the making of a trip towards a destination never visited before, when compared to a destination frequently visited, more strongly affects the order of observed average needs for specific types of information among transit-users than it does among car-drivers.

4.5 Conclusions

This paper investigated (determinants of) travelers' needs concerning travel information, based on a web survey filled out by 488 individuals. It aims at narrowing down three identified gaps in empirical literature available on this topic. Firstly, the paper addresses the role of behavioral factors, in specific travelers’ perception of their own knowledge levels. Secondly, instead of focusing only on currently available types of travel information, this paper also discusses travelers’ need for a number of more advanced types of travel information, such as personalized early warning functions. Thirdly, this study considers car-drivers and transit-users simultaneously, and makes comparisons between the two.

Based on the analysis made in the previous Sections, a number of conclusions may be drawn concerning (the determinants of) travelers' need for information. A first set of conclusions concerns the role of knowledge; it was found that there is a strong positive relationship between destination familiarity and perceived resourcefulness (operationalized as one's perceived awareness of alternative routes for a given mode and destination). Level of experience with a given mode is found to be of far lesser importance. Concerning perceived reliability of estimates for all sorts of trip characteristics (such as travel times and costs), destination familiarity also appeared to play an important role. Concerning travel time estimates, the occurrence of non-normal trip circumstances was a crucial factor: incidental circumstances such as the occurrence of deviations or accidents appeared to induce a more negative influence than does the occurrence of more 'recurrent' circumstances such as peak hour conditions. This signals the important role of ‘learning by doing’ among travelers. When investigating the effect of perceived (lack of) knowledge on perceived need for information, significant but certainly not substantial relationships were found. This signals that many other factors co-determine travelers' information needs. Although this latter remark may appear intuitive to most, the fact that we did not find substantial relationships is surprising in the light of the often made assumption (in research papers as well as in transport policy documents) that travelers will acquire information when faced with knowledge limitations.

Concerning travelers' need for specific types of information, it was found that there appears to be a genuine need for 'basic' time-related information, and cost-related information as well, especially for destinations never visited before. Secondly, as far as the more advanced types of information are concerned, it appears that especially those types of information that promise to make traveling 'easier' are needed (such as early warning functions), rather than information types that facilitate advanced search possibilities (such as multimodal information). This indicates the inclination of travelers to aim for reduction of the *non-monetary* costs of travel, such as the 'costs of thinking' (Shugan, 1980), rather than focusing on gains in terms of travel times and monetary costs only.

Thirdly, concerning the distinction between car-drivers and transit-users, it was shown that car-drivers' perception of their resourcefulness was substantially higher than transit-users' for trips towards frequently visited destinations. However, the opposite was found to be the case for trips towards destinations never visited before. Car-drivers had a higher confidence in their time-estimates of trips than transit-users, the opposite being the case for cost-related trip aspects. The negative relationship between incidental congestion and perceived travel times reliability was higher among transit-users than among car-drivers. However, the opposite was found for recurrent congestion such as peak hour conditions. It was also found that car-drivers, at least the ones in our sample, appeared less knowledgeable concerning transit than the other way around. In combination with the often found result that car-drivers' perception of transit travel times and reliability is overly pessimistic (e.g. Bonsall et al., 2004), this signals a potential role of transit information provided to car-drivers in order to 'educate' them. However, it should be kept in mind that changing car-drivers' mode-choices is a difficult feat to accomplish with travel information only (see Chorus et al. (2006d) for a literature review of studies addressing this issue). The need for travel time information for trips towards frequently visited destinations was higher for car-drivers than for transit-users, but the opposite was found for trips towards destinations never visited before. Finally, car-drivers indicated a much higher need for multimodal information than transit-users.

Summarizing, we feel that focusing on behavioral rather than manifest determinants, taking into account needs for basic as well as advanced types of information, and distinguishing between car-drivers and transit-users is a fruitful path for contributing to our knowledge concerning travelers' need for information. However, this study should best be regarded a beginning of the exploration of this path, leaving open many possible issues to be dealt with in future research efforts: firstly, it should once again be stressed that the participants to this web survey do not form a random sample. Particularly, they are likely to be far less captive with respect to either car or transit than the average traveler, due to the framing of the survey in the recruitment process. The study of random samples of travelers will no doubt provide a range of interesting, additional insights into the determinants of their information needs. Secondly, in order to be able to test a wide number of hypotheses in this exploratory study, it was decided in this study to use single measurements for a variety of behavioral constructs (such as knowledge levels and information needs for a wide number of trip circumstances) rather than use multiple measurements for a limited number of constructs. As a result, the strength of some of the analyzed relationships was presumably suppressed by relatively large measurement errors. We feel that a more confirmatory approach, using factor analysis and structural equation modeling in order to test behavioral hypotheses, would be an interesting direction for future research. Thirdly, this survey focused on *stated needs* for information, often in a rather abstract way. Although this has enabled us to report some interesting findings concerning behavioral determinants of information needs, we feel that data concerning *revealed use* of (advanced) information services remains very much needed in order to contribute to our insight into travelers' potential use of such services. A compromise between the two types of data can be obtained by performing laboratory experiments like the ones reported in Denant-Boemont & Petiot (2003) and Chorus et al. (2006c). Fourthly, where this study focused on knowledge levels as determinants of information needs, literature suggests that decision styles may be equally important behavioral factors (Payne et al., 1993, 1996; Verplanken et al., 1997; Aarts et al., 1997). Where our data unfortunately did not support a meaningful investigation of the role of decision styles, the collection and analyses of data concerning the role of travelers' decision styles seems to be another promising path of research.

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Chapter 5

Chorus, C.G., Molin, E.J.E., Arentze, T.A., Hoogendoorn, S.P., Timmermans, H.J.P., van Wee, G.P., 2007. Validating a multimodal travel simulator with information provision. *Submitted for publication* [25]

Abstract

This paper presents a computer based travel simulator for collecting data concerning the use of next-generation ATIS and their effects on travelers' decision making in a multimodal travel environment. The tool distinguishes itself by presenting a completely abstract multimodal transport network, where knowledge levels are fully controlled for in terms of awareness of mode-route combinations as well as in terms of variability of characteristics of known alternatives. Furthermore, it contains an information service-module that provides a variety of advanced types of travel information, with controlled for levels of reliability. These novel features warrant an extensive validation of the travel simulator. Such a validation is performed, using two datasets (one with revealed data, one with data from an experiment held in the simulator) obtained among 264 participants. It is shown that indeed, the simulator succeeds in collecting valid data on multimodal travel choice making under provision of advanced types of travel information.

[25] This Chapter forms a revised and extended version of: Chorus, C.G., Molin, E.J.E., Arentze, T.A., Hoogendoorn, S.P., Timmermans, H.J.P., van Wee, G.P., 2006. Observing the making of travel choices under uncertainty and information: validation of travel simulator. Paper presented at the 85^{th} *annual meeting of the Transportation Research Board*, Washington DC, United States

5.1 Introduction

Ongoing advances in telecommunication technology will allow the development and implementation of a next-generation of ATIS that will deliver personalized, dynamic, multimodal travel information, asked for as well as on its own initiative through a mobile device such as a mobile phone. Such information may take the form of estimates for characteristics of known travel alternatives such as travel times over known routes, but also the generation of complete mode-route combinations that were unknown to the traveler and the provision of early warning messages in case of unexpected disturbances in the transport system will be possible with such services (e.g. Adler & Blue, 1998, Kenyon & Lyons, 2003; Chorus et al., 2006a). Although potentially, these next-generation ATIS may become widely used and may have an effect on travelers' choices for departure times, routes and travel modes, it currently remains an open and important question what levels of use and effect will be reached. Because the costs of developing and implementing these next-generation information services are enormous in terms of time and money invested, it is critical to gain insights, preferably based on empirical data, into probable use and effects before introducing them to the market. Because they combine a high level of flexibility at a feasible level of costs, the use of travel simulators seems potentially well suited for collecting such empirical data. Such travel simulation data may provide a stepping stone for future, more elaborate forms of testing, e.g. using prototypes of these next-generation ATIS in real life travel situations. In order for travel simulators to be useful for the ex ante evaluation of this next generation in ATIS, they should be able to provide participants with multimodal transport networks with in-trip travel choice adaptation possibilities, as well as with an information service module that provides a variety of advanced types of information, both asked for and on its own initiative. Furthermore, it seems crucial to the understanding of the use and effects of these next-generation ATIS to explicitly capture the role of travelers' knowledge (in terms of both awareness of mode-route combinations as well as knowledge of their characteristics such as travel times) by applying a fully abstract representation of a transport network. Currently, to the authors' knowledge no travel simulator exists that can accommodate the type of data-collection described here.

This paper presents such a travel simulator. We feel that, although this simulator presents a potentially powerful tool for the ex ante evaluation of next-generation ATIS and other complex travel demand measures, its distinguishing features give rise to validity concerns: will the abstract multi-modal network and the information service with advanced functionalities trigger behavior in terms of information acquisition and effect as well as multi-modal travel choices that resemble those potentially made in (future) reality? These issues are certainly not self-evident and cannot be dealt with by simply looking at successful earlier validations of travel simulators as these did not include the acquisition of travel information nor the making of multi-modal travel choices (e.g. Bonsall et al., 1997; Mahmassani & Jou, 2000). Therefore, this paper also presents an extensive validation effort of the presented travel simulator. This is done using data from both an experiment that was performed in the simulator among 264 participants as well as data on revealed behavior in real life that was obtained from them.

The contribution of this paper to literature lies in the presentation and validation of a travel simulator that can be used for data collection concerning i) the making of travel choices in an abstract multimodal travel environment, ii) the acquisition of several types of travel information and iii) the (pre- and in-trip) effect of received information on choices for modes and routes. The remainder of the paper is structured as follows: Section 5.2 describes the workings and features of the travel simulator in more detail. Also, the structure of the experiment is discussed that was used for data-collection. Section 5.3 presents the validation of the simulator, after which conclusions are drawn in Section 5.4.

5.2 Features of the simulator and set-up of the experiment

5.2.1 TSL*, a module of a Travel Simulator Laboratory

The simulator, which we will denote *TSL** form here on, is a module of an extensive Travel simulator Laboratory (TSL) developed by Serge Hoogendoorn at TU Delft (Hoogendoorn, 2003, 2005; De Groot & Hellendoorn, 2004). TSL aims at combining the advantages of stated preference approaches of travel behavior data collection (e.g. Polak & Jones, 1993, 1997; Khattak et al., 1993a; Wardman et al., 1997; Reed et al., 1997; Abdel-Aty, 2001; de Palma & Picard, 2005) with those of revealed preference approaches (e.g. Emmerink et al., 1996; Polydoropoulou & Ben-Akiva, 1998; Hato et al., 1999; Lam & Small, 2001; Peng et al., 2004), while avoiding their respective disadvantages. That is, TSL is developed in order to be able to on the one hand study in a controlled environment hypothetical, or not yet existing, combinations of travel demand measures such as complex road pricing schemes and ATIS *without* on the one hand the burden of expensive and labor-intensive field trials and on the other hand the limited experimental possibilities[26] and external validity of more basic stated preference surveys. It stands in a long tradition of computer-based travel simulator tools of varying levels of sophistication[27] (e.g. Adler et al., 1993; Chen & Mahmassani, 1993; Adler & McNally, 1994; Koutsopoulos et al., 1994; Walker & Ben-Akiva, 1996; Bonsall et al., 1997; Mahmassani & Liu, 1999; Katsikopoulos et al., 2002; Bonsall & Palmer, 2004) and distinguishes itself by its modular, open-source approach, enabling integrated study of the impact of a variety of advanced travel demand measures in multimodal networks. *TSL**, a module of TSL, was developed specifically to accommodate experiments concerning the use and effects of next-generation ATIS. It shares with TSL its user interface, as well as many of its features, and distinguishes itself by presenting a fully abstract network and an interactive information service with advanced functionalities.

Figure 1 shows the screen plot of an arbitrary travel situation that a participant to an experiment in *TSL** may be confronted with. The workings of *TSL** will be discussed by going through this Figure. The screen consists of 4 parts: lower left presents the trip context, upper-left shows the transport network, upper right presents the information service and lower right shows a visual aid.

The trip context

The main part of trip context consists of a story line describing trip purpose and possibly preferred arrival times, generated at random for each trip from a set of predefined options. These story lines were presented at the beginning of each new trip through pop-up windows, after which they were located at the lower left of the screen during the completion of the trip. Next to the story line, the trip context displays a clock, presenting accelerated time. It ticks away one minute waiting time or in-vehicle time per actual second. In pre-trip conditions as well as during information acquisition and at the interchange point, the clock stands still.

[26] For example, the development of an experiment that involves sequential decision making under conditions of uncertainty and information provision, e.g. decisions to acquire information followed by a route choice adaptation based on a received message, is hardly possible with basic stated preference approaches.

[27] See Koutsopoulos et al. (1995) and Bonsall (2004) for extensive overviews.

Finally, beneath the clock, a money counter registered the amount of money spend so far on a given trip, including both travel costs and costs of information acquisition.

The transport network

A purely fictive O-D pair was created, connected by four paths displayed as arrows. Every path consists of two legs, as can be seen in the upper left part of the screen presented in Figure 1. Changing towards another path is possible halfway at the interchange point. The two left arrows symbolize two car-options, i.e. highway routes. The two routes are equivalent except that they may differ in terms of travel times and costs. Next to these two car-options, two intercity train options exist which are also equivalent, except that they may also differ in travel time and cost, as well as seat availability. Furthermore, the left one of the two trains departs once every 15 minutes, the right one once every 5 minutes, thus inducing a lower expected waiting time. The number of a priori 'known' alternatives varies per trip. 'Unknown' alternatives are marked grey instead of black, and there is no prior knowledge concerning their characteristics. These alternatives are inactive, and cannot be executed by the traveler. For the trip displayed in Figure 1, one car-option and the 15 minute train option are known a priori. The other train alternative is activated by the information service (see further below).

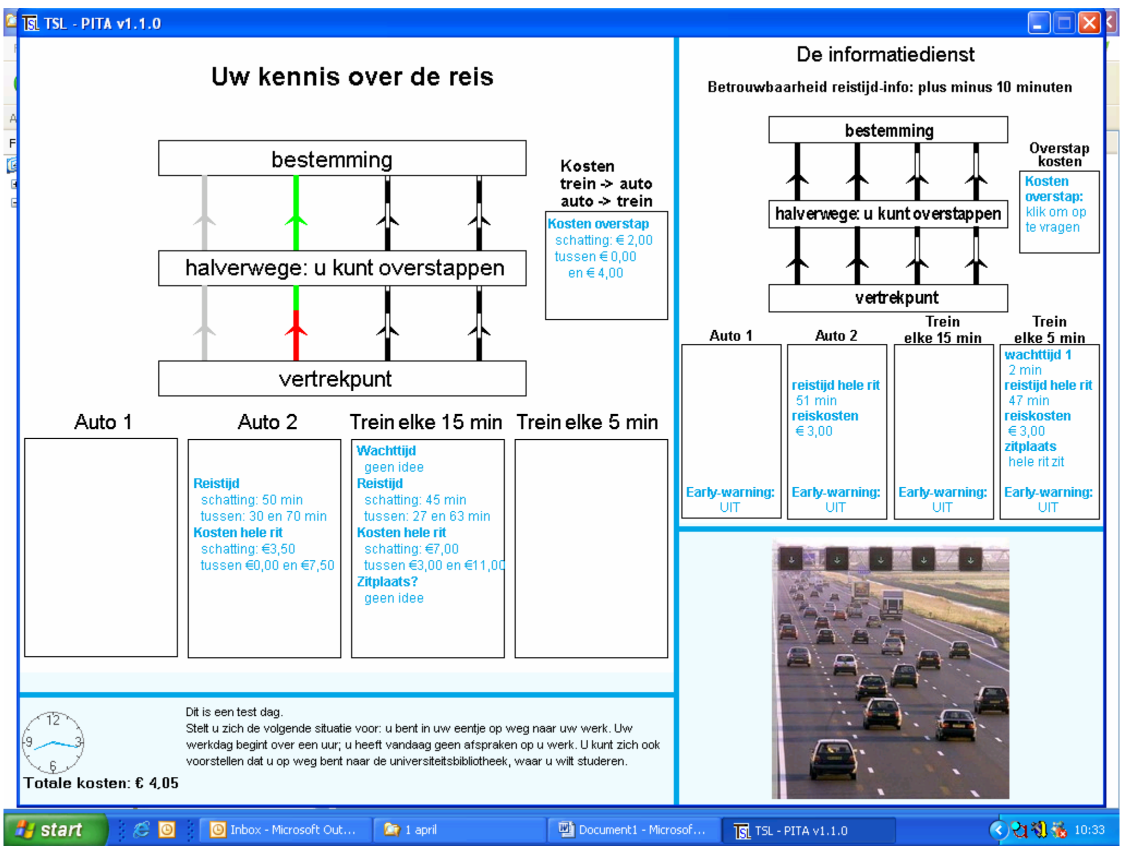

Figure 1: screen plot of *TSL* (in Dutch)*

The participant's knowledge concerning 'known' alternatives is presented in the boxes below the black arrows. The boxes provide the following a piori knowledge: for both car and train options, i) *best guesses* for travel times[28] and travel costs[29] are provided, as well as ii) *certainty intervals*, i.e. ranges of times[30] and costs[31] within which the actual values fall almost certainly. A priori, train travelers do not know the exact departure time (although they do know the service's frequency), neither do they know whether or not a seat is available.

A participant starts his journey by clicking one of the arrows, and subsequently confirming his choice in the appearing pop-up window. By confirming his or her choice, there is no possibility of adaptation until the interchange point is reached. Directly after confirmation, the traveler is confronted with the actual costs of the alternative, and train travelers were also informed whether or not they had a seat. These actual travel costs were drawn from a normal distribution, having the best guess as mean, and a quarter of the length of the certainty interval as standard deviation. Seat availability was randomly drawn from a discrete distribution. As the trip commences (Figure 1 shows the situation where a car option is chosen), the clock starts ticking and the arrow that represents the chosen alternative incrementally turns red, indicating the amount of distance traveled so far. In other words, as the trip is executed, the traveler is confronted with the actual travel time. Actual travel times were generated in the same way as travel costs. Furthermore, as was made clear to travelers that the interchange point was exactly at the middle of the distance between origin and destination and that travel speed was comparable for the first and second leg for the same mode-route combination, travelers could see halfway whether or not they were going to arrive at a potentially preferred time when proceeding the trip with the chosen mode-route combination. At the interchange point, travelers were given the opportunity to adapt their route or mode. Changes from car towards train were framed as interchanges at P&R-facilities, changes from train towards car are framed as boarding a taxi at a railway station. When interchanging between car and train, an interchange fee was charged, which was just like the other travel costs not known in advance, although a best guess and a certainty interval were provided. At arrival, a brief trip summary was given, after which a new trip began. In order to suppress learning effects, it was explicitly stated that the O-D pair for the new trip was different from that of any of the trips engaged in before.

The information service

As can be seen in Figure 1, the information service's layout is an exact copy of the transport network. The service presents three ways of acquiring information: firstly, a traveler can ask the service to generate or activate one or more alternatives that are currently 'unknown' to him or her. This is done by clicking on an arrow within the information service screen that corresponds to an unknown alternative in the transport network. After this is done, a pop-up window appears that states the price of the information acquisition (being varied between .45, .60 and .75 eurocents) and asks for a confirmation. After confirmation, the alternative is made active, that is, its color turns black in the transport network, and the alternative can be executed from now on. Furthermore, the information service provides estimates for all the alternative's characteristics. These estimates are displayed in the box below the activated

[28] Travel times were framed as door to door for car-trips, and door-to-door minus waiting times for train-trips. All 'best guess' travel times were randomly varied beforehand and could take the values of 50 and 60 minutes for the car-option and 45 and 55 minutes for the train option (since to the latter also waiting times had to be added to get the total travel time).

[29] Travel costs were framed as fuel expenditures + parking costs for car-trips, and ticket tariffs for train-trips. Travel costs were randomly assigned beforehand the values of 3.5 euro or either 7 euro.

[30] These ranges were centered around the best guesses and their length was assigned either the value of 20, 30 or 40 minutes.

[31] These ranges were centered around the best guesses and their length was assigned either the value of 2, 4 or 8 euro.

alternative in the information service screen part. Figure 1 presents such an information acquisition for the 5 minute train option. Note that all provided information concerning costs, waiting times and seat availability is completely reliable, and travelers are made aware of this. However, the reliability of the information concerning travel times is, just like in reality, not fully reliable. This is expressed by denoting on top of the information service's screen part one of the following lines: i) travel time information reliability: completely reliable; ii) travel time information reliability: ± 5 minutes; iii) travel time information reliability: ± 10 minutes. In case of limited information reliability, travel time messages that are provided by the information service are drawn from a normal distribution having the actual value as mean, and half of the maximum deviation (either 5 or 10 minutes) as standard deviation. In all other cases, information messages equaled the actual values for times, costs, etc.

Secondly, a traveler may acquire information concerning a particular characteristic of a known alternative, be it travel time or cost for a car or train option, waiting time or seat availability for train options or interchange costs. This is done by first clicking on the arrow of a 'known' alternative and subsequently checking the boxes for those characteristics for which information is needed (the information price is listed at every box, and varies between .15, .30, .45 eurocents). After the boxes are checked, the service displays the information in the information box. Figure 1 presents the situation where for one of the car-options, both travel time and costs are informed about by the information service. Travelers are faced with two, possibly conflicting estimates: their a priori knowledge and a message from the information service which is not necessarily fully reliable. Since mechanisms of perception updating are part of the behavior researched, the travelers were not instructed how to deal with this integration of knowledge and information.

Thirdly, a traveler may activate the so-called early-warning function. This function notifies a traveler when an alternative that is about to be chosen has an actual travel time that substantially deviates from the traveler's best guess (no strict level of travel time differences that triggers these messages is mentioned to the travelers). This type of information is acquired by clicking on a known alternative and checking the early warning box. Note that all these types of information can be acquired either pre-trip, as well during the trip or at the interchange point, which makes the information service 'mobile'. Information acquired at the interchange point refers to the remainder of the trip (e.g. travel times over the second leg, or the generation of the second leg of an alternative).

The visual aid
In the lower right, pictures are placed that help the traveler identify with the situation at hand: several pictures were available to describe a number of possible pre- and in-trip situations for car (e.g. with and without congestion) as well as train (e.g. waiting at the station, being underway).

5.2.2 The experiment

Participants were recruited through placement of advertisements in a campus newspaper and a free newspaper for the town of Delft. Also a mail was sent out to all ± 500 students of the Faculty of Technology, Policy & Management. Participants were asked to join a 2 hour computer experiment concerning the use and effects of travel time information during one of the 9 possible time slots. Criterion for participation was that participants had some experience with traveling by both car and train. A 20 euro reward was offered for participation. In total, 264 individuals were recruited this way. Table 1 presents some response group characteristics and shows a rather heterogeneous group in terms of socio-economic characteristics. However, it should be noted that the participants were not average travelers in the sense that they were selected on whether they had some experience with both car and train travel.

Every one of the 9 sessions followed the same program. After a brief introduction, an extensive web survey was filled out concerning among other things the participant's actual travel behavior and his or her acquisition of travel information through different media. The web survey consisted of 94 questions and took about 25 minutes to fill out on average. Subsequently, a brief stated mode choice experiment was performed, which on average took about 10 minutes to complete.

Table 1: response group characteristics

Variable	**Proportion %**	**Cumulative %**
Gender		
female	49	49
male	51	100
Age		
< 25	45	45
< 40	27	72
< 65	27	99
< 91	1	100
Completed education		
lower education	2	2
secondary school	67	69
higher education	31	100
Main out-of-home activity		
paid work	41	41
education	45	86
other	14	100
Drivers' license		
yes	91	91
no	9	100
Car availability		
always	39	39
usually	18	57
sometimes	26	83
less than sometimes	17	100
Public Transport (PT) season ticket		
some form of	62	62
none	38	100

Following this, the participants were given a rather extensive introduction in *TSL**, as they were walked through several trips, explaining all *TSL** 's functionalities. Moreover, participants were asked very explicitly to not regard the *TSL**-experiment as some form of a game (e.g. by trying to travel as fast as possible, or spending as much or as little money as possible), but rather to try to identify with the travel situations presented and make choices that they would make, would they be confronted with such a situation in real life. This point is made several time throughout the introduction. It is known that in simulated travel situations like the ones presented in this experiment, the issue of motivation is a difficult one. See

Carson et al. (2000) and Bonsall (2002) for overviews of possible incentive-caveats. In order to increase the motivation of participants to put effort in identifying themselves with the simulated travel environment, the following approach was chosen: participants were told during the introduction that they could win a 7,5 euro bonus, to be awarded to about half of the respondents, based on the success of their identification effort. It was mentioned that the correspondence of their choice-behavior as observed in the *TSL** experiment with the choice-behavior observed in the stated mode choice experiment and the answers to web-survey questions concerning revealed behavior would be used to measure the degree of identification. However, it was made clear to the participants that they would probably be most likely to obtain the bonus by simply making a real effort to identify with each of the travel situations presented. After the introduction, about 50 minutes were left. In these 50 minutes, participants made two test-rides, during which they were encouraged to try out all types of traveling and information acquisition. These trips were not saved in the database, as was told to the participants. After these two trips, two trips were performed and saved without information being available. Subsequently, a number of trips (maximum 25) were made in the presence of information services. It was made clear that no objective function was to be maximized in any way, and that the number of trips made was of no importance for being awarded the bonus. About half of the participants finished all trips before the end of the session. In total 5258 trips were made; during 4714 trips travel information of some kind was available.

Table 3: Self-reported judgments of the experiment

Variable (average)	Proportion %	Cumulative %
1. I found it difficult to remain concentrated during the experiment (2.24)		
1 very much disagree	24	24
2 disagree	46	70
3 neither disagree nor agree	15	85
4 agree	13	98
5 very much agree	2	100
2. I found it difficult to identify with the different travel situations (1.94)		
1 very much disagree	33	33
2	49	82
3	10	92
4	7	99
5 very much agree	1	100
3. I found the travel simulator easy to understand (4.19)		
1 very much disagree	0	0
2	5	5
3	7	12
4	52	64
5 very much agree	36	100
4. I enjoyed participating in the experiment (4.47)		
1 very much disagree	0	0
2	1	1
3	4	5
4	42	47
5 very much agree	53	100

Before leaving the room, participants were asked to fill in a brief anonymous evaluation survey, see Table 3. It consisted of 4 propositions, which had to be evaluated on a 1 to 5 scale, 1 meaning *very much disagree*, 5 meaning *very much agree*. The responses provide some first evidence of the suitability of the *TSL** as a research tool, as a vast majority of participants stated they had little trouble concentrating and identifying with the presented travel situations, and that furthermore they did not find the *TSL** difficult to understand and did enjoy the experiment as a whole. Some of these findings were rather surprising to the authors, as they felt beforehand that *TSL** might be relatively difficult to understand for a possibly substantial share of the participants. Correlations between propositions 1 and 4 (-.16), 2 and 4 (-.16) as well as 3 and 4 (.15) are all of the expected sign and significant (p-values are .009, .007, .016 respectively), indicating that participants somewhat more enjoyed the experiment if they found it easy to remain concentrated, to identify with the presented travel situations and to understand the workings of *TSL**.

5.3 Validating *TSL** as a research tool

A crucial aspect of travel simulator based research efforts is the validation of the simulator as a tool for data-collection. Ultimately, a travel simulator can be considered a valid research tool when it is established that *observed choices made within the simulator resemble those made in real life under comparable conditions*. Earlier studies that dealt with the issue of validation of travel simulators (see Bonsall et al. (1997) or Mahmassani & Jou, 2000 for extensive treatments of the topic) have already indicated that in principle, the concept of computer-based simulators are rather successful in inducing valid, or real-life like, travel behavior. However, as *TSL** presents a completely abstracted multimodal network with fully controlled for knowledge levels and as it focuses not only on mode-route choices, but on choices whether or not to acquire information in one form or the other as well, this insight should not be simply extrapolated to the *TSL** case: a separate validation of *TSL** as a research tool is warranted and may contribute to our understanding of the suitability of travel simulators for the analysis of the use and effects of ATIS.

However, the fact that both the travel situation itself is completely abstracted from any existing situation in combination with the fact that the provided information service is far more advanced than any currently available information service, makes it impossible to validate the research tool in the way described above: no actual choices for any comparable situation are available, or can be easily made available. Therefore, we are forced to adopt a less strict definition of validation: *TSL** may be considered a valid research tool when it is established that observed choices made within *TSL** *i) resemble our intuitions concerning what kind of choices would be made in real life under comparable conditions and ii) relate in intuitively meaningful ways to choices made in real life under different conditions.* Both conditions concern the making of travel choices under conditions of knowledge limitations in the presence of information and include the choice whether or not to acquire information. The former condition refers to the internal consistency or face validity of *TSL** data. When evaluating this internal consistency of choices made in *TSL**, especially those concerning the use and effects of a next-generation in ATIS, much attention should be paid to the formulation of intuitions: it must be avoided that intuitions are formulated that make observed choices appear 'counterintuitive' whereas in reality they provide new insights, possibly conflicting with our knowledge and intuitions. That is, in no case, we would want to formulate intuitions that would possibly identify new, valid insights concerning the use and effects of next-generation ATIS as being 'counterintuitive'. Therefore, only very basic intuitions are formulated concerning the internal consistency of choices made in the simulator. The latter condition refers to the external consistency or convergent validity of *TSL** data and suggests that some elements of the use and effects of a next-generation ATIS might relate to the use and effects among travelers of currently available ATIS. Also here, care must be exercised when 'intuitive relations' are formulated. The remainder of this Section presents a validation effort that focuses on the two conditions stated above and begins with the issue of external consistency.

5.3.1 External consistency of TSL* data

As mentioned in Section 5.2, every participant to the experiment first filled in an extensive web-survey concerning among other things their current travel behavior and their use of travel information (services) in a variety of real-life travel situations. Answers to questions posed in that survey are used in this Sub-section in the external validation of choices made in *TSL**. Let us first discuss what intuitions might be formulated concerning the relations between revealed travel behavior and observed behavior in *TSL**. First, it appears intuitively reasonable to expect that market shares for different travel modes that are observed in *TSL** should, on the individual level, reflect corresponding revealed mode choices. Secondly, it sounds intuitively reasonable to expect that individuals' use of the information service in *TSL** reflects their use in real life of information services that are in some way of comparable functionality as the service available in *TSL**. Finally, it appears reasonable to expect that the effect of information services on choices for modes and routes in real life resembles the effect of messages provided by the information services in *TSL**. However, it was felt that the effect of messages received on travel choices in real life is a highly complicated issue, involving a number of complex mental processes, and that simply asking people about the effect of information on their choices for travel alternatives would therefore not give a credible account of the actual effect (see Nisbett & Wilson (1977) for a seminal treatment of verbal reports on complex mental processes). Therefore, no revealed data on the effect of information was available for testing of the external validity of choices made in *TSL**. This leaves us with the following two intuitions:

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i. *the more travelers use their car in real life, the more they will choose the car option in TSL*.*
ii. *the more travelers acquire travel information in real life, the more they will do so in TSL*.*

Before examining whether these intuitions hold, note that since choices made in *TSL** are made under completely controlled conditions, we can only expect to find correspondences of modest magnitudes between real life behavior and observed choices in *TSL**. For example, due to the experimentally varied levels of availability and travel times and costs of car and train options in *TSL**, a traveler may well (be forced to) make mode choices that do not resemble those made in real life, simply because travel modes in real life may differ substantially from the ones provided in the experiment in terms of their availability and characteristics. The same reasoning applies even more to the functionalities of information services.

In order to see whether intuition i) holds, correlations are examined between on the one hand the number of times travelers choose the car-option for the first leg in *TSL** (CarTSL*) and on the other hand their revealed mode-choice behavior. This latter behavior is observed by asking travelers how many times they used car (CAR) or Public Transport (PT) per week[32]. Correlations and their 2-tailed significance levels are presented in Table 3, and suggest that condition i) is indeed fulfilled, as correlation between CarTSL* and CAR is of the expected sign and of a high level of significance. Note that the correlation between CAR and PT in real life (i.e. the sample of revealed data), which is not reported in Table 3, equals -.322 (sig = .000). In that light, also the correlation between CarTSL* and PT appears realistic.

Table 3: comparing mode-choices with revealed data

Correlations	CarTSL*
CAR	.422 (.000)
PT	-.202 (.001)

Before checking intuition ii), we will first state more clearly what type of relation we would expect to hold. The web survey asked travelers about their acquisition of information through a number of media: radio, mobile phone, internet, road maps, time Tables, television and advice from other individuals. Answers were given on a scale from 1 (almost never) to 5 (almost always) for trips towards destinations never visited before as well as for trips to frequently visited destinations. Since the only medium that provides functionalities that come close to the ones provided by the information service in *TSL** is the internet (e.g. as it may provide dynamic, multimodal information), this is the only medium that appears suitable for the analyses. Since all trips in *TSL** are made in a purely fictive transport network with completely controlled for knowledge levels, only revealed information acquisition for trips towards destinations never visited before will be considered.

The following data on information acquisition in *TSL** will be used for analyzing the relation between information acquisition in *TSL** and revealed travel information acquisition through the internet: the number of times participants acquired travel time information (TT), travel cost information (TC), waiting time information (WT) and the number of times travelers generated 'unknown' mode-route combinations (GEN). Also, the total number of times information was acquired (TOT) is considered. Note that, as Dutch internet-based information services generally do not provide travelers with information on seat availability and early warning functions, these two types of information acquisition are not taken into account in the analysis. Table 4 provides the correlations between the five identified types of information acquisition in TSL* on the one hand and the reported use of internet as a travel information service in real life trips towards destinations never visited before (INTERNET).

Table 4: comparing information acquisition with revealed data

Correlations	INTERNET
TT	.128 (.037)
TC	.188 (.002)
WT	.152 (.013)
GEN	.120 (.051)
TOT	.161 (.009)

[32] The answers were given on a 1-5 scale for two trip purposes (*work / education* and *other*). 1 stands for '(less than) once a week', 2 stands for '2 times a week' etc and 5 stands for '(more than) 5 times a week'. Combined, the answers were thus given on a 2-10 scale.

2-tailed significance levels are displayed in parentheses. Again, all found correlations are of the expected signs and of very acceptable levels of significance.

5.3.2 Internal consistency of TSL* data

The internal validity of *TSL** data refers to our *intuition* concerning the behavior of travelers in real life under conditions that resemble the ones presented in *TSL**. Again, we will first specify what these intuitions may consist of. For reasons mentioned earlier, intuitions will be formulated at a very basic, general level. Like in the previous Sub-section, we will categorize these intuitions into those referring to mode choices, those that deal with information acquisition and those that deal with information effect. The following intuitions were formulated, which are all well established in the international literature:

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i) mode choices

a. *the higher the travel time, the lower the choice probability*
b. *the higher the travel costs, the lower the choice probability*

ii) information acquisition

a. *the lower the knowledge levels, the more information will be acquired*
b. *the higher the information reliability, the more information will be acquired*
c. *the higher the price of information, the less information will be acquired*
d. *the less attractive the travel alternative, the less information will be acquired about it*

iii) information effect

a. *reception of disappointing messages (e.g. predictions of high travel times) induces a lower choice probability of the considered alternative*

Note that none of these intuitions refers to the role of knowledge limitations in the making of travel choices, and the effect of information reliability on travel choice adaptation. The reason for this lies in the fact that concerning these issues, basic intuitions are difficult to formulate. The role of knowledge limitations (particularly travel time uncertainty) in travel choice making currently is a very important topic in travel behavior literature, and provokes a variety of sometimes conflicting findings. Examples of this recent literature are de Palma & Picard (2005) and Avineri & Prashker (2005). Furthermore, the topic of the effect of information reliability on the adaptation of travel choices has been of similar interest in current research and also displays a large degree of variety in ideas (e.g. Jou et al., 2005; Arentze & Timmermans, 2005)[33]. For both cases, when testing the internal validity of *TSL** data one would very easily end up testing behavioral theories. To avoid this potential confusion, no intuitions are formulated concerning the above two topics.

In order to test whether intuition i) holds, all *TSL** trips were selected where no information service was available (so that perceptions of travel times and costs could not be blurred by received messages). In all these trips, one car alternative and one train alternative were 'known'. In total, 504 trips were selected this way. A logistic regression was performed to estimate a logistic regression model where a choice for the car option was coded 1, and a choice for the train option was coded 0. Dependent variables were the differences in travelers' best guesses for travel time (diffTT) and travel costs (diffTC), defined as car travel time minus train travel time (minutes) and car travel costs minus train travel costs (euros). As such, negative parameters are expected for both diffTT and diffTC. No strong expectations exist

[33] Actually, the testing of different theories of choice making under conditions of knowledge limitations and the provision of information with varying levels of reliability is a reason for the development of *TSL** in the first place.

concerning the constant, although when travel time is controlled for, a positive constant might be expected due to the fact that the train option has an unknown waiting time of maximum 5 minutes, whereas the car option does not have a waiting time. Table 5 presents the results of the performed logistic regression.

Likelihood-ratio index equals 0.268, signaling an accepTable goodness-of-fit. More important, all parameters are of the expected sign, and are highly significant. In order to see whether the value of travel time savings (VTTS) that individuals displayed indirectly in *TSL** makes sense intuitively, it is calculated for the sample as follows: $VTTS = \beta_{diffTT} \cdot 60 / \beta_{diffTC}$, equaling 9.81 euro / hour. Taking into account the large share of students in the sample, having a rather low 'wage rate', this value is in line with findings of recent studies on the issue of VTTS (e.g. Brownstone & Small, 2005; Hess et al., 2005; Steimetz & Brownstone, 2005).

Table 5: internal consistency of mode choices

Logistic Regression	B	SE	Sig (2-tailed)
diffTT	-.061	.014	.000
diffTC	-.373	.042	.000
Constant	.398	.116	.001

In order to test whether intuition ii) referring to the acquisition of information holds, a distinction will be made between information acquisition aiming at the generation of unknown alternatives and information acquired for the assessment of known alternatives (e.g. through acquiring travel time estimates). We will start with two analyses concerning the generating of alternatives. The following data is used for the first of these: for every trip made in the presence of an information service, it is observed how many alternatives are known by the traveler (signaling his or her knowledge level), and it is observed how many alternatives are activated by him or her before a choice is made for some mode-route combination. Note that the maximum and minimum number of alternatives that might be generated is determined by the number of alternatives known (i.e. when no alternatives are known, travelers have no choice but to activate at least one alternative; when four alternatives are known, generation of alternatives is not possible). Therefore only those trips where either 1, 2 or 3 alternatives are known are selected for the sample, totaling 3967 trips. For those trips, the correlation between the number of known alternatives and the number of activated alternatives was computed. Following intuition ii)a), a negative correlation would be expected. Indeed the correlation equaled -.353 (sig = .000), signaling an effect of knowledge level on information acquisition. Taking into account the expected impact of a variety of other determinants of information acquisition such as its price and reliability and the characteristics of known and unknown alternatives, this correlation indeed provides support for intuition ii). However, in order to gain more detailed insights into the issue of information acquisition for alternative generation and also investigate intuitions ii)b), c) and d), a second analysis was performed, using a different sample.

All trips were selected where only one alternative was known to the traveler, and either 0 or 1 alternative was generated, giving a total of 345 trips. In 73 of these cases, an alternative has been generated. For all 345 trips, the impact of characteristics of known and unknown alternatives as well as the characteristics of the information service, on the decision whether or not to generate an alternative is investigated. We would expect a number of effects to be found: concerning the characteristics of the information service, we would expect that the more unreliable the service's travel time estimates are (InfoUnrel, operationalized as the maximum deviation from the true value) and the more expensive the information (InfoCost), the less it will be used for alternative generation, as mentioned in intuition ii)b) and c). Concerning characteristics of known alternatives, we would expect that the less attractive the *known* alternative is, the more likely it is that the traveler will ask the information service to generate an unknown alternative, as mentioned in intuition ii)d). It is thus expected that the maximum travel time of the known alternative (KnownMaxTT) positively effects information acquisition in the form of generating unknown alternatives. This KnownMaxTT is coded as average travel time + half of the certainty interval + (for train options) the maximum waiting time. Maximum travel costs of the known alternative (KnownMaxTC) is coded as average travel costs + half of the certainty interval. Parallel to this, and also referring to intuition ii)d), we would expect that the more attractive the unknown alternative seems to be, the more the traveler will be prone to ask the information service to have it generated: it is expected that the expected waiting time (UnknownExpWT) of the unknown alternative negatively influences the traveler's inclination to generate the alternative[34]. This latter expectation is operationalized by acknowledging that car options have zero waiting time, and that the expected waiting times for the two train options are 2.5 and 7.5 minutes respectively. When the waiting time is controlled for this way, it is expected that the generation of car-options (UnknownCar) will be perceived as less attractive than train options, since their in-vehicle travel time is generally larger than that of train options (in order to end up with comparable total travel times). Table 7 presents the results of the logistic regression performed to estimate the effects (the dependent variable is coded 1 if an alternative is generated, 0 otherwise). Given the limited number of times alternatives have been generated in the sampled trips, a negative constant is expected. The model's likelihood-ratio index equals .206, signaling an accepTable model fit. More importantly, all parameters are of the expected sign, and most of them reaching high levels of significance.

Table 7: internal consistency of choices for alternative generation

Logistic Regression	B	SE	Sig (2-tailed)
KnownMaxTT	.064	.031	.038
KnownMaxTC	.213	.080	.008
UnknownExpWT	-.253	.079	.001
UnknownCar	-1.775	.452	.000
InfoUnrel	-.034	.043	.423
InfoCosts	-2.392	1.511	.114
Constant	-6.652	2.283	.004

Intuition ii)d) concerning the role of characteristics of known and unknown alternatives is greatly endorsed by these findings. However, it does appear that information reliability plays a somewhat marginal role. This fact can be partly explained by referring to the fact that information unreliability only plays a role with respect to estimations of in-vehicle travel times. For generated alternatives however, next to in-vehicle travel times, also travel costs (and waiting times and seat availability for train options) are provided by the information service, all with full reliability. The impact of information service unreliability thus remains rather limited. It is somewhat more problematic that apparently the costs of information acquisition do not very significantly affect information acquisition, signaling that either the

[34] Note here that, apart from the train's waiting times, no knowledge concerning unknown alternatives is available to the traveler before deciding whether or not to ask the service to generate an alternative.

prices were somewhat too low to be taken seriously (prices varied between .45, .60 and .75 eurocents per generated alternative), or that the whole set up where participants' rewards were not coupled to expenditures in the experiments created an inclination to take prices of information not too seriously. Because the earlier computed VTTS did take on realistic values, the latter explanation of these two seems to be not supported at this point. Either way, the cost-parameter is of the expected sign, and significance, certainly when interpreted 1-tailed, remains within reasonable levels. Also, note that the subset of trips analyzed is relatively small. Future research efforts, particularly the estimation of detailed behavioral choice-models, may provide more insight concerning the role of information costs.

Let us now turn to the issue of information acquisition concerning characteristics of known alternatives. We here focus on the acquisition of in-vehicle travel-time information, as that is the only type of information were the level of information reliability plays a role. The sample used for analysis was constructed as follows: for every trip made in the presence of an information service, one of the four travel alternatives was randomly drawn, giving 4714 alternatives. Subsequently, all unknown alternatives were deleted from the sample, after which 2865 known alternatives remained; for these alternatives, travel time estimates were acquired 500 times in total. For these 2865 alternatives, it was investigated what determined the acquisition of travel time estimates. Following intuition ii)a), it is expected that the initial variation in travel time (VarTT), operationalized as the length of the certainty interval, positively affects the acquisition of travel time information. Following intuition ii)b) and c), information unreliability (InfoUnrel) is expected to have a negative impact on information acquisition, just as information costs (InfoCosts). Following intuition ii)d), it is also expected that higher average travel costs (AverTC) and to a somewhat lesser extent higher average travel times (AverTT) of the known alternative negatively affect the inclination to acquire information concerning the alternative's travel time. A binary logistic regression was performed where the choice to acquire travel time information for the selected alternative was coded as 1, see Table 8.

Table 8: internal consistency of choices for alternative assessment

Logistic Regression	B	SE	Sig (2-tailed)
VarTT	.034	.006	.000
InfoUnrel	-.062	.013	.000
InfoCosts	-.529	.398	.183
AverTC	-.164	.031	.000
AverTT	-.015	.009	.100
Constant	-.515	.545	.345

The likelihood-ratio index is quite low (.039), which signals that apart from the included independent variables, many other aspects play an important role in participants' choice to acquire travel time information; however, the low index may also relate to the fact that information was acquired only for a relatively low percentage of the sampled trips. Again all parameters are of the expected sign and most are highly significant. Only the effect of information costs remains somewhat insignificant, in line with findings of the previous analysis. Note that here, as expected, information unreliability does become highly significant.

After having evaluated the internal validity of mode choices and information acquisition, only intuition iii) concerning the effect of information remains to be tested. As mentioned earlier, we will here only test a very basic intuition concerning the effect of messages received on choice adaptation, in order to avoid the pitfall of testing complex behavioral assumptions. The following sample was obtained for the analysis: for every trip made, one of the four alternatives available was selected at random. Subsequently, all alternatives that were not known were removed from the sample, just as all alternatives that were known but for which no travel time information was acquired pre-trip. In total, 1154 travel alternatives were selected. For this sample, the relation was investigated between the received message (i.e. the received travel time estimate) and whether or not the alternative that was informed about, was eventually chosen. This dependent variable was coded a 1 if the alternative for which a time estimate was acquired and received was chosen, and a 0 otherwise. Should participants take the information service and its messages seriously (in other words, should intuition iii)a) hold), a negative relation should appear: a high travel time estimate, when taken seriously, should make the corresponding alternative less attractive. Indeed, the found correlation equals -.378 (sig .000), signaling a substantial and significant negative relation between the reception of travel time messages and a traveler's choices.

5.4 Conclusions

This paper presented a travel simulator (denoted *TSL**) that enables an empirical investigation into the use and effects of a next-generation in ATIS among travelers that move through multimodal networks under conditions of uncertainty. The simulator forms a module of the TU Delft Travel Simulator Laboratory. It presents a completely abstract multimodal transport network, which distinguishes itself from other simulators by fully controlling knowledge levels both in terms of awareness of mode-route combinations as well as in terms of knowledge concerning characteristics of known alternatives, and by presenting an information service-module that provides a variety of advanced types of travel information, with controlled for levels of reliability.

Because of the abstraction made in the transport network representation and the provision of a variety of advanced types of travel information that are currently not yet available in the market, the validity of data obtained through experiments in such *TSL** is far from self-evident and cannot be deduced from earlier studies into travel simulator validity (e.g. Bonsall et al., 1997; Mahmassani & Jou, 2000). Therefore, an extensive validation of the observed behavior in *TSL** is performed, using data obtained in *TSL** in an experiment among 264 participants, as well as revealed data obtained in a accompanying web survey filled in by the same participants. The *TSL** data appears to be of a very acceptable, if not high level of validity. First, it appears that participants to the experiment enjoyed participation and indicated that they found the *TSL** as a whole and the simulated travel situations in specific easy to interpret and identify with. Secondly, a comparison of observed behavior in *TSL** with revealed mode choice data as well as data on information acquisition in real life travel situations shows significant relations of expected signs. Taking into account that all choices made in *TSL** may be expected to be very much determined by the specific conditions that were varied per trip (such as travel times and costs for different modes, price and reliability of information services), which limits relations with external data, the found results are a firm indication that participants have made a successful effort to exhibit behavior that resembles their behavior in comparable real life travel situations. Thirdly, it appears that the choices made in *TSL** are determined by a variety of determinants in ways that are perfectly in line with intuition. That is, choices for travel modes, choices whether or not to acquire information (for generation of unknown or assessment of known alternatives) as well as reactions to received messages appear to be made in an explainable and reasonable manner. Only the effect of information costs appears less significant than was expected, a finding that deserves our attention in further research. Overall, it can be said that notwithstanding the high level of abstraction (which was needed to be able to control for the participants' knowledge levels) and the provision of not-yet existing information services, participants' motivation and capability to exhibit consistent and real-life like behavior remained strong. *TSL** thus appears to offer a means to generate valid data concerning multimodal travel behavior under conditions of knowledge limitations, in the presence of several types of advanced information services.

One potentially important issue concerning the face validity of the obtained data, has not been investigated here: it has and could not be tested whether the intuitions concerning traveler behavior that were used for validation are valid themselves. It would not be the first time that intuitions concerning human behavior had to be revised after repeated empirical counterintuitive evidence is found. This has happened particularly in the field of decision making under uncertainty, where carefully constructed choice experiments (e.g. Kahneman & Tversky, 1979) has provided massive evidence of 'counterintuitive' behavior of individuals. It is tried here to avoid this pitfall by formulating only the most basic intuitions and not getting into any potentially disputable intuitions such as those concerning the impact of uncertainty of travel times and costs on mode-choices and the impact of information reliability on the effect of received messages. However, the possibility remains that the simulator has created a travel environment that triggered behavior that is consistent with our intuitions, where actual travel behavior in real life is not. For example, it might be argued that the present experimental set up, or the set up of *TSL** as a research tool, may suppress the formation or execution of habitual travel behavior (e.g. Triandis, 1977, Verplanken et al., 1997) due to for example the so-called 'good subject' effect, which suggests that participants to experiments try to behave in ways that they think they are supposed to behave, leading to overly rational behavior (Bonsall, 2002).

The only way to address such topics with more adequacy is by investigating travelers' choices made in real life over long periods of time, using (prototypes of) next-generation ATIS; however, benefits of examining ATIS' use and effects among travelers are highest in an early stage of development of the service, before high investments are made for prototype development. It appears that *TSL** may suit very well this purpose of ex-ante evaluating the use and effect of next-generation ATIS against relatively low costs and acceptable levels of validity. Encouraged by the present findings, future research will use the data contained in this experiment in order to validate and estimate a variety of theoretical models concerning the dynamics of decision making under conditions of knowledge limitations and information availability (e.g. Chorus et al., 2006b). These analyses should provide valuable insights in the potential usage levels of next-generation ATIS, and the potential effects of received messages on the choices travelers make in the uncertain environment.

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Chapter 6

Chorus, C.G., Walker, J.L., Ben-Akiva, M.E., 2007. A model of travel information response: describing the full sequence of information acquisition and travel choice. *Working paper* [35]

Abstract

This paper presents a discrete-choice based model of traveler response to information. It contributes to existing approaches in three ways: firstly, instead of focusing on either the acquisition of information or the effect of received information on travel choices, this model describes the full sequence of possibly multiple information acquisitions, followed by a travel choice. In doing so, the model provides a more accurate account of actual travel behavior under conditions of knowledge limitations and information provision. Secondly, instead of modeling the utility of information acquisition in an ad-hoc fashion (e.g. as a linear function of attributes of the information service and the trip context), we conceive the utility of information acquisition in terms of the anticipated utility of the travel choice set after having received the information. Thirdly, instead of focusing on a specific type of knowledge limitation and a specific type of information, we describe response to a variety of information types, resulting from a variety of knowledge limitations. This model of travel information response is then estimated on data collected in a multimodal travel simulator-experiment with travel information provision. Estimation results provide face validity to the proposed modeling approach, as a substantial share of the variation in choices for a variety of information options and travel alternatives appears to be captured by the model. Furthermore, a number of new insights are gained with respect to the role of travel information in multimodal travel choice making. For example, it is found that travelers hold intrinsic preferences of some information types (i.e. the generation of new travel alternatives) over others (e.g. the assessment of already known alternatives) that are beyond straight economic explanations.

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6.1 Introduction

Abundant bodies of empirical literature exist concerning travelers' *acquisition* of travel information (e.g. Polak & Jones, 1993; Aarts et al., 1997; Khattak et al., 2003) and especially concerning the *effect* of received travel information on their travel choices (e.g. Adler & McNally, 1994; Mahmassani & Liu, 1999; Chatterjee & McDonald, 2004; Abdel-Aty & Abdalla, 2004; Bogers et al., 2005). Furthermore, a smaller but still substantial number of empirical studies has considered both the acquisition of travel information *as well as* its effect on travel choices (e.g. Emmerink et al., 1996; Polydoropoulou et al., 1998; Hato et al., 1999; Denant-Boemont & Petiot, 2003; Kenyon & Lyons, 2003). See Chorus et al. (2006a) for an overview of how these streams of literature have increased our understanding of the role of information in traveler decision making. However, from a travel behavior modeling-point of view, this body of research has three important limitations: firstly, although theoretically it is widely acknowledged (e.g. Ben-Akiva et al., 1991; Arentze & Timmermans, 2005; Chorus et al., 2006b) that traveler response to information takes the form of a sequence of possibly multiple information acquisitions, eventually followed by a travel choice, this perspective has not yet resulted in the development and empirical estimation of such operational (microeconometric) models of traveler behavior. In failing to acknowledge the sequential nature of traveler response to information, existing empirical studies have been limited to solving pieces of the puzzle, rather than capturing the full behavioral complexity of traveler decision making. Secondly, in existing studies the utility of acquiring information is usually specified in a rather ad-hoc fashion, for example a linear function of explanatory variables. Such a formulation is less theoretically appealing and presumably less behaviorally realistic than the search–theoretical approach, where information utility is conceived in terms of the anticipated choice situation after having received the information (e.g. Raiffa & Schlaifer, 1961; Weibull, 1978; Richardson, 1982): a traveler will only acquire information to the extent that she anticipates that she will derive substantial additional utility from her subsequent travel choice. Thirdly, the overwhelming majority of research on response to travel information has focused on particular types of knowledge limitations and response to particular types of information (predominantly, the focus is on travel time uncertainty and travel time information). Given that our transport networks are becoming more and more complex and that available travel information services more and more sophisticated, such a narrow focus is increasingly limiting our understanding of actual traveler travel behavior.

This paper addresses these three shortcomings as by presenting an operational, discrete-choice based model of traveler response to information that i) acknowledges the potentially sequential nature of this response, ii) specifies, following search theory-literature, the utility of information acquisition in terms of the anticipated utility of the travel choice set after having received the information[36] and iii) deals with a wide variety of knowledge limitations and information types.

In order to test and estimate the developed model, a travel simulator is used that provides participants with an abstract multimodal travel network and a personal intelligent travel assistant. The network consists of a number of mode-route combinations that are not necessarily all of them known to the traveler at the outset. Furthermore, the attributes of

[36] Note that there are two additional advantages to this search-theory based notion of information utility: first, it enables the derivation of choice probabilities for a wide variety of information acquisition options while using only a limited number of travel related parameters. Second, it provides the opportunity to estimate travel related parameters (e.g. travel time valuations) directly from observed information acquisition behavior (e.g. travel time information acquisition).

known alternatives (travel times and costs for car-options, and also waiting times and seat availability for train options) have uncertainty attached to them. The travel assistant is capable of i) providing estimates for the attributes of known alternatives, ii) generating previously unknown mode-route combinations and iii) providing warnings in case an alternative is selected that has a substantially higher travel time than the traveler expects. Per trip, a traveler may (repeatedly) acquire information of these types, and subsequently execute a mode-route combination.

This paper builds upon a previous paper (Chorus et al., Submitted), where we consider a traveler, faced with the above mentioned type of choice between the acquisition of information and the execution of uncertain travel alternatives. Parts of the model framework presented here also appear in this previous paper, and the same data-collection effort is used for model estimation. The main differences between the two contributions are the following: firstly, here, we consider not only a traveler's initial choice to acquire information or execute a travel alternative, but rather her full sequence of decisions for a given trip, thus covering the complete spectrum of possible response to information. Secondly, here, we present the formal econometrical model in full detail, whereas the earlier paper communicates details on a conceptual level. The paper is organized as follows: The model specification is presented in Section 6.2. The travel simulator and the experimental set-up are presented in Section 6.3. Section 6.4 presents the model estimation and results, and Section 6.5 draws conclusions and points at directions for further research.

6.2 A model of traveler response to information

In this work, we aim to develop a model that simultaneously represents travelers' information acquisition choices and the effect of acquired information on their travel choices, under conditions of knowledge limitations and information availability. In developing the model, we assume the following scenario. First, a traveler faces a choice situation that consists of a number of mode- and route-alternatives, which are not all necessarily known to her at the outset. Furthermore, attributes of known alternatives (such as travel times and travel costs) are uncertain, although the traveler may have ideas of their distributions, for example in terms of means and variability. The traveler then can either directly choose one of the known mode-route combinations based on her existing knowledge, or decide to purchase information first and choose a travel alternative later. In case information is acquired, e.g. a travel time estimate for a car-route, the traveler receives the information and is again faced with the choice either to execute one of the known travel alternatives (based on her initial knowledge *and* the received information) or to acquire additional information. Per trip, a traveler thus exhibits a full sequence of decisions, consisting of a number of (possibly zero) information acquisitions, followed by one travel choice. In our scenario, we consider three types of information that help the traveler deal with the uncertainty of the travel situation and her limited network knowledge: i) she may acquire fully reliable estimates concerning attributes of known alternatives (denoted as type *A* for assessment), ii) she may generate new travel alternatives and be provided with fully reliable estimates of their attributes as well, i.e. she may add formerly unknown mode-route combinations to her choice set (denoted by type *G* for generation) and iii) she may choose to be provided with early warnings in case travel options are selected with travel times that strongly deviate from the perceived travel time mean (denoted by type *W* for warning).

6.2.1 Notation and basic derivations

Let us denote individuals by n , trips by t and decision stages by d. The notion of a decision stage is virtual: it is used here to describe the sequential nature of choices made by the individual within one and the same pre-trip situation. Every trip t has a starting situation S_t . At any decision stage d of trip t, the individual has the opportunity to choose to acquire some form of information, $I_{ntd} = r$ of types A, G or W from the set of information options available to her at that moment, C^I_{ntd} . Let us denote the total number of decision stages used to acquire information as D_{nt} . When information is acquired at stage d , the individual proceeds to stage d+1 of trip t. When instead of acquiring information, a travel alternative is executed from the set of available travel options, $T_{ntd} = i, i \in C^T_{ntd}$, the trip is undertaken and the individual proceeds to stage d=1 of trip t+1. The total choice set faced by individual n at stage d of trip t consists of both travel alternatives and information options: $C_{ntd} = \{C^T_{ntd}, C^I_{ntd}\}$. For every trip, a sequence is thus observed of a number of information acquisitions followed by one travel choice. Let us denote this sequence in general as $\left[\{I_{ntd}, d = 1,2,..., D_{nt}\}, T_{ntD_{nt}+1}\right]$. The indexing with respect to n , d and t of the choice sets reflects their conditionality on the information acquired by the individual earlier in the trip. This conditionality works as follows: every bit of information can only be acquired once, so that an acquired bit of information at stage d is no longer element of the choice set of information options at stage d+1. Furthermore, the individual can acquire information in terms of the generation of previously unknown travel alternatives (type G). Acquisition of such information at stage d adds a travel alternative to the choice set of travel alternatives at stage d+1. Next to this choice set conditionality, a second source of conditionality exists which stems from the fact that information received concerning one or more of the attributes of previously known alternatives is assumed to alter the individual's perception of these attributes. This latter source of conditionality will be discussed in more detail below. When writing the probability of observing a particular sequence of information acquisitions followed by a travel choice, conditionality is reflected by formulating this probability as a series of conditional probabilities (e.g. Lerman & Mahmassani, 1985):

$$P([\{I_{ntd}, d = 1,2,..., D_{nt}\}, T_{nt}]) = P(I_{nt1} | S_t) \cdot P(I_{nt2} | I_{nt1}, S_t) \cdot ... \cdot P(T_{ntD_{nt}+1} | I_{ntD_{nt}}, ..., I_{nt2}, I_{nt1}, S_t) \quad (1)$$

As an example, suppose that $D_{nt} = 2$, i.e. we observe a sequence of 2 information acquisitions $I_{nt1} = r, I_{nt2} = s,$ followed by a travel choice $T_{nt} = i$. This sequence is denoted as $[\{I_{nt1} = r, I_{nt2} = s\}, T_{nt} = i]$, meaning that first information bit r is acquired (e.g. an estimate for car-travel time); after having received bit r, bit s is acquired (e.g. an estimate for train travel time); after having received bit s, travel alternative i is executed (e.g. commence the journey by car). This sequence, whose probability is given by the product of conditional probabilities:

$P(I_{nt1} = r | S_t) \cdot P(I_{nt2} = s | I_{nt1} = r, S_t) \cdot P(T_{nt3} = i | I_{nt2} = s, I_{nt1} = r, S_t)$, is depicted in Figure 1.

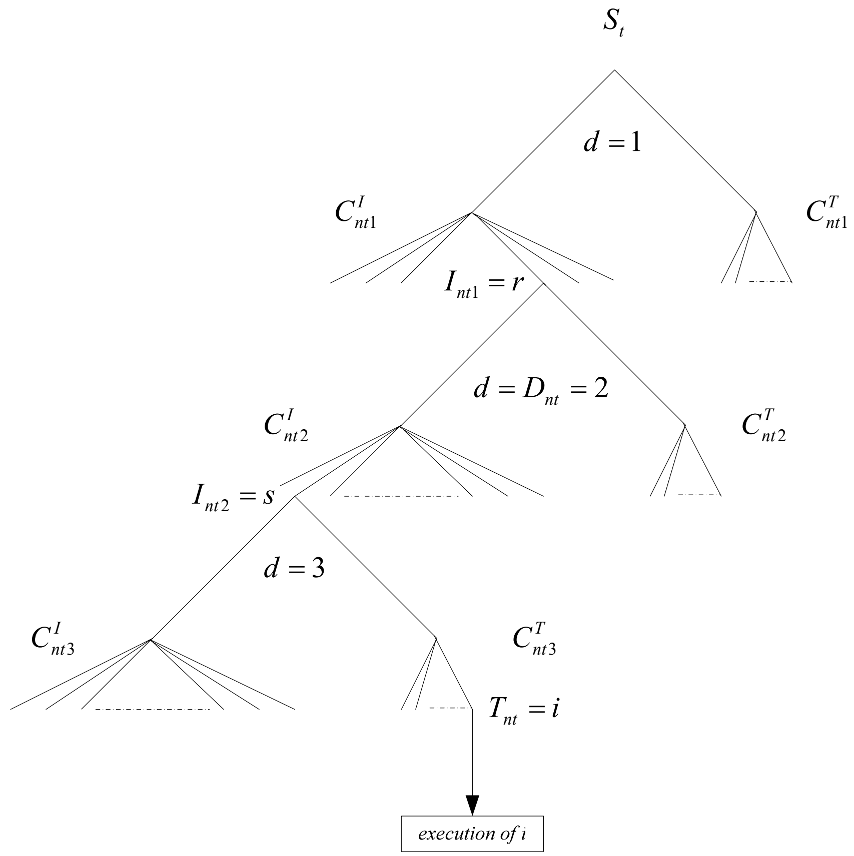

Figure 1: depiction of sequence $\left[\{I_{nt1}=r, I_{nt2}=s,\}, T_{nt3}=i\right]$

In order to be able to estimate a simultaneous model of information acquisition and mode/route choice based on the observed sequences, we need to write the probabilities in the right-hand side of Equation (1) in terms of the utility of travel alternatives and information acquisition options. Sub-section 6.2.2 provides the specification for the travel alternatives' utilities, Sub-section 6.2.3 does the same for the information acquisition options. Sub-section 6.2.4 then derives the resulting choice probabilities and log-likelihood.

6.2.2 Utility-specification of travel alternatives

Equation (2) specifies the utility perceived to be derived by individual *n* at stage *d* of trip *t* when selecting a travel alternative $i \in C^T_{ntd}$:

$$U^i_{ntd} = \sum_{k=1}^{K} \beta^k \cdot \hat{x}^{ik}_{ntd} + \sum_{k=1}^{K} \theta^k \cdot \tilde{x}^{ik}_{ntd} + \alpha^i_n + \varepsilon^i_{ntd} \tag{2}$$

This specification assumes that individuals perceive each alternative *i* as a bundle of attributes $x^{i1}_{ntd}, x^{i2}_{ntd}, \ldots$. More specifically, as each of these attributes may be uncertain, we model them through probability density functions $f_{ntd}\left(x^{ik}\right)$, assuming a mean-variability model with expected values $\hat{x}^{ik}_{ntd}$, variability $\tilde{x}^{ik}_{ntd}$ and no covariances. The indexing with respect to n, d and t represents the fact an individual's *perception* of travel alternatives' attributes is conditional on the information acquired by her at earlier decision stages. This conditionality works as follows: $f_{ntd}\left(x^{ik}\right)$ of an attribute k for which a message $\overline{x}^{ik}$ is received through information acquisition at an earlier stage equals 1 for $x^{ik} = \overline{x}^{ik}$ and 0 for $x^{ik} \neq \overline{x}^{ik}$.[37] In other words, we assume the information to be fully reliable. The expected value and variability of an attribute about which no information is acquired at earlier stages, equal those provided to the traveler at the starting situation for that trip. Parameters β^k represent preferences with respect to the expected value of attribute k, parameters θ^k reflect risk attitudes with respect to the same attribute. An error component α_n^i represents the individual's intrinsic preferences for specific travel alternatives, ε_{ntd}^i is i.i.d.-extreme value distributed. In the next Section, we derive the utility functions concerning information acquisition options. Importantly, note beforehand that our specification of the utility of information acquisition in Section 6.2.3 involves no additional parameters than those that enter Equation (2), with the exception of parameters related to the cost of the information. This will enable us on the one hand to limit the number of parameters needed in model estimation, and on the other hand to use observed information acquisition behavior directly to estimate travelers' valuation of the attributes of travel alternatives (β^k) and the uncertainty attached to them (θ^k).

6.2.3 Utility-specification of information acquisition options

We define the utility of acquiring information bit *r* at stage *d* of trip *t* by individual *n* as the utility that is anticipated by that individual at stage *d*, to be derived from the choice set of travel alternatives at stage *d*+1 after having acquired information.[38] The utility of information, defined in words as above, depends on the following anticipations by individual *n* at stage *d* of trip *t*, anticipation being denoted by the symbol $\cup$:

i) her anticipation of the constitution of the travel choice set at stage *d*+1, which depends on the information acquired at stage d : $\breve{C}_{ntd+1}^T$.

ii) Her anticipation of the utility of travel alternatives in the anticipated choice set at stage *d*+1, which depends on the information acquired at stage *d*: $\breve{U}_{ntd+1}^i$. This anticipated utility is itself fully specified through applying Equation (2), based on the following two anticipations by the individual:

   a. her anticipation of the attributes of travel alternatives in this choice set at stage *d*+1, which depend on the acquired information at stage d : $\breve{f}_{ntd+1}\left(x^{ik}\right)$

   b. her anticipation[39] of the unobserved parts of the utility of these alternatives at stage *d*+1: $\breve{\varepsilon}_{ntd+1}^i$ and $\breve{\alpha}_n^i$.

We can now formalize the utility of acquiring a particular bit of information *r* as a traveler's expected maximum utility of the travel choice after having acquired the information, minus

[37] An exception is the activation of the early warning function for travel times, discussed in detail in Section 3.

[38] Note that when faced with the choice *whether or not* to acquire information, it is the anticipated *incremental* utility from the travel choice set that matters. In our model however, we are concerned with modeling choices from a choice set that contains information acquisition options as well as travel alternatives, which leads to the specification of information utility in *absolute* terms.

[39] As the α 's are time-inspecific, $\breve{\alpha}_n^i = \alpha_n^i$. We furthermore assume $\breve{\varepsilon}_{ntd+1}^i$ to be independent from ε_{ntd+1}^i and ε_{ntd}^i for all *i*'s.

the costs of acquiring the information. Note that the expected maximum is a function of the anticipated information r:

$$U^{r}_{ntd} = E\left(\max_{i \in \breve{C}^{T}_{ntd+1}} \left\{\breve{U}^{i}_{ntd+1}\right\}\right) - c^{r}_{ntd} + \delta^{r}_{n} + \varepsilon^{r}_{ntd} \tag{3}$$

The perceived cost of acquiring information bit r, c^{r}_{ntd}, may consist of monetary costs but also costs in terms of time, effort, attention, etc. Variation in unobserved utility of an information bit across individuals, trips and nodes is captured here by two error components $\delta^{r}_{n}, \varepsilon^{r}_{ntd}$ - δ^{r}_{n} represents an agent effect, reflecting the individual's latent preference for acquiring this particular information bit r and ε^{r}_{ntd} is an i.i.d.-error component. Note that the value of acquiring information (being the utility minus the costs) is now fully specified in terms of the (anticipated) utilities of the travel alternatives. What anticipations the traveler might have concerning the travel choice set and the attributes of alternatives therein, as denoted above, depends on the type of information acquisition. Below, for each of the considered information types - A, G and W - these anticipations concerning the travel choice set and the attributes of alternatives therein are derived, followed by derivation of the utility of acquiring information of that type.

Assessment of known alternatives (A)[40]

As acquiring an information bit concerning the assessment of known alternatives (denoted r^{A}) does not add any alternative to the choice set, the individual anticipates no changes in choice set composition due to acquiring an information bit of this type:

$$\breve{C}^{T}_{ntd+1} = C^{T}_{ntd} \tag{4}$$

Her anticipation of the utility of travel alternatives in this choice set, $\breve{U}^{i}_{ntd+1}, \forall i \in \breve{C}^{T}_{ntd+1}$, depends on her anticipated perception $\breve{f}_{ntd+1}\left(x^{ik}\right)$ of the attributes of these alternatives, after having acquired the information. Acquiring information for alternative j's l th attribute is not anticipated by the individual to alter her perceptions of attributes of any alternative $i \neq j$, nor of attributes $k \neq l$ of alternative j:

$$\breve{f}_{ntd+1}\left(x^{ik}\right) = f_{ntd}\left(x^{ik}\right), \forall i \neq j, \forall k \neq l \tag{5}$$

However, the individual does anticipate her perception concerning alternative j's attribute l to be affected by acquiring information of type A. In particular, she anticipates that her perceptions will be affected by received messages. Conditional on receiving some estimate $\bar{x}^{jl}$ for j's attribute l, her anticipation, denoted $\breve{f}_{ntd+1}\left(x^{jl} \middle| \bar{x}^{jl}\right)$, is that she will obtain the true value of the attribute $\bar{x}^{jl}$ with zero uncertainty attached. Therefore, $\breve{f}_{ntd+1}\left(x^{jl} \middle| \bar{x}^{jl}\right)$ can take on two values: 1 if $x^{jl} = \bar{x}^{jl}$ and 0 otherwise. Of course, when considering whether to assess attribute x^{jl}, the individual does not know what estimate (message) she will receive.

[40] For simplicity of presentation, we cover here the case of acquiring information for *one* of the attributes of a known alternative; extension of these formulations to the case of acquisition of estimates for multiple attributes simultaneously is straightforward.

Therefore, the utility of the assessment must be integrated over the probability density function of the anticipated message, denoted $f_{ntd}\left(\bar{x}^{jl}\right)$, which depends on the traveler's initial perceptions of the attribute $f_{ntd}\left(x^{jl}\right)$ as well as on the perceived reliability of the information[41]. Together, this gives us the following specification of the utility of acquiring a bit of information r of type A:

$$U_{ntd}^{r^A} = \int_{\bar{x}^{jk}} \left(E\left(\max_{i \in \breve{C}_{ntd+1}^T} \left\{ \breve{U}_{ntd+1}^i \right\} \right) \right) \cdot f_{ntd}\left(\bar{x}^{jl}\right) d\bar{x}^{jl} - c_{ntd}^{r^A} + \delta_n^{r^A} + \varepsilon_{ntd}^{r^A} \tag{6}$$

As $\breve{\varepsilon}_{ntd+1}^i$ is assumed to be independent from ε_{ntd+1}^i and ε_{ntd}^i for all travel alternatives (see Footnote 39), we can integrate out this error component immediately by replacing the expected max-operator in (6) with a logsum:

$$U_{ntd}^{r^A} = \int_{\bar{x}^{jk}} \left(\ln\left[\sum_{i \in \breve{C}_{ntd+1}^T} \exp\left(\breve{V}_{ntd+1}^i + \alpha_n^i \right) \right] \right) \cdot f_{ntd}\left(\bar{x}^{jl}\right) d\bar{x}^{jl} - c_{ntd}^{r^A} + \delta_n^{r^A} + \varepsilon_{ntd}^{r^A} \tag{7}$$

Here, $\breve{V}_{ntd+1}^i$ represents the deterministic part of $\breve{U}_{ntd+1}^i$, the utility of travel alternative i. In the following Sub-sections, we will directly move to the logsum-formulation.

Generation of unknown alternatives (G)

By acquiring an information bit of this type (denoted r^G), a previously unknown travel alternative, e.g. alternative j, is generated and the true values of all of its attributes are provided. We thus assume that the individual anticipates that her choice set of travel alternatives, after having received the information, is enriched with the acquired travel alternative:

$$\breve{C}_{ntd+1}^T = \left\{ C_{ntd}^T, j \right\} \tag{8}$$

Her anticipation of the deterministic utility of travel alternatives in this choice set, $\breve{V}_{ntd+1}^i, \forall i \in \breve{C}_{ntd+1}^T$, depends on $\breve{f}_{ntd+1}\left(x^{ik}\right)$. Generating travel alternative j is not anticipated by the individual to alter her perceptions of attributes of any alternative $i \neq j$ that is not generated by the information service:

$$\breve{f}_{ntd+1}\left(x^{ik}\right) = f_{ntd}\left(x^{ik}\right), \forall i \neq j \tag{9}$$

However, the individual does anticipate her perception concerning the generated alternative j's attributes to be affected. In particular, she anticipates that her perceptions for all L_j attributes will be given by the received message: as she knows the information is fully

[41] In fact, for our case of completely reliable information, we may assume that $f_{ntd}\left(\bar{x}^{jl}\right) = f_{ntd}\left(x^{jl}\right)$. In Section 4.1, we go into more detail with respect to our assumptions concerning the distributions of anticipated messages.

reliable, she anticipates that, conditional on receiving an estimate $\bar{x}^{j1},...,\bar{x}^{jL_j}$, her perceptions are: $\breve{f}_{ntd+1}\left(x^{jl},...,x^{jL_j}\middle|\bar{x}^{j1},...,\bar{x}^{jL_j}\right)=\breve{f}_{ntd+1}\left(x^{jl}\middle|\bar{x}^{j1}\right)\cdot...\cdot\breve{f}_{ntd+1}\left(x^{jL_j}\middle|\bar{x}^{jL_j}\right)$ - note that we have assumed no covariances between perceptions of different attributes for the same alternative. This latter product of density functions can take on two values: 1 if $x^{j1}=\bar{x}^{j1},...,x^{jL_j}=\bar{x}^{jL_j}$, 0 otherwise. Of course, the individual does again not know what estimates she will receive when considering the generation of alternative j. Therefore again, we need to integrate over the probability density function describing what message she thinks she might receive $f_{ntd}\left(\bar{x}^{jl}\right)\cdot...\cdot f_{ntd}\left(\bar{x}^{jL_j}\right)$. Directly using the logsum-formulation, this leads to the following specification of the utility of acquiring information bit r^G:

$$U_{ntd}^{r^G}=\int\limits_{\bar{x}^{j1}..\bar{x}^{jL_j}}\left(\ln\left[\sum_{i\in\breve{C}_{ntd+1}^T}\exp\left(\breve{V}_{ntd+1}^i+\alpha_n^i\right)\right]\right)f_{ntd}\left(\bar{x}^{j1}\right)..f_{ntd}\left(\bar{x}^{jL_j}\right)\cdot d\bar{x}^{j1}..d\bar{x}^{jL_j}-c_{ntd}^{r^G}+\delta_n^{r^G}+\varepsilon_{ntd}^{r^G} \quad (10)$$

Activating the early warning function (W)

This type of information differs from the former two in that no message is received directly after acquiring the information. Rather, information bit r^W is an insurance against strongly deviating travel times: by activating the early warning function, the individual receives a message when the travel alternative she is about to choose has a travel time, denoted as attribute *l*, that deviates strongly (for example, more than *g* minutes) from the travel time under normal conditions, due to e.g. an incident. This message does NOT contain an estimate for the travel time. As the early warning function does not add any alternative to the choice set, the individual anticipates no changes in choice set due acquiring information of this type:

$$\breve{C}_{ntd+1}^T=C_{ntd}^T \quad (11)$$

Her anticipation of the deterministic utility of travel alternatives in this choice set, $\breve{V}_{ntd+1}^i,\forall i\in\breve{C}_{ntd+1}^T$, depends on $\breve{f}_{ntd+1}\left(x^{ik}\right)$. Activating the early warning function is not anticipated by the individual to alter her perceptions of other attributes than travel times of any alternative in her choice set, in other words:

$$\breve{f}_{ntd+1}\left(x^{ik}\right)=f_{ntd}\left(x^{ik}\right),\forall k\neq l \quad (12)$$

However, the individual does anticipate her perceptions concerning attribute l, being travel time, to be affected for all alternatives by acquiring information of type *W*. Although she knows that the expected travel time does not change as a result of activating the early warning function (in notation: $\breve{\hat{x}}_{ntd+1}^{jl}=\hat{x}_{ntd}^{jl}$), she is assumed to anticipate that the variability of travel time of all alternatives is reduced to some number *z*, which itself depends on the value of *g* introduced directly before Equation (11) above, if the variation does not already equal zero as a result of earlier information acquisition: $\breve{\tilde{x}}_{ntd+1}^{jl}=\min\left\{z,\tilde{x}_{ntd}^{jl}\right\}$. Directly using the logsum-formulation, this leads to the following specification of the utility of acquiring information bit r^W:

$$U_{ntd}^{r^W} = \ln\left[\sum_{i \in \bar{C}_{ntd+1}^T} \exp\left(\breve{V}_{ntd+1}^i + \alpha_n^i\right)\right] - c_{ntd}^{r^W} + \delta_n^{r^W} + \varepsilon_{ntd}^{r^W} \tag{13}$$

6.2.4 Choice probabilities and Sample Likelihood

Now that the utilities have been specified, we can formulate the probability that an individual *n* at decision stage *d* of trip *t* will choose to acquire some form of travel information or to execute one of the available travel alternatives. Deriving the choice probabilities for information acquisition options and travel alternatives involves the integration over the i.i.d.-extreme value terms as well as the individual specific error terms. Let us briefly revisit these error components before formulating the choice probabilities and the sample likelihood. First, there's the error components of the travel alternatives. As specified in Equation (2), these consist of i.i.d.-extreme value terms $\varepsilon_{ntd}^i, \varepsilon_{ntd}^j,...$ and individual specific intrinsic preferences for travel alternatives $\alpha_n^i, \alpha_n^j,...$. Note that besides entering the utilities of travel alternatives, the latter, individual specific, error components also codetermine the utilities of information acquisition options, as can be seen in Equations (7), (10) and (13), where the presence of the $\alpha_n^i, \alpha_n^j,...$'s is mentioned explicitly. Then we have the error components that relate directly to the information acquisition options, consisting of i.i.d.-extreme value components $\varepsilon_{ntd}^r, \varepsilon_{ntd}^s,...$ and individual-specific preferences for different information bits $\delta_{ntd}^r, \delta_{ntd}^s,...$ (or different information types $\delta_{ntd}^{r^A}, \delta_{ntd}^{r^G}, \delta_{ntd}^{r^W}$). This leads to the following formulation of choice probabilities, unconditional with respect to the i.i.d.-error components, but conditional on the individual-specific error components $\alpha_n^i, \alpha_n^j,...$ and $\delta_n^r, \delta_n^s,...$:

$$P\left(I_{ntd} = r \middle| \alpha_n^i, \alpha_n^j,..., \delta_n^r, \delta_n^s,...\right) = \frac{\exp\left(V_{ntd}^r + \delta_n^r\right)}{\sum_{s \in C_{ntd}^I}\left[\exp\left(V_{ntd}^s + \delta_n^s\right)\right] + \sum_{i \in C_{ntd}^T}\left[\exp\left(V_{ntd}^i + \alpha_n^i\right)\right]} \tag{14}$$

and

$$P\left(T_{ntd} = i \middle| \alpha_n^i, \alpha_n^j,..., \delta_n^r, \delta_n^s,...\right) = \frac{\exp\left(V_{ntd}^i + \alpha_n^i\right)}{\sum_{r \in C_{ntd}^I}\left[\exp\left(V_{ntd}^r + \delta_n^r\right)\right] + \sum_{j \in C_{ntd}^T}\left[\exp\left(V_{ntd}^j + \alpha_n^j\right)\right]} \tag{15}$$

where V_{ntd}^r and V_{ntd}^s represent the deterministic parts of the utility of particular information acquisition options *r* and *s*, given by Equations (7), (10) and (13); V_{ntd}^i and V_{ntd}^j represent the deterministic parts of the utility of executing particular travel alternatives *i* and *j*, given by Equation (2). Given the above formulations and by applying the notation of Equation (1), we now have the means to calculate the unconditional sample likelihood, which can be written as follows (denoting $\alpha_n^i, \alpha_n^j,...$ by α and $\delta_n^r, \delta_n^s,...$ by δ):

$$L = \prod_{n=1}^{N} \int_{\alpha,\delta} \left(\prod_{t=1}^{T_n} P\left[\left(I_{ntd}, d = 1,...,D_{nt} \right), T_{ntD_{nt}+1} \right] . \left| \alpha,\delta \right. \right) \cdot f\left(\alpha,\delta\right) d\left(\alpha,\delta\right) \quad (16)$$

6.3 Data-collection: a travel simulator experiment

In order to estimate the model presented in Section 6.2, data requirements include the following: firstly, the traveler must be provided a number of travel alternatives (e.g., routes by car and/or train) simultaneously with a number of information acquisition options (of types *A*, *G* and *W*). Secondly, the traveler must perceive her knowledge as being incomplete; that is, she must be aware of the fact that her choice set does not necessarily include all available travel alternatives, and that she does not know the exact value of the attributes (travel times, costs, etc.) of the alternatives in her choice set. Thirdly, the analyst must be able to make fair assumptions concerning the traveler's lack of knowledge, in terms of the alternatives in her choice set and the uncertainty of attributes of known travel alternatives. Fourthly, the traveler must be able to make a sequence of information acquisition choices, followed by one travel choice per trip. In order to meet these data requirements, a travel simulator was built, which is described in the next Section. A more extensive description of the simulator, including the validation of the simulator as a research tool, can be found in Chorus et al. (2006c).

6.3.1 A multimodal travel simulator with information provision

The constructed simulator is geared towards the study of decision making under incomplete knowledge in multimodal networks, in the presence of highly functional travel information services. It stands in a long tradition of computer-based travel simulator tools of varying levels of sophistication[42] (e.g. Adler et al., 1993; Chen & Mahmassani, 1993; Adler & McNally, 1994; Koutsopoulos et al., 1994; Walker & Ben-Akiva, 1996; Bonsall et al., 1997; Mahmassani & Liu, 1999; Katsikopoulos et al., 2002; Bonsall & Palmer, 2004). Figure 2 shows the screen plot of an arbitrary travel situation that a participant may be confronted with. The workings of the simulator will be discussed by going through this Figure. The screen consists of 4 parts: lower left presents the trip context, upper-left shows the transport network, upper right presents the information service and lower right shows a visual aid.

The transport network

A purely fictive O-D pair was created, connected by four paths displayed as arrows and an interchange facility halfway; as our current analyses do not deal with in-trip choice adaptation, we will not discuss the interchange possibilities here. The two left arrows symbolize two car-options, i.e. highway routes. The two routes are equivalent except that they may differ in terms of travel times and costs. Next to these two car-options, two intercity train options exist which are also equivalent, except that they may also differ in travel time and cost, as well as seat availability. Furthermore, the left one of the two trains departs once every 15 minutes, the right one once every 5 minutes, thus inducing a lower expected and maximum waiting time. The number of alternatives 'known' to the traveler at the outset varies per trip. 'Unknown' alternatives are marked grey instead of black, and the traveler initially has no knowledge concerning their characteristics. These alternatives are inactive, and cannot be executed by the traveler. For the trip displayed in Figure 1, one car-option and the 15 minute

[42] See Koutsopoulos et al. (1995) and Bonsall (2004) for useful overviews.

train option are known a priori. The other train alternative is activated by the information service (see further below).

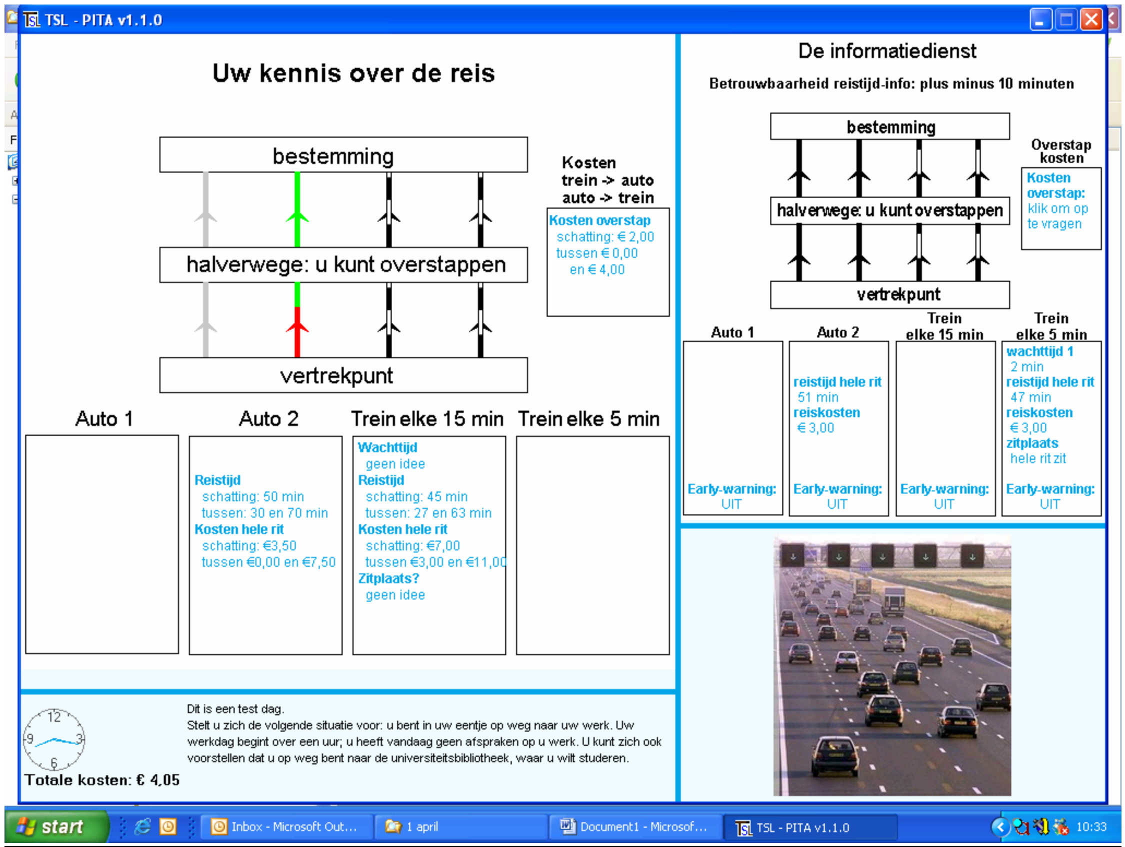

Figure 2: screen plot of the simulator *(in Dutch)*

The participant's initial knowledge of the alternatives (i.e., before acquiring any information) is presented in the boxes below the black arrows. The following a priori knowledge is provided to the traveler for the known alternatives: for both car and train options, i) *best guesses* for travel times and travel costs[43] are provided, as well as ii) 'certainty' *intervals*, i.e. ranges of times and costs within which the participants are told (correctly) that actual values will fall almost certainly. A priori, train travelers do not know the exact departure times (although they do know the service's frequency), neither do they know whether or not a seat is available for them. Let us focus first on the situation where a traveler decides not to acquire information, but to directly embark on a trip by executing one of the known travel alternatives: a participant may start his journey by clicking one of the arrows in the transport network, and subsequently confirming his choice in the appearing pop-up window. By confirming his or her choice, there is no possibility of adaptation until the interchange point is reached. Directly after confirmation, the traveler is confronted with the actual costs of the

[43] Travel times were framed as door to door for car-trips, and door-to-door minus waiting times for train-trips. All 'best guess' travel times were randomly varied beforehand and could take the values of 50 and 60 minutes for the car-option and 45 and 55 minutes for the train option (since to the latter also waiting times had to be added to get the total travel time). Travel costs were framed as fuel expenditures + parking costs for car-trips, and ticket tariffs for train-trips. Travel costs were randomly assigned beforehand the values of 3.5 euro or either 7 euro.

alternative, and train travelers were also informed whether or not they had a seat. As the trip commences (Figure 2 shows the situation where a car option is chosen), the clock starts ticking and the arrow that represents the chosen alternative incrementally turns red, indicating the amount of distance traveled so far. These actual travel costs were drawn from a normal distribution, having the best guess as mean, and a quarter of the length of the 'certainty' interval as standard deviation, so that 95% of the drawn actual values would indeed fall within the 'certainty' interval. The same applies to the generation of actual travel times. Seat availability was randomly drawn from a discrete distribution (50% chance of having a seat), waiting times from a uniform distribution between 0 and the headway (either 5 or 15 minutes).

The information service

Let us focus now on the information acquisition options: as can be seen in Figure 2, the information service's layout is an exact copy of the transport network. In the sample used for our current analyses all provided information was fully reliable, meaning that every received message corresponds to the actual value of that particular attribute. Participants were told about this complete reliability. The service presents three ways of acquiring information: firstly, a traveler may acquire information concerning one or more particular attributes of a known alternative, be it travel times and/or costs for a car or train option, and/or waiting times and seat availability for train options. This is done by first clicking on the arrow of a 'known' alternative and subsequently checking the boxes for those attributes for which information is needed (the information price is listed at every box, and varies between .15, .30, .45 eurocents). After the boxes are checked, the service displays the information in the information box. Figure 2 presents the situation where for one of the car-options, both travel time and costs are informed about by the information service. Secondly, a traveler can ask the service to generate or activate one or more alternatives that are currently 'unknown' to him or her. This is done by clicking on an arrow within the information service screen that corresponds to an unknown alternative in the transport network. After this is done, a pop-up window appears that states the price of the information acquisition (being varied between .45, .60 and .75 eurocents) and asks for a confirmation. After confirmation, the alternative is made active, that is, its color turns black in the transport network, and the alternative can be executed from now on. Furthermore, the information service provides estimates for all the alternative's characteristics. These estimates are displayed in the box below the activated alternative in the information service screen part. Figure 1 presents such an information acquisition for the 5 minute train option. Thirdly, a traveler may activate the so-called early-warning function. This function notifies a traveler when an alternative that is about to be chosen has an actual travel time that is substantially larger than the traveler's best guess (no strict level of travel time differences that triggers these messages is mentioned to the travelers). This type of information is acquired by clicking on a known alternative and checking the early warning box.

Note that all these types of information can be acquired either pre-trip, as well during the trip or at the interchange point, which makes the information service 'mobile'. However, we focus on pre-trip information acquisition here. Note furthermore that the choice set size of information options depends on the choice set size of travel options: when a travel alternative is unknown, it can not be assessed in terms of its attributes; when it is known, it cannot be generated by the information service. Since there are more assessment options per known alternative than there are generation options per unknown alternative, the size of the information choice set is positively correlated with the size of the travel choice set. The early warning function is always available, irrespective the number of available travel alternatives in the traveler's travel choice set. However, once an attribute of a known alternative is assessed, it cannot be assed once more; once an unknown alternative is generated, it cannot be generated once more or have its attributes assessed once more; once the early warning function is activated, it cannot be (de)activated once more.

The visual aid
In the lower right, pictures are placed that help the traveler identify with the situation at hand: several pictures were available to describe a number of possible pre- and in-trip situations for car (e.g. with and without congestion) as well as train (e.g. waiting at the station, being underway).

Trip purpose
The trip purpose consists of a story line describing trip purpose and possibly preferred arrival times, generated at random for each trip from a set of predefined options. These story lines were presented at the beginning of each new trip through pop-up windows, after which they were located at the lower left of the screen during the completion of the trip (see Table 1).

Table 1: trip purposes

Context	Text
Business	*Please envisage the following:* “You are on your way to an important business meeting, which starts at exactly one hour from now.” *You may also envisage the following:* “You are on your way towards a job interview for an internship as part of your education”.
Commute	*Please envisage the following:* “You are on your way to work. Your working day starts within an hour from now. You have no appointments today.” *You may also envisage the following:* “You are on your way to the university library, where you want to study.”
Social	*Please envisage the following:* “During your leisure time, you are on your way for a lunch with friends at their home. You told them that you would be there in about an hour.”
Leisure	*Please envisage the following:* “During your leisure time, you are on your way towards a museum, on your own. The day is still young; you have plenty of time to visit the museum.” *You may also envisage the following:* “You are on your way to the beach or the woods, for a walk”.

Next to the story line, the trip context displays a clock, presenting accelerated time. It ticks away one minute waiting time or in-vehicle time per actual second, after a travel alternative is executed. Finally, beneath the clock, a money counter registers the amount of money spent so far on a given trip, including both travel costs and costs of information acquisition.

6.3.2 The experiment

Participants were recruited through placement of advertisements in a campus newspaper and another free newspaper. Also a mail was sent out to ± 500 students. A 20 euro reward was offered for participation. All participants were required to have had some experience with both car and train travel. In total, 264 individuals were recruited this way, of which 31 were randomly assigned to the experimental conditions on which we focus here (i.e. fully reliable information conditions). Table 2 presents response group characteristics, and shows a rather heterogeneous group in terms of socio-economic characteristics.

Table 2: response group characteristics (N=31)

Variable	Frequency
Gender	
female	14
male	17
Age	
< 25	16
< 40	10
< 65	5
Completed education	
lower education	0
secondary school	21
higher education	10
Main out-of-home activity	
paid work	9
education	18
other	4
Drivers' license	
yes	27
no[44]	4
Car availability	
always / usually	11
sometimes	14
less than sometimes	6
Public Transport (PT) season ticket	
some form of	24
none	7

Before commencing with the simulator experiment, an extensive web survey was filled out by the participants concerning among other things their actual travel behavior. Following this, the participants were given a rather extensive introduction in the simulator. Participants were asked very explicitly to not regard the experiment as some form of a game (e.g. by trying to travel as fast as possible, or spending as much or as little money as possible), but rather to try to identify with the travel situations presented and make choices that they would make, would they be confronted with such a situation in real life. It is known that in simulated travel situations like the ones presented in this experiment, the issue of motivation is a difficult one. See Carson et al. (2000) and Bonsall (2002) for overviews of possible incentive-caveats. In order to increase the motivation of participants to put effort in identifying themselves with the simulated travel environment, the following approach was chosen: participants were told during the introduction that they could win a 7,5 euro bonus, to be awarded to about half of the respondents, based on the success of their identification effort. It was mentioned that the correspondence of their choice-behavior as observed in the simulator experiment with the answers to web-survey questions concerning revealed behavior would be used to measure the degree of identification. However, it was made clear to the participants that they would probably be most likely to obtain the bonus by simply making a real effort to identify with

[44] Note that drivers without a license still might choose for traveling by car, as they might charter a family member as a driver.

each of the travel situations presented. After the introduction, about 50 minutes were left. In these 50 minutes, participants made two test-rides, during which they were encouraged to try out all possible types of traveling and information acquisition. These trips were not saved in the database, as was told to the participants. After these two trips, two trips were performed and saved without information being available. Subsequently, a number of trips (maximum 25) were to be made in the presence of information services. In total, the 31 participants made 559 trips (excluding the test-trips and the trips without information service available), on average equaling about 18 trips per participant. Some 30% of trips made fell under trip purpose of an important business trip. See Table 3 for the availability of information acquisition options and travel alternatives, and the observed choice frequencies.

On average, the travel choice set at the starting situation C^T_{nt1} contained 2.37 alternatives (1.35 car routes and 1.02 train routes). Also on average, the information choice set at starting situation C^I_{nt1} contained 21.93 information options. More specifically, 1 early warning option was available per trip at the outset, on average 1.63 options for alternative generation (1.63 equaling the difference between the maximum choice set size of 4 and the average number of known alternatives 2.37) and 19.30 assessment options for known alternatives. Note here that this last number reflects that travelers could acquire information for more than one attribute simultaneously, and that this is considered a separate information alternative. In total, 931 times information is acquired (1.67 times per trip on average). Together, this makes that 931 + 559 = 1490 decision stages were observed. In 6.1% of the observed decision stages the early warning function was activated. In 7.6% of the cases, an unknown car-option was generated, in 17.2% a train option. Also 17.2% of observed decision stages consisted of assessment of known car-alternatives, 14.4% of assessment of known train options. Note that these numbers also reflect the fact that, on average, more cars than trains were in the choice set at the starting situation. In 37.5% of the observed actions, no information was acquired and a travel alternative was chosen from the travel choice set directly. In 17.4% of the cases, a car-option was executed immediately; a train option in 20.1% of the observations.

Table 3: Choice frequencies for information acquisition and travel choices

	Choice alternative	# Times available at starting situation	Freq. (N=1490 decision stages)
Information acquisition choice set	Activate early warning function	559	91
	Generate car 1	192	55
	Generate car 2	169	58
	Generate train 1	204	94
	Generate train 2	364	162
	Assess car 1 travel time	367	53
	Assess car 1 travel costs	367	46
	Assess car 1 travel time, travel costs	367	28
	Assess car 2 travel time	390	65
	Assess car 2 travel costs	390	39
	Assess car 2 travel time, travel costs	390	25
	Assess train 1 travel time	355	30
	Assess train 1 travel costs	355	48
	Assess train 1 waiting time	355	13
	Assess train 1 seat availability	355	4
	Assess train 1 travel time, travel costs	355	11
	Assess train 1 travel time, waiting time	355	21
	Assess train 1 travel time, seat availability	355	0
	Assess train 1 travel costs, waiting time	355	1
	Assess train 1 travel costs, seat availability	355	1
	Assess train 1 waiting time, seat availability	355	0
	Assess train 1 travel time, travel costs, waiting time	355	4
	Assess train 1 travel time, travel costs, seat availability	355	2
	Assess train 1 travel time, waiting time, seat availability	355	4
	Assess train 1 travel costs, waiting time, seat availability	355	0
	Assess train 1 travel time, travel costs, waiting time, seat availability	355	14
	Assess train 2 travel time	213	9
	Assess train 2 travel costs	213	26
	Assess train 2 waiting time	213	5
	Assess train 2 seat availability	213	2
	Assess train 2 travel time, travel costs	213	5
	Assess train 2 travel time, waiting time	213	6
	Assess train 2 travel time, seat availability	213	0
	Assess train 2 travel costs, waiting time	213	0
	Assess train 2 travel costs, seat availability	213	0
	Assess train 2 waiting time, seat availability	213	0
	Assess train 2 travel time, travel costs, waiting time	213	3
	Assess train 2 travel time, travel costs, seat availability	213	0
	Assess train 2 travel time, waiting time, seat availability	213	0
	Assess train 2 travel costs, waiting time, seat availability	213	0
	Assess train 2 travel time, travel costs, waiting time, seat availability	213	6
Travel choice set	Execute car 1	367	136
	Execute car 2	390	123
	Execute train 1	355	199
	Execute train 2	213	101

6.4 Model estimation and results

Before reporting the estimation results in Sub-section 6.4.3., we here identify how we operationalized some aspects of our model to match the data obtained through the travel simulator experiment (4.1), and which parameters were estimated (4.2).

6.4.1 Model operationalization

In order to match the available data, three types of additional operational assumptions need to be made with respect to the developed model: i) assumptions with respect to the mean-variability utility structure of travel alternatives, ii) assumptions with respect to what messages are expected to be received when acquiring information for alternative generation and assessment, and iii) assumptions with respect to the anticipated effect of activating the early warning function.

The first issue is to specify the mean-variability variables in Equation (2). Let us look at the starting situation first, containing ‘best guesses’ and ‘confidence intervals’ for attributes: the ‘best guesses’ are now regarded as proxies for mean or expected values, and the length of the ‘confidence intervals’ as proxies for the variability of the attributes. Concerning waiting times for trains, 0.5 * headway is used as proxy of expected waiting time, and headway as proxy for waiting time variability. A negative parameter value for a variability-proxy may thus be interpreted as a proxy for risk aversion for that particular attribute. After information is received for an attribute, we assume that the expected value takes the value of the received message, and the variability drops to zero (as is elaborated on in Section 6.2).

The second issue concerns the probability density functions that describe what messages the traveler believes she might receive when acquiring information. For the specific case of assessment of known alternatives and fully reliable information, we assume, as mentioned in Footnote 41 of Section 6.2, that a traveler believes that messages are drawn from his initial perception (in terms of best guesses and confidence intervals) of the relevant attribute. For this purpose, we specify the initial perceptions as follows: perceptions of travel times and costs, presented to the participant through a ‘best guess’ and a ‘certainty’ interval, are assumed to consist of a normal distribution around this ‘best guess’ with a standard deviation that equals one-quarter of the length of the ‘confidence interval’. Perceptions of waiting time for trains, presented to participants through a headway (“a train departs every x minutes”), are assumed to consist of a uniform distribution between 0 and x. Perceptions of seat availability are assumed to consist of a discrete distribution between “yes” –coded as 1- and “no” –coded as 0- , each having a probability of occurrence of 50%. Note that these distributions match those that are used to generate messages and actual attributes of travel alternatives – that is, we assume the participants’ perceptions and beliefs to contain no structural bias. For the case of alternative generation we need to make additional assumptions as no best guesses and confidence intervals are presented to the participant on the outset for unknown alternatives. Recall that by generating an alternative, it enters a traveler’s choice set and all its attributes are disclosed by the fully reliable information service. With respect to the disclosure of travel times and costs of unknown alternatives, we need to specify the mean and variance of the distribution from which we assume the traveler to believe that messages are drawn when generating an unknown alternative. For the variances, we assume that the traveler knows the length of the respective ‘certainty’ intervals (and therefore the variance of the distributions for travel times and costs) for the unknown alternatives, just like he does for known alternatives.

This is a relatively safe assumption, given that these lengths are invariable over all trips in the starting situation (it always equals 40 minutes for car-options and the ‘once every 5 minutes’ train, and 36 minutes for the ‘once every 5 minutes’ train). Concerning travelers’ best guesses for travel times and costs, that is the mean of the normal distribution that represents their initial perceptions and thus their beliefs regarding what messages may be received when acquiring information, we assume the following: participants are aware of the fact that best guesses for an alternative’s travel time and cost were drawn randomly from two values, a high and a low one. They take as a best guess for the unknown alternative’s value the average of the two. Since the traveler knows whether she activates the train with high or low headway, we assume waiting time perceptions to match those of known train options. Concerning ‘seat availability’, we assume that the traveler expects the average availability, coded as 0.5. Thus it can be said that, also for the case of generation of unknown alternatives, travelers’ beliefs concerning what messages might be received, are free of structural bias.

The third set of additional assumptions refers to travelers beliefs with respect to the precise workings of the early warning function. In particular, we need to make assumptions regarding how travelers believe activating the early warning function affects the length of their ‘certainty’ interval for travel times. The true trigger for an early warning to be given was set in the experiment to a deviation of more than 7.5 minutes from best guess travel times[45]. Although we did not inform participants of this exact number of minutes, we assume that they believed that the trigger was set at this level. As a result of this, we assume that the anticipated length of the ‘certainty’ interval for travel times after having activated the early warning function takes on the value of 15 minutes (0 ± 7.5 minutes).

The second and third type of additional assumptions may appear somewhat heavy. However, we feel that it is more appropriate to make these assumptions, than to assume that travelers have no expectations at all when searching for information, especially since participants made two test trips with, and two without, information provision before performing actually observed trips. Concerning the second type of assumptions, it is argued in Chorus et al. (2006b) why it makes sense to assume that travelers do have beliefs concerning what messages might be received when acquiring information, and that these beliefs are a function of their initial perceptions and the perceived reliability of the information service. Concerning the third type of assumptions; we tested a much simpler specification, not involving assumptions regarding anticipated variability. These simplifications resulted in a substantial drop in log-likelihood, which we will not report on more elaborately due to space limitations.

6.4.2 Parameters to be estimated

We estimate a car-constant, representing preference for car as a travel mode over train, and we let the socio-demographic factor ‘license holder’ interact with this constant. Furthermore, we estimate mode-inspecific parameters for travel time and travel cost (for both the expected value and variability terms). Regarding train alternatives, additional parameters were estimated concerning expected waiting time and its variability[46], and for seat availability. Trip purpose-related interaction effects are also included: after a preliminary analysis, it was decided to dummy code trip purpose ‘business’ for the important business meeting context

[45] Due to a design flaw of the simulator, warnings were only issued when travel times were more than 7.5 minutes *higher*, not lower, than a best guess. However, the participants did not know about this flaw.

[46] Although these two attributes are clearly correlated in the starting situation, the individual is assumed in our model to believe that after having acquired a waiting time estimate, she will have the received message as a best guess, and zero variation. Due to this absence of correlation in the assumed (anticipated) choice situation after information acquisition, we are able to estimate parameters for both waiting time and waiting time variation.

(see Table 1) and have it interact with the proxies for expected travel time, expected waiting time and their variability. We also estimate parameters that concern the monetary costs of information acquisition. Furthermore, we estimate an information type-inspecific constant, as well as type-specific constants representing the *additional* utility of activating the early warning function, respectively of generating unknown alternatives. Note that as the benefit of information acquisition is specified fully in terms of one's preferences for travel alternatives and their attributes, these *constants can be regarded representations of all non-monetary costs incurred when acquiring a particular bit of information.* Based on earlier findings in literature (e.g. Petrella & Lappin, 2004), it was decided to have education level interact with the general constant of information acquisition, the former being coded from 1 to 5, representing increasing education levels for the Dutch educational system. Finally, we estimate the standard deviations of the individual-specific random parts of the car-constant, the generic information acquisition constant and the early warning constant, in order to i) represent potential heterogeneity in the population, ii) reflect the fact that choices made by the same individual may be correlated, and iii) account for nesting effects between different travel modes and information acquisition options. Note again that nesting effects that concern the utility of travel modes impact the utility of acquiring information about these modes, as is formalized by having these error components enter Equations (7), (10) and (13) in Section 6.2.2. For example, a traveler that has a strong unobserved dislike for transit will be particularly unlikely to acquire information about a train service's departure time.

6.4.3 Model estimation and results

The model as conceptualized in Section 6.2 and operationalized in Section 6.4.1 was coded in GAUSS 7.0. As can be seen in Section 6.2, the computation of the likelihood function involves evaluation of two sets of integrals: one three-dimensional integral captures the intrinsic individual-specific preferences for traveling by car, for acquiring information in general and activating the early warning function in specific (the $f(\alpha,\delta)$ in Equation 16). A second set of integrals reflects that travelers do not know beforehand what message they will receive when acquiring information. Their belief of the utility of information is specified through the integration of the utility of receiving a particular message, over the probability density function representing what message might be received (these density functions appear as $f_{ntd}\left(\bar{x}^{jl}\right)$ and $f_{ntd}\left(\bar{x}^{jl}\right)\cdot\ldots\cdot f_{ntd}\left(\bar{x}^{jL_j}\right)$ in Equations (7) and (10)). The dimensionality of these integrals depends on the information acquired: e.g. assessing a known alternative's travel time involves evaluation of a one-dimensional integral, generating a new car-alternative involves a two-dimensional integral (as messages for travel times and costs are received in the process of alternative generation). Note the crucial difference in terms of interpretation between the two sets of integrals: where the error component integrals reflect the *lack of knowledge from the side of the analyst* with respect to the traveler's intrinsic preferences, the message integrals reflect the *traveler's lack of knowledge* with respect to what message will be received when acquiring information. Both sets of integrals were evaluated through simulation, using 250 Halton draws per individual per dimension for the error components, and 50 Halton draws per dimension for the message-probability functions[47]. That is, for each of the 250 multidimensional draws for the error components, 50 draws are made to simulate anticipated messages from the information service, totaling a number of 12500 Halton draws

[47] It is interesting to note here that it appears that estimation results appear to be far less sensitive with respect to the number of draws made for evaluating the message-integrals, than they are with respect to the number of draws made for evaluating the error component integrals. Experimenting with varying numbers of draws for the message-integrals shows that 50 draws is a sufficient number for their evaluation.

per observation. Kenneth Train's code is gratefully used for making the draws. Table 4 shows the estimation results.

As our model differs from existing approaches in three non-trivial ways - i) the sequential nature of traveler response to information is acknowledged, ii) the utility of information is conceived in a search-theoretical fashion and iii) a variety of knowledge limitations and information types is considered – we will first evaluate the performance of the model as a whole.

Table 4: estimation results

Variable	Parameter	t-Statistic
Travel related variables		
Car constant	0.4053	0.990
Sigma (car constant)	-0.6092	-4.649
License-holder dummy (to be added to car constant)	0.5690	1.374
Travel time (minutes)	-0.1552	-14.228
Travel time variability (minutes)	-0.0125	-3.216
Travel costs (euros)	-0.5512	-13.378
Travel costs variability (euros)	-0.0504	-3.228
Waiting time (train, minutes)	-0.1076	-4.206
Waiting time variability (train, minutes)	0.0720	4.637
Seat availability (on transit constant)	0.7461	2.887
Travel time * Business (to be added to travel time parameter)	0.0180	1.193
Travel time variability * Business	-0.1016	-11.872
Waiting time * Business	-0.0246	-0.720
Waiting time variability * Business	-0.0996	-4.138
Variables relating to information costs		
Information acquisition constant	-4.7978	-5.804
Sigma (Information acquisition constant)	1.4038	8.410
Monetary costs of information acquisition (euros)	-1.7171	-9.219
Early warning constant	0.4429	1.138
Sigma (Early warning constant)	-2.2681	-8.670
Alternative generation constant	1.7543	15.779
Education level * Information acq.	0.5075	2.504
Model statistics		
0-Log-Likelihood	-4477	
Log-likelihood at convergence	-3103	
Number of cases	1490	

As can be seen in Table 4, it appears that parameters are generally significant and of the expected sign. Furthermore, it can be said that a substantial part of the variation in travelers' choices for a wide range of information acquisition travel mode-route options (see Table 3) is captured, while using a rather limited number of only 21 parameters. As mentioned in Section 6.2, this is due to the fact that we specify the value of information fully in terms of the (anticipated) utility of the travel alternatives that enter the choice situation; no additional parameters enter the utility-functions of information acquisition except for constants and one parameter concerning monetary information costs. Together, the model fit in combination with the significance and expected sign of the parameters suggest the validity of the proposed model specification, the assumptions made to operationalize the model, and the simulator-experiment.

A detailed look at the parameters reveals some more interesting results. Starting with travel alternative-related parameters, there appears to be no significant preference for the car-mode over traveling by train, but substantial heterogeneity does exist with respect to mode preferences (as indicated by the sigma car constant). Concerning travel and waiting times, it can be seen that for most trip purposes, it is expected travel time itself more than its variability that is negatively valued. For non-business trip purposes, even a small positive valuation of waiting time variability is found. For trips towards important business meetings however, travel time variability is strongly negatively valued. For these trips, no additional negative valuation of expected travel time an sich is found. Implied values of expected travel time are 17 euro per hour for all trip purposes. Implied values of travel time variability (in terms of the length of the confidence interval) are 1.3 euro per hour for non-business trips, and 12.4 euro per hour for business trips.

Moving to the parameters referring to information acquisition, it is seen that there is a large and negative information acquisition constant. Since a separate parameter is estimated for monetary information costs, this constant can be regarded a representative for all generalized non-monetary costs of information acquisition, incorporating costs in terms of effort, attention, time, etc. These costs appear to be substantial. Note however, the large and positive parameter for the interaction between education level and information constant. Those individuals with a relatively high education diploma on average incur substantially less generalized non-monetary costs when acquiring information, as opposed to those with no education other than primary school. Comparing these generalized non-monetary costs with the parameter for monetary costs, it can be seen that the monetary equivalent of the non-monetary costs of acquiring information ranges from somewhat less than 1 euro to somewhat more than 2.5 euros, depending on the education level. However, note that cost-sensitivity is likely to be correlated with education level, too, a relation we did not take into account in model estimation[48].

The significant and quite substantial constant for alternative generation indicates that individuals on average derive more utility from generating unknown alternatives than they do from other types of information acquisition. At this point it is interesting to note that, should our specification of information benefits as done in Section 6.2 perfectly reflect travelers' beliefs, the additional constants for generating alternatives and activating the early warning function would be both insignificantly different from zero, as no real difference exists in terms of non-monetary costs between these types of information and information acquired for alternative assessment (all types could be acquired by two mouse clicks). Now, although the early warning constant is not significant, the alternative generation constant clearly is. Thus, it appears that travelers generally have intrinsic preferences for having unknown alternatives generated over other information types, preferences that do not necessarily coincide with (our specification of) the economic value of these information types. This intrinsic preference for alternative generation is certainly not counter-intuitive: travelers might feel that they get more

[48] It should be also noted here that parameters referring to information costs should not be directly compared to travel-related parameters, as the latter enter the utility functions for information acquisition only indirectly, through a logsum.

'bang' for their 'buck' by adding something new to their choice set, rather than assessing alternatives that are already known to them. Finally note the considerable heterogeneity in the population with respect to the constants for information acquisition in general and activating the early warning function in specific, as can be deduced from their constants' large and significant sigma's. This heterogeneity calls for further studies into the existence of segments within the population with respect to the acquisition of travel information.

6.5 Conclusions

An integrative behavioral model of traveler response to pre-trip information acquisition is developed, which is geared towards understanding the full dimensionality and iterative nature of traveler behavior in uncertain multimodal travel situations where a variety of travel information sources is available before embarking on a trip. The model is built around the notion that when a traveler decides to acquire information, received messages may alter the traveler's perceptions (in terms of number of known travel alternatives or uncertainty attached to their attributes). Based on these updated perceptions, the traveler again faces a choice from a choice set that contains additional information acquisition options as well as travel alternatives. This makes that per trip made by the traveler a full sequence of decisions is observed, consisting of a number of (possibly zero) information acquisitions, followed by one travel choice.

In order to test and estimate the developed model, a travel simulator was built that provided participants with an abstract multimodal travel network and a personal intelligent travel assistant. The travel assistant was able to i) provide estimates for the uncertain attributes of known alternatives, ii) generate formerly unknown travel alternatives and iii) warn the traveler in case a travel alternative is selected that has a travel time that strongly deviates from their expectation. 31 individuals made a total number of 559 trips in the simulated travel environment, making 1490 choices in total (559 travel choices and 931 information acquisitions). Estimation results show that the proposed model specification captures a substantial part of the variation in travelers' choices for a wide range of information acquisition options, as well as the effect of acquired information on multimodal travel choices, while using a rather limited number of only 21 parameters. It is found that for most trip purposes, time itself and not its variation is negatively valued. However, for business trips, travel time uncertainty is valued negatively. Non-monetary costs of information acquisition appear quite substantial. Furthermore, it appears that travelers generally have intrinsic preferences for having unknown alternatives generated, over other types of information acquisition and that higher education levels induce substantially more information acquisition. Mode preferences, as well as preferences for acquiring (specific types of) information, appear to differ widely within the population.

Based on the limitations of the presented study, directions for further research include the following: firstly, whereas we only focused on fully reliable information, it should be acknowledged that in reality, travel information may be (perceived as) unreliable. Taking this unreliability into account may lead to more realistic, but also more complex and computationally intensive modeling frameworks. The same reasoning holds for extending the model in order to capture processes of in-trip information acquisition and choice adaptation. Thirdly, it cannot be ruled out that some of the found effects may partly stem from the chosen type of stated-preference data-collection, using a computer based travel simulator. Although another study (Chorus et al., 2006d) has indicated that the applied simulator is suitable for the collection of valid choice observations, a field study with a working, highly functional, travel information prototype would greatly add to our insight into the topics discussed in this paper. Another logical extension of the model specification would be to allow for random parameters (e.g. travel time and travel cost parameters). Currently, high run times due to the evaluation of message-integrals in combination with the integrals reflecting intrinsic preferences for alternatives are prohibitive to adding further degrees of dimensionality. Fourthly, it might be interesting to derive travelers' preferences for travel alternatives and (variability of) their attributes by analyzing their information acquisition behavior only. Theoretically, there is no apparent reason why this might not work, although in practice, rather complicated identification issues may arise. Finally, it would be worth while to study how the conceptualizations presented here may be applied for the benefit of operational travel forecasting models and transport policy evaluation models. For example, application of our model of traveler response to information may increase the accuracy and behavioral realism of microsimulation models of travel demand, by putting more focus on how knowledge limitations and information provision may influence traveler behavior at the disaggregate level, and thus influence traffic flows at the aggregate level. Presumably, models that address such aspects of travel behavior with increased rigor will be able to provide increasingly reliable evaluations of the effect of a variety of travel information based demand measures.

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Chapter 7

Chorus, C.G., Molin, E.J.E., van Wee, G.P., 2006. Travel information as an instrument to change car-drivers' travel choices: a literature review. *European Journal of Transport and Infrastructure Research*, 6(4), pp. 335-364

Abstract

This paper aims to provide insights that help transport academics and policy makers appreciate the potentials and limitations of information provision as a means to changing car-drivers' travel choices. The focus is on a modal shift from private car to public transport and changes in car-drivers' choices for departure times and routes towards a more even distribution of traffic within the available road network. These insights are gained through a review of more than 15 years of literature concerning the use and effects of travel information among car-drivers. Based on the performed review, a number of generic, integrative insights are derived, including the following: it appears that our expectations with respect to the effects of information provision on travel choices in general may be mildly optimistic, particularly for behavioural changes not involving changes in mode-choice. In the longer term, the effects of information provision, when presented to travelers in suitable formats, are likely to be somewhat stronger than the short term effects, due to learning dynamics.

7.1 Introduction

Fairly high expectations exist among transport policy-makers concerning the potential of travel information to alter car-drivers' behaviour in ways that would reduce passenger transport externalities such as congestion, fossil fuel exhaustion, noise etc. The most often cited examples of such expected changes are modal shifts towards transit and adaptations of departure time and route choices (e.g. Commission of the European Communities, 2001; Ministry of Transport, Public Works and Water Management, 2002; Department for Transport, 2004; Federal Transit Administration, 2003). Generally, this expected behavioural change, and the ultimate reduction of transport externalities caused by car-drivers, are put forward as an important motivation for governments to financially support the development and deployment of travel information services, which require enormous investments in terms of money, time and energy. Not surprisingly, a large body of academic literature has, over the last 15 years or so, investigated these expectations of behavioural change due to the provision of information. These studies provide us with a wide variety of valuable insights into the impact of the provision of specific types of information (route guidance, descriptive information etc.) delivered through specific types of media (internet, text-messages, Variable Message Signs etc.) on specific types of choices (departure time, route, or mode etc.), made under specific types of contexts (habitual trips, business trips, recreational trips etc.) in specific types of travel situations (pre- or in-trip, normal or accident conditions etc.). One thing the separate papers in this body of literature do not do is provide an integrative, generic insight into the overall potential and limitations of travel information as a means to change car-drivers' travel choices. It is the opinion of the authors that such integrative, generic insights are needed in the arenas of transport academics and transport policy alike, as a fundament for i) academic research into the potential effects of ever more advanced travel information services and ii) transport policy initiatives involving the provision of travel information to car-drivers.

This paper aims to help provide these insights by providing a literature review of studies into the effect of providing travel information on car-drivers' choices for modes, routes and departure times. Based on this literature review, we will draw up a list of ten integrative, generic insights which may aid transport academics and policy makers to appreciate the potentials and limitations of information provision as a means to change car-drivers' travel choices along the dimensions considered here.

Due to the potential vagueness associated with terminology like 'travel information' and 'changes in travel choices', a rather extensive research specification is needed and presented here, before starting the actual review in Section 6.2. The scope of research is specified along nine dimensions: firstly, let us define what types of travel information are considered here. Following the bulk of available literature, we consider all types of information that have been, or may be, provided to travelers pre- or in-trip, on either the performance of their current or intended travel alternative (i.e. mode-route-departure time combination) as well as on the availability and performance of other travel alternatives. Such information may for example take the form of travel time information or route-advisories displayed on Variable Message Signs, dynamic transit timetables provided through the internet, congestion warnings provided through text-messages on mobile phones, etc. We do not consider commercials. Secondly, we particularly consider information provision by a transportation agent (e.g. road authority, local or national departments of transport) with the aim of helping induce a change of travel choices in ways that are beneficial to the transport system. That is, we do not consider travel information that is provided by other actors, having different aims (such as information provided by newspapers as a form of service to their readers). Thirdly, we focus on the choice adaptations of car-drivers in particular. Although it has been appreciated that travel information might play an important role in transit too, e.g. to retain customers or increase the efficiency of their choices in transit networks (e.g. Hickman & Wilson, 1995; Gentile et al., 2005), the majority of research and transport policy documents regarding the effect of travel information on choice behaviour focuses on car-drivers' choices, and so do we. A fourth dimension along which this research is specified is the following: we focus on three types of potential behavioural changes that are generally expected to reduce passenger transport externalities: i) a modal shift from private car to public transport and changes in ii) departure times and iii) routes among car-drivers that lead to a more even distribution of traffic within the available road network. Notwithstanding this, many of the findings presented here might also be of interest to readers interested in the effect of information on other choice dimensions such as activity schedules or destination choices. Furthermore, this paper's research is based on the notion that behavioral changes among car-drivers in terms of their mode, route and departure time-choices are often claimed to be a means towards reducing passenger transport externalities. That is, we do not focus on investigating this claim of reduction in externalities itself. Furthermore, we look into those effects of information provision that follow travelers' use of the available information. That is, we do not cover here the potential effect of information *availability per se* on travelers' choice for routes and modes, as discussed in Zhang & Levinson (2006) and Abdel-Aty et al. (1997) for the case of route choice and Abdel-Aty et al. (1996), Reed et al. (1997), Ouwersloot et al. (1997), Abdel-Aty (2001) and Benjamin (2006) for the case of mode-choice. Another specification in research scope is that we consider *empirical* literature on the *outcomes* of traveler decision-making. That is, we do not consider *theoretical* work on the topic, nor do we discuss *process*-oriented research efforts, predominantly from the field of psychology, that focus on issues like information processing and persuasion. This is not to say that we consider theoretical and process-oriented work to be of little value; rather that this choice is made for the clarity of the discussion and for reasons of space limitations. This research is also specified in terms of the sources considered: with a few exceptions, we selected, due to quality considerations, material from reviewed international scholarly journals and reviewed international conference proceedings. Finally, although the research presented in this paper may serve as an input for policy-makers who consider the provision of information as a TDM-tool towards car-drivers, it should be acknowledged that the successful development and deployment of travel information services as TDMs involves a variety of other (mainly organizational and technological) challenges that are not addressed here: we do not provide guidelines towards such a successful development and deployment of travel information strategies.

The outline of the rest of this paper is as follows: Section 7.2 reviews the abundant body of literature available on the topic of travelers' use of provided travel information and its impact on their choices. Subsequently, Section 7.3 provides ten integrative, generic insights that may be derived from the literature review and which may aid transport academics and policy makers appreciate the potentials and limitations of information provision as a means to change car-drivers' travel choices. Section 7.4 draws conclusions and gives pointers for further research.

7.2 Potential impact of information provision on travel choices: a literature review

7.2.1 Providing a conceptual framework for literature review

Let us assume that some transportation agent provides travelers with information that she hopes or thinks may help induce a change of travel choices in ways that are beneficial to the transport system. In order for such a change to occur, travelers must 1) acquire the information and 2) the acquired information must lead to the wanted behavioral change. Many travel demand studies either explicitly or implicitly frame a traveler's decision to acquire travel information and/or to change behaviour as a result of acquired information as a cost-benefit decision (e.g. Schofer et al., 1993; Bonsall, 2001; Yang & Meng, 2001; Golledge, 2002; Khattak et al., 2003; Denant-Boèmont & Petiot, 2003, Srinivasan & Mahmassani, 2003; Sun et al., 2005; Arentze & Timmermans, 2005a; Chorus et al., 2006a). We feel that this is an intuitively appealing approach, and will use it as a means to structure our literature review. Let us adopt the following notation: T represents the traveler's current chosen alternative (i.e. a mode-route-departure time combination), or an alternative that she intends to choose. T^+ stands for the goal alternative, i.e. a travel alternative which is considered by the transportation agent to have a less negative impact on the performance of the transport system than the traveler's current or currently intended choice. In our study, T^+ may differ from T in terms of the chosen mode and/or route and/or departure time. The wanted behavioral change from T to T^+ is denoted by Δ^+. Finally, I stands for the information that the transportation agent hopes or thinks will help realize the wanted choice adaptation Δ^+. Using the concept of utility as the ultimate driver of choices made by a traveler, we may conceptualize the utility of acquiring the relevant information (1) and the utility of choice adaptation after having acquired the information (2), as follows:

$$U(I) = f\left(U\left(T^+\right) - U(T); Q/K; C\left(\Delta^+\right) + C(I)\right) \tag{1}$$

$$U\left(\Delta^+\right) = f\left(U\left(T^+\right) - U(T); C\left(\Delta^+\right)\right) \tag{2}$$

Where $U(I)$ stands for the traveler's utility of acquiring the relevant information[49], $U\left(\Delta^+\right)$ stands for her perception of the utility to be derived from the behavioural change that is wanted by the transportation agent, after having acquired the information. $U(T)$ represents the utility, perceived by the traveler, of executing the intended or current travel option, $U\left(T^+\right)$ stands for her perceived utility of the transportation agent's goal alternative. The quality of the information or information service, in terms of its potential to identify the utility difference between T and T^+, is represented by Q, and the traveler's perception of her own knowledge needed to identify this utility difference is given by K. Furthermore, $C\left(\Delta^+\right)$ stands for the perceived costs of choice adaptation towards T^+, $C(I)$ represents the generalized costs of acquiring information, including monetary as well as non-monetary costs[50]. The above formulations imply that the potential of information *provision* for wanted choice adaptation, i.e. its potential to fulfill conditions 1) and 2) presented above, is mainly determined through the interplay of $U(T)$, $U\left(T^+\right)$, Q, K, $C\left(\Delta^+\right)$ and $C(I)$. In words, Equation (1) and (2) imply that the extent to which travel information provision may invoke behavioural adaptation in

[49] By *acquiring* information we mean here that the information is *searched for* (or paid attention to) by the traveler and *processed* by her, including a potential update of her perceptions.

[50] Note that the utilities evaluated in Equation (2) are in fact conditional on the received message. However, it may be assumed that information-providers do not want to present travelers with untrue information on purpose, making the content of messages not suiTable as a policy-variable. We will thus ignore the conditionality on the content of received messages. This does not mean to say that the *format* and *type* of information are outside the scope of this study.

ways that are beneficial to the transport system depends on (see Table 1 and 2 for a schematic representation):

a) the perceived utility of the intended or currently chosen travel option $U(T)$ and the perceived utility of alternative options (including the goal alternative $U(T^+)$);
b) the perceived own knowledge-level K and perceived information quality-level Q;
c) the perceived costs of choice adaptation $C(\Delta^+)$ and of acquiring information $C(I)$;

Table 1: Conceptualized determinants of the utility of information acquisition

$U(I)$		$C(\Delta^+)+C(I)$			
		Low		High	
		Q/K			
		Low	High	Low	High
$U(T^+)$-$U(T)$	Low	-	+	--	-
	High	+	++	-	+

Table 2: Conceptualized determinants of the utility of choice adaptation

$U(\Delta^+)$		$C(\Delta^+)$	
		Low	High
$U(T^+)$-$U(T)$	Low	+/-	-
	High	+	+/-

In this paper we will use these three sets of theoretical determinants of the impact of travel information provision as a framework within which findings from academic literature on the topic are presented and discussed, as it is felt that this categorization based on behavioural determinants allows for a generic, integrative review of literature. Note however, that the use and effects of travel information are acknowledged to be the result of a complex interplay between a number of determinants, including, but not limited to, the ones mentioned here. A systematic discussion like the one we propose is therefore bound to sometimes oversimplify how things work in reality. Where relevant, we will discuss findings from literature in the light of this complex interplay. Those findings from literature that in reality may relate to multiple sets of determinants are discussed under the heading of the determinant with which the relation is most obvious, those for which correspondence with none of these three determinants is directly apparent are discussed separately afterwards.

7.2.2 A review of the literature

Perceived utility of the intended or currently chosen travel option $\boldsymbol{U(T)}$ *and of alternative options, including the goal alternative* $\boldsymbol{U(T^+)}$

Let us start with discussing findings from the literature concerning the role of the performance or utility of the currently chosen or intended travel option: abundant evidence is found for the proposition that expected or actual bad performance of the current or intended alternative induces the acquisition of travel information (Khattak et al., 1996; Polydoropoulou & Ben-Akiva, 1998; Chatterjee et al., 1999; Lappin, 2000; Targa et al., 2003; Pierce & Lappin, 2004; Petrella & Lappin, 2004). Furthermore, it appears that travelers are relatively prone to change to other alternatives when information is received concerning poor performance of the intended or currently chosen alternative[51] (Mannering, 1989; Khattak et al., 1993b; Adler & McNally, 1994; Polydoropoulou et al., 1996; Polydoropoulou & Ben-Akiva, 1998; Mahmassani & Liu, 1999; Srinivasan & Mahmassani, 2003; Chatterjee & McDonald, 2004; Abdel-Aty & Abdalla, 2004; van der Horst & Ettema, 2005; Chorus et al., 2006b). Poor performance is expected especially during peak hours, bad weather or incident conditions. Information acquisition and changing to an alternative other than the chosen or intended one is especially likely when travelers face a potential deviation from a preferred arrival time (Emmerink et al., 1996; Srinivasan et al., 1999; Pierce & Lappin, 2004), particularly the prospect of a late arrival (Mahmassani & Liu, 1999; Srinivasan & Mahmassani, 2003). Complementary to these insights, it might be expected that when travelers perceive their current or intended alternative as satisfactory, information acquisition (and the potential resulting choice adaptation) becomes unlikely. This expectation is indeed underpinned for the case of mode-choices by studies concerning the impact of providing transit information to car-drivers: Chorus et al. (2006c) found that, even when transit is considered by car-drivers as a feasible mode, satisfactory performance of the car-option is a serious barrier to transit information acquisition. Polak & Jones (1993) found that the availability of free parking reduces information enquiries by car-drivers into the bus as an alternative . In combination with the suggestion by Bonsall et al. (2004) that car-drivers are likely to underestimate the cost of driving (and overestimate the costs of riding transit), this would imply that information acquisition among car-drivers about other modes is lower than it might be given more realistic perceptions among car-drivers concerning the actual performance of their preferred mode.

Moving to the perceived utility of other travel options, it is found that, although travelers generally search for information concerning their currently chosen or preferred travel alternative in the first instance (Polak & Jones, 1993; van der Horst & Ettema, 2005; Chorus et al., 2006c), there appears to be a need to be informed about other alternatives, e.g. through multimodal information (Polak & Jones, 1993; Srinivasan et al., 1999; Yim & Khattak, 2002; Chorus et al., 2006d). Complementary to these findings, many studies suggest that information provision on alternative routes and modes to the currently chosen or intended one does lead to more changes to these alternatives (see Khattak et al. (1993a), Polydoropoulou et al. (1996), Srinivasan & Mahmassani (2003), Dia (2003), Bogers et al. (2005) for the case of route choice and Khattak et al. (1996) and Abdel-Aty (1996, 2001) for the case of mode-choice). The perceived availability (Emmerink et al., 1996; Lappin, 2000; Chatterjee & McDonald, 2004; Peirce & Lappin, 2004; van der Horst & Ettema, 2005) and perceived or reported quality (Khattak et al., 1993b; Hato et al., 1999; Chen et al., 1999; Srinivasan & Mahmassani, 2000; Abdel-Aty & Abdalla, 2004; Jou et al., 2005) of these alternative routes or modes is found to be a main determinant of the use and effect of travel information concerning these alternative options. Consistent with this insight is the finding that delays caused by bad weather conditions or recurrent congestion induce less route change than comparable delays due to incident congestion. The former congestion types are likely to affect the network as a whole, so the quality of alternative routes is deemed to be not much better than that of the currently chosen or intended route (Khattak et al., 1993b; Polydoropoulou et al., 1996). Note that travelers' availability-perceptions of alternative travel options may be considered a relative notion: Peirce & Lappin (2004) found that the number of times that

[51] The mentioned studies focus on *travel time and reliability aspects* of performance. Note however, that Tertoolen et al. (1998) found that repeatedly and extensively mentioning to car-drivers the poor performance of the car in terms of *environmental costs* had virtually no effect on their travel behaviour. Instead of altering behaviour, car-drivers rather changed their attitudes as environmental aspects became less important to them than they were initially, which forms a classic example of dissonance theory (Festinger, 1957).

travelers report that they could not change due to the unavailability of alternatives decreases as the delay on the current route increases.

Information acquisition concerning other than the usual mode-route-departure time combination, as well as changes to these alternatives, appears to be more likely for travelers with schedule flexibility than for those with fixed arrival times (Lappin, 2000; Targa et al., 2003). This finding can be explained as follows: greater schedule flexibility implies that alternative travel options that are attractive in terms of attributes other than time-related ones but less satisfactory than the normally chosen option from a travel time point of view become more feasible choice options. Take the situation where a tight schedule would induce a traveler to take the fast and reliable (but expensive) toll road, whereas the same traveler facing a flexible schedule might decide to acquire information about and subsequently travel over a toll-free road with longer or more variable travel time. Petrella & Lappin (2004) argue that such differences in schedule flexibility partly account for the often[52] noticed phenomenon that information acquisition and diversion to other than the usual travel alternative is more likely to occur in the evening than in the morning commute (Jou & Mahmassani, 1996; Polydoropoulou et al., 1996; Lappin, 2000; Petrella & Lappin, 2004). These findings might appear paradoxical in relation to the earlier reported increase in information use and diversion probability when schedule delays are expected. It may be interesting to note here though, that both behaviors can be considered to be driven by completely different aims: the latter type of behaviour (fixed schedule) can be seen as driven by the aim of damage control, the former (flexible schedule) more by the aim of searching for interesting opportunities.

It should also be noted that many agree upon the fact that the utility of alternative routes, and especially modes, that are suggested by travel information services depends on many more factors than their travel times and costs alone (e.g. Golledge, 1995, 2002; Abdel-Aty et al., 1996; Abdel-Aty, 2001; Chorus et al., 2006c): information concerning factors such as convenience (Lyons, 2001), accessibility (van der Horst & Ettema, 2005) and perhaps even image (Kenyon & Lyons, 2003; Bonsall et al., 2004) is important to travelers as well. These notions are in congruence with a growing body of literature on mode-choice determinants that stresses the importance of such ‘soft’ modal attributes (Hague Consulting Group, 1991; Tertoolen et al., 1998; Steg et al., 2001; Thogersen, 2001; Ellaway et al., 2003; Bos et al., 2004; Steg, 2005; Anable & Gatersleben, 2005). Together, these findings provide the following picture concerning the potential of travel information as a means to induce a modal shift from private car-use to transit use: for many car-drivers, transit is perceived as a low-quality alternative, based on a mix of ‘hard’ (travel times and costs) and ‘soft’ (image, convenience) factors. It is known that the perceptions of ‘hard’ factors among car-drivers may be negatively biased towards transit, and positively towards the car (e.g. Bonsall et al., 2004), which might create a role for travel information services to correct these misperceptions and induce greater use of transit, as suggested by e.g. Watling & van Vuren (1993). However, as travelers are unlikely to seek for or pay attention to information concerning alternatives they perceive as low-quality, such transit information might not be acquired by car-drivers in the first place. Furthermore, as travel information predominantly concerns the ‘hard’ characteristics of car and transit (travel information services are hardly the ideal tool to convey image-related messages)[53], the effect of acquired information on mode choices is bound to be limited.

[52] Khattak et al. (1993b) and Mehndiratta et al. (2000) however, find the opposite.

[53] Although it should be mentioned here that car advertisements do appear to be quite successful in conveying ‘soft’ factors such as image and status.

As a final note on the role of the perceived utility of alternative travel options on information use and effects, note that it is well recognized that information acquisition and diversion from intended or current alternatives is found to be especially likely pre-trip (Abdel-Aty et al., 1997; Lyons, 2001; Srinivasan & Mahmassani, 2003; Abdel-Aty & Abdalla, 2004; Mahmassani & Srinivisan, 2004; Geweke & Zumkeller, 2006), or in-trip near the origin (Chatterjee et al., 1999; Jou et al., 2005), or for longer trips in general (Emmerink et al., 1996; Abdel-Aty et al., 1997; Mehndiratta et al., 2000; Khattak et al., 2003; Peirce & Lappin, 2004). An explanation for these findings can be found in the notion that, on average, more feasible travel alternatives are available pre- than in-trip, more at the beginning of the trip than near the end of it, and more during long than short trips: the window of opportunity to change to feasible departure time-, route- and modal options becomes smaller as the traveler approaches her destination (e.g. Polak & Jones, 1993). Note that these findings can also be explained by pointing at the role of travelers' knowledge limitations: as the destination is approached, and for short trips in general, there is generally less expected variation in the performance of chosen travel alternatives (for the remainder of the trip) than there is before or at the beginning of a (long) trip.

Perceived own knowledge-level K and perceived information quality-level Q
As mentioned in Footnote 49, we regard here information acquisition as the combination of the search for and processing of information. As we will see, perceived knowledge levels and information quality play a role during both these two processes.

Starting with a traveler's search for information, it is generally acknowledged that the making of complex trips induces a relatively high need for detailed information (e.g. Srinivasan et al., 1999; Mehndiratta et al., 2000), as do trips that are made for the first time (Chorus et al., 2006d). These findings are in line with what would be expected, as these latter situations imply a relatively low level of knowledge on the side of the traveler, which might be increased through information acquisition. The expectation of unpredictable traffic or travel times (Lappin, 2000; Chorus et al., 2006d) is also found to induce a higher level of need for information. It should be noted however that it is the expected variability in, or lack of knowledge concerning, *pay-offs* that drives information acquisition, rather than just a variability of travel times or other attributes. That is, variability in the attributes of alternatives only leads to information acquisition to the extent this variation leads to a variation in the utilities or *pay-offs* derived from choosing the alternatives. For arrival-time insensitive trips, travel time-variability might not lead to information acquisition as this variability does not lead to a substantial *pay-off* variability. This nuance is incorporated in recent behavioral models of information acquisition and effect (e.g. Denant-Boemont & Petiot, 2003; Arentze & Timmermans, 2005a; Chorus et al., 2006e). Therefore it should be noted that the distinction we make between low expected utility of the current alternative and low knowledge levels is to some extent artificial. In order to be perceived as able to fill a traveler's knowledge gap, information must be perceived as accurate: it appears that indeed, reliability is found by travelers to be of paramount importance in their decisions to search for, or pay attention to, the available information (e.g. Polydoropoulou & Ben-Akiva, 1998; Lyons, 2001; Jou et al., 2004; Fayish & Jovanis, 2004; Bogers et al., 2005; Sun et al., 2005). As Petrella & Lappin (2004) state, it is more important to travelers that the information received is precise than that the information service has advanced features. In this light, it is somewhat worrying to see that, as found by Yim & Khattak (2002) and Chorus et al. (2006d), it is exactly in those situations where travelers perceive their own knowledge to be particularly unreliable, e.g. in the case of an accident or other incident, that information is also perceived to be particularly unreliable. Finally, there appears to be a relation between perceived knowledge levels and the type of information needed (Adler & McNally, 1994): as travelers become more experienced in a road network, their needs shift from prescriptive info ("take route A") towards descriptive info ("route A's travel time equals x, route B's equals y").

We will now move our attention to the second part of the information acquisition process, being the actual processing of received information - possibly leading to perception updating. Intuitively, it would be expected that the less knowledge a traveler thinks she has, the more susceptible she will be to update her perceptions with received information, and to potentially adapt her current or intended choice. This intuitive notion of weighed perception updating, often theoretically underpinned by applying Bayes' law of perception updating, is increasingly used in traveler behavior research (e.g. Horowitz, 1984; Kaysi, 1991; Ben-Akiva et al., 1991; Jha et al., 1998; Chen & Mahmassani, 2005; Arentze & Timmermans, 2005a, b; Sun et al., 2005; Chorus et al., 2006e). Indeed, empirical evidence is available to support this intuition. To start with, as mentioned above, the widely established fact that diversion from intended or current alternatives, after having received information, is found to be especially likely pre-trip, or in-trip near the origin can be at least partly explained by pointing to the fact that in those situations there is a relatively strong perceived variation in the performance of the chosen or intended travel alternatives than there is near the end of a trip. Due to these high levels of perceived variation, travelers appear to be relatively susceptible to updating their perceptions using received information. Furthermore, it is argued by Petrella & Lappin (2004) that greater variability of travel times during the evening commute is one of the reasons why travelers are relatively prone to switch routes after having received information (compared to the morning commute). Abdel-Aty et al. (1997) found that a high perceived reliability of the route normally taken induces a low willingness to switch to other routes under information provision. This inclination to follow received information particularly when the traveler's own knowledge is perceived as insufficient, such as in the middle of a trip (Bovy & Stern, 1990), or in the context of trips towards destinations never visited before (Chorus et al., 2006d), implies the potential for providing information on other alternatives in these situations.

However, care should always be exercised when providing information on alternative travel options. It has been found that reporting to travelers the high performance of routes or modes other than the chosen ones when the facts don't support such information, e.g. in order to induce high short term deviations, is not a good idea. Bonsall et al. (2004), concerning mode-choice, and Chen et al. (1999), Srinivasan & Mahmassani (2000) and Jou et al. (2005), concerning route choice, all present evidence that bad experiences with choice adaptation due to inaccurate travel information on alternative options may seriously affect a traveler's propensity to adapt their choices based on received information in the future. The latter three studies found that especially underestimation of travel times appears to negatively affect this propensity. Good experiences however, do lead to a greater propensity to use travel information (Emmerink et al., 1996; Polydoropoulou & Ben-Akiva, 1998) and to comply with its suggestions (Chen et al., 1999). These findings again strongly suggest the paramount importance of information reliability, not only for the information to be searched for (as discussed above), but particularly for found information to be used in a process of perception (and choice) updating: there is abundant empirical underpinning for the suggestion that received information leads to perception and choice updates only to the extent that it is considered reliable (van Berkum & van der Mede, 1991; Khattak et al., 1993a; Wardman et al., 1997; Fox & Boehm-Davis, 1998; Chen et al., 1999; Jou et al., 2004; Mahmassani & Srinivasan, 2004; Bogers et al., 2005). Another indication of the often suggested notion that travelers use received information and their prior knowledge of network dynamics in some form of a weighed updating process, is the empirical insight that travelers appear to be sensitive to the cause of delays reported by travel information: simply explaining the cause of a delay induces higher rates of route-switching, especially when the delays are caused by incidents (Khattak et al., 1993b; Wardman et al., 1997; Chatterjee et al., 2002). Thus, it appears that more elaborate information may lead to a higher rate of route change (Polydoropoulou & Ben-Akiva, 1998). There is a trade-off to be made here however, as travelers may not be able to comprehend long messages presented while travelling, especially when driving a car. This may hold particularly when elaborate text-messages are displayed on cell-phone displays (Dicke & de Groot, 2005). Finally, the importance of reliability is also reflected by the finding that travelers that are confronted with *ex-post* information on their chosen alternative as well as on the performance of other alternatives, are quite prone to switching in subsequent trips (Chen et al., 1999; Srinivasan & Mahmassani, 2003; Mahmassani & Srinivasan, 2004; Bogers et al., 2005): this *ex-post* information may be considered by travelers as much more reliable than information provided pre- or in-trip.

Another insight that follows from the above finding that bad experiences lead to less information use is that in the longer term travelers actually *learn* during the process of information acquisition and subsequent travel choice making. This learning concerns getting to know the dynamic nature of the transport network with the help of information services, as well as learning the potential of these information services to support choices in this network. For theoretical models of how the dynamics behind such a learning process can be described, see Avineri & Prashker (2003) and Sun et al. (2005). Where most agree that information provision *induces* learning (e.g. van Berkum & van der Mede, 1991; Watling & van Vuren, 1993; Emmerink et al., 1996; Polydoropouluo & Ben-Akiva, 1998; Chatterjee et al., 1999; Adler, 2001; Kreitz et al., 2002; Kenyon & Lyons, 2003; Avineri & Prashker, 2003, 2006; Viti et al., 2005), some argue that travel information provision, particularly the provision of advice, may actually *hinder* aspects of long term transport network learning, such as a traveler's cognitive representation of the spatial environment (Jackson, 1996). We will return to this issue below.

Note that it is increasingly acknowledged (Katsikopoulos et al., 2000, 2002; Avineri & Prashker, 2003; Arentze & Timmermans, 2005a) that a traveler's learning from information may involve principles from Prospect Theory (Kahneman & Tversky, 1979, 1992), such as framing- and reference-effects. Katsikopoulos et al. (2000, 2002) strongly suggest that such effects should be taken into account when information is presented to travelers (e.g. the framing of uncertain travel time estimates as either gains or losses, in order to induce risk-averse or risk-seeking behaviour).

Perceived costs of choice adaptation $\boldsymbol{C}(\Delta^{+})$ *and information acquisition* $\boldsymbol{C}(\boldsymbol{I})$

Starting with the issue of choice adaptation costs, intuition says that no matter how attractive an alternative other than the one currently (intended to be) chosen may be perceived to be, if the perceived costs of adaptation towards that alternative are too high, travelers will limit their information acquisition concerning the other alternative and stick to their current or intended travel option. These adaptation costs may take the form of monetary costs or costs in terms of time. However, also more intangible costs such as time, effort and attention may be important components of these adaptation costs (as Haselkorn et al (1989) point out, diversion causes stress). Literature on this topic predominantly considers the role of adaptation costs implicitly[54]: a number of studies, predominantly based on the stated or revealed preferences of car-drivers, found that choice adaptation is relatively likely towards a route or departure time other than the normal one, and unlikely towards other than the normal mode, be it pre-trip or in-trip using Park&Ride facilities (Kitamura et al., 1995; Tertoolen, 1998; Chatterjee et al.,

[54] Some studies use the concept of inertia to describe how travelers prefer to stick to a chosen or intended travel alternative (e.g. Srinivasan & Mahmassani, 2000; 2003; Bogers et al., 2005).

1999; Mehndiratta et al., 2000; Neuhertz et al., 2000; Yim & Khattak, 2002; Chatterjee & McDonald, 2004; Loukopoulos et al., 2004; van der Horst & Ettema, 2005)[55]. There is no consensus about whether route (Neuhertz et al., 2000; Petrella & Lappin, 2004) or departure time (Jou & Mahmassani, 1996) switching is the most likely adaptation due to information provision. Furthermore, it is suggested that travelers simultaneously consider both route and departure time switching as one package choice (Caplice & Mahmassani, 1992; Mahmassani & Liu, 1999). Although many factors may co-determine differences in these diversion likelihoods, it may be safely assumed that these differences are partly attributable to differences in adaptation costs (e.g. Garling et al., 2002; 2004; Loukopoulos et al., 2004): changing from one (intended) mode to another, say an en-route change from private car to transit, may involve costly actions such as parking the car at a Park&Ride facility, walking towards the train platform (possibly while carrying luggage), buying a ticket and waiting at the platform. As Bos et al. (2003, 2004) argue, these tangible and intangible costs are important elements in a traveler's decision whether or not to use Park&Ride facilities. Furthermore, it should be noted here that by changing modes (either pre- or in-trip) a traveler loses flexibility with respect to mode-use for the next trip: e.g., changing from car to transit halfway through the morning commute means that the private car is not available for the first part of the evening commute. This loss in flexibility should be considered as an adaptation cost as well.

Complementary to these findings, it is often suggested that when travel information leads to an increase in transit ridership, this increase is due mainly to an increase in transit-use among current transit-users, rather than to a modal shift among car-drivers (Chatterjee et al., 1999; Bonsall et al., 2004). Furthermore note that diversion rates to alternative routes are negatively correlated with the distance between the current and the alternative route (Chen et al., 1999; Srinivasan & Mahmassani, 2000; 2003). Another finding that appears consistent with the importance of adaptation costs is that travelers appear to be more prone to switch pre-trip from an intended alternative, than in-trip from an already chosen alternative (Mahmassani & Srinivasan, 2004), as the former type of adaptation generally induces lower adaptation costs. Trip cancellation appears to be a very unlikely adaptation due to travel information acquisition (Khattak et al., 2003), probably due to the fact that such cancellation induces high levels of tangible and intangible costs. Another adaptation possibility with relatively low adaptation costs attached (and a relatively high adaptation benefit) is to make additional stops underway when high congestion levels are encountered, e.g. to do groceries (Mehndiratta et al., 2000; Petrella & Lappin, 2004). The inclination, mentioned earlier, of travelers to initially search for information concerning the travel alternative they currently (intend to) use can also be partly explained by the adaptation costs: if the information signals that the current alternative will perform satisfactorily, no adaptation is needed – and the traveler that acquires information anticipates this.

Another factor that appears to play a dominant role in travelers' information acquisition and choice adaptation processes, and that can be at least partly explained through the notion of adaptation costs, is the notion of network familiarity: several studies point out that travelers are more inclined to pay attention to information concerning, and subsequently switch to, travel alternatives that they consider to be familiar to them (Huchingson et al., 1979; Haselkorn et al., 1989; Khattak et al., 1993a; Adler & McNally, 1994; Lotan, 1997; Yang & Fricker, 2001). At first sight, this finding may appear to be paradoxical in relation to the earlier mentioned finding that low knowledge levels induce information search and perception updating. It may be interesting then to consider that the adaptation costs incurred by changing

[55] Although Khattak et al. (1996) find that mode shares did change substantially in favor of transit as a result of information provision, particularly under incident conditions.

to other routes in familiar parts of the network are known more precisely, and are likely to be lower, than those incurred by changes towards unfamiliar routes. Choice adaptation towards unfamiliar routes may involve a costly wayfinding process and even the very costly possibility of getting lost; taking into account these differences in adaptation costs between diversion to familiar and unfamiliar routes, the important role of familiarity appears quite logical. Note that the finding that travelers who share a ride are relatively prone to divert to other routes (Khattak et al., 1993b) may also be considered a familiarity-effect, as two know more than one.

Moving to the topic of information acquisition costs, it is widely acknowledged throughout the social sciences that the non-monetary costs of acquiring information (in the sense of searching for and processing information) may be substantial in terms of effort, time, attention and the possibility to forego already found alternatives[56] (e.g. Simon, 1955, 1978; Weibull, 1978; Shugan, 1980; Smith, 1991; Payne et al., 1993; Hauser et al., 1993; Mehta et al., 2003; Lu et al., 2005). Many traveler behaviour studies suggest that this general insight is particularly applicable to the context of travel choice making, where travelers dislike to engage in a lengthy search- and decision-process, and rather apply myopic or heuristic decision strategies (Foerster, 1978; Hey, 1982; Richardson, 1982; Polak & Jones, 1993; Stern, 1999; Fujiwara et al., 2004; Jou et al., 2005). The finding of Chorus et al. (2006d) that travelers appear to desire information that makes traveling easier (e.g. route guidance or early warning functions) rather than information that helps them optimize their decisions (e.g. personalized, multimodal information) is consistent with this insight. As a result, the usability of travel information services appears to be a crucial determinant of its usage among travelers (Golledge, 2002; Kenyon & Lyons, 2003; Fayish & Jovanis, 2004; Geweke & Zumkeller, 2006; Kihl, 2006). Furthermore, limited awareness of the availability and capabilities of travel information services is found to be a potentially substantial barrier to the propensity of travelers to search for the information (Kenyon & Lyons, 2003; Goulias et al., 2004; Peirce & Lappin, 2004): active marketing efforts are needed to help travelers find the information they might be looking for. Besides the non-monetary costs of information acquisition discussed above, travelers generally appear to have a very low willingness to pay for acquiring travel information[57] (e.g. Emmerink et al., 1996; Polydoropoulou et al., 1997; Zhao & Harata, 2001; Khattak et al., 2003; Zhang & Levinson, 2006), especially for transit information (Vance & Balcombe, 1997; Neuherz et al., 2000; Molin & Chorus, 2004; Molin et al., 2006). This latter finding can be explained by acknowledging that potential transit-users mostly feel that they have already paid for information provision by buying their ticket. Furthermore, it appears that there is a widespread dislike among travelers to pay for information about delayed trains. If information must be paid for, travelers prefer to pay per acquisition rather than paying a flat fee per month (Polydoropoulou et al., 1997; Khattak et al., 2003; Molin & Chorus, 2004; Wolinetz et al., 2004). It should be noted that willingness to incur (non-) monetary costs when acquiring information appears to differ widely between travelers (Denant-Boemont & Petiot, 2003; Chorus et al., 2006f). Given this average low willingness to pay for information among travelers, but depending on the market structure of information suppliers and the transport policy goals of government, subsidization of information supply could be considered a welfare enhancing policy (Zhang & Verhoef, 2006).

[56] E.g. driving past a highway-exit during the process of trying to find information about whether it is a good idea or not to take this or a next exit.

[57] Although estimates appear to differ quite widely between studies: for example, Tam & Lam (2005) find a rather high willingness to pay for travel information. Furthermore, although no empirical results were found in this regard, it appears that in-car route guidance systems are rapidly gaining in popularity among car-drivers, notwithstanding their relatively high prices. Willingness to pay for information (services) thus seems to depend on the type of information (service).

Another phenomenon that plays an important role in everyday traveler behavior and which can be explained by referring to the concept of information acquisition costs, is the notion of habitual travel behavior. It has recently been widely acknowledged (e.g. Lyons, 2001; Fujii et al., 2001; Fujii & Kitamura, 2003; Fujii & Gärling, 2003; Schlich & Axhausen, 2003; Bogers et al., 2005) that many travel choices are made out of habit: the same alternative is chosen repeatedly, without any conscious deliberation from the side of the traveler[58]. As found by Aarts et al. (1997) and Verplanken et al. (1997) in the context of mode choices, travel information acquisition is virtually non-existent during the execution of travel habits. Some might say that this lack of deliberation and information acquisition implies that habit execution should not be considered an actual 'decision'. However, it may be argued that when relevant past behaviour exists, executing a habit is in a sense an economizing mode of decision-making as the costs of decision-making and information acquisition are practically non-existent (Gärling et al., 2001; Golledge, 2002; Gärling & Axhausen, 2003). The absence of information acquisition during habit execution does not mean that travelers that make most of their travel choices out of habit never use travel information. As habitual behaviour is mostly very dependent on the choice context (in terms of destination, time-of-day, trip purpose), choices that are made by the same traveler in (even slightly) different contexts are likely to be made in a less habitual fashion and may thus involve information acquisition. This information might indirectly help break down habits. Indirect evidence for this argument appears in van der Horst & Ettema (2005) and Jou et al. (2004), where travel information use and effects is found to be higher during weekends than during weekdays, and also relatively high during non-daily recreational trips. Other studies point to the fact that habits may be broken in situations where the habitual alternative performs very badly, e.g. due to incidents or road works (Fujii et al., 2001). In these situations, travel information use and effects are likely to reach relatively high levels.

Cross-category and miscellaneous findings

As indicated in Section 7.2.1, a number of findings from the literature concerning travel information use and effects do not clearly relate to one of the identified sets of determinants: there appears either to be a relation with all three sets of determinants, or with none. Two groups of findings are found to be especially difficult to categorize, and will therefore be discussed here separately: the first group refers to the role of sociodemographic and socioeconomic factors, the second group refers to the role of information format and the type of medium that is used for information provision. Note that while reviewing these two groups of findings we will only make limited attempts to find reasons behind the empirical relations found, as these are often simply not clear.

Sociodemographic and socioeconomic factors

In general, many studies point to the fact that there is a large variation in travelers' use of travel information, and its effect on their travel choices (e.g. Watling & van Vuren, 1993; Golledge, 2002; Denant-Boemont & Petiot, 2003; Chorus et al., 2006f). Generally, it is acknowledged that although a traveler's personality (Khattak et al., 1993a; Chatterjee et al., 1999; Golledge, 2002), the constraints they face (Golledge, 2002), the regional travel context[59] (Bonsall, 1992; Polak & Jones, 1993) and the various determinants discussed above play an important role as causes for this variation, sociodemographic or socioeconomic grounds can also explain a substantial part (e.g. Srinivasan et al., 1999; Geweke & Zumkeller,

[58] However, as Chatterjee et al., (1999) argue, executing a habit may not always mean there is only one habitual alternative: depending on e.g. the departure time and en-route conditions, multiple habitual routes may exist.

[59] It should be noted however, that Jou & Mahmassani (1996) and Petrella & Lappin (2004) find remarkable resemblances between information use and effects among travelers in different regions of the United States.

2006). Concerning the acquisition of provided travel information, it is generally found that the following groups of travelers are relatively prone to search for (and pay for) available travel information: young, male[60] travelers and travelers with high education and income levels (Lappin, 2000; Mehndiratta et al., 2000; Targa et al., 2002; Yim & Khattak, 2002; Petrella & Lappin, 2004; van der Horst & Ettema, 2005). Given the reception of travel information, it is found that male travelers (Emmerink et al., 1996; Wardman et al., 1997; Mannering, 1998; Mahmassani & Liu, 1999; Dia, 2003; Mahmassani & Srinivasan, 2004; Jou et al., 2005), young travelers (Abdel-Aty et al., 1997; Mahmassani & Liu, 1999; Dia, 2003; Srinivasan & Mahmassani, 2003; Jou et al., 2005) and high-income travelers (Khattak et al., 1993b; Jou et al., 2005) are also relatively prone to change to other than the currently chosen or intended travel alternative. However, Wardman et al (1997) found that younger travelers are less likely to comply with advice given by travel information services. Abdel-Aty and Abdalla (2004) found the same relation, but for higher educated travelers. Note that, as Chorus et al. (2006a) state, these sociodemographic and -economic determinants for travel information use and effects are in fact likely to be proxies for more fundamental behavioural determinants: for example, younger travelers are likely to be more technology-oriented, and are therefore likely to be more aware of available information services and to perceive their use as less costly in terms of effort and attention. This may explain their relative susceptibility to acquire travel information, when compared to older travelers.

Information format and medium type
Quite a lot of research has been done to identify which information format affects travelers' choices the most, in terms of diversion levels[61]. Format is here defined as the way in which some information content is translated into a message that is provided to the traveler. Such a message may for example take the form of advice or a travel time estimate, a qualitative or quantitative message, a one phrase message or an integral story, etc. Many studies stress the relatively high potential of advice or prescriptive information (e.g. "take route A") to alter traveler behavior in the short run (Khattak et al., 1996; Chen et al., 1999; Mahmassani & Srinivasan, 2004; Abdel-Aty & Abdalla, 2004; Jou et al., 2005), as well as the provision of ex-post information on the current and best available alternative (Chen et al., 1999; Srinivasan & Mahmassani, 2003; Mahmassani & Srinivasan, 2004; Bogers et al., 2005). The provision of predictive and quantitative information ("due to an accident, the expected delay on route A equals 25 minutes") is found to have more effect on choices than historic and qualitative information ("due to an accident, there are delays on route A") (Khattak et al., 1996; Dia, 2003; Jou et al., 2005). Furthermore, increasing the level of detail is found to increase diversion levels (Khattak et al., 1993a; Polydoropoulou & Ben-Akiva, 1998; Yang & Fricker, 2001; Yim & Khattak, 2002). Note however again the trade-off with respect to readability and comprehensibility of the information (Dicke & de Groot, 2005; Kihl, 2006). Chatterjee & McDonald (2004) also argue that the use of arrows and the combination of fixed and variable elements are likely to confuse travelers, although learning might eliminate this confusion in the longer run. Bogers et al. (2005) found that travelers are well able to derive efficient travel choices from queue length information. In order to influence car-drivers' mode-choices (and persuade them to consider taking or actually take transit), it is generally acknowledged (e.g. Lyons, 2001; Abdel-Aty, 2001; Kenyon & Lyons, 2003) that information should be presented to them that compares both modes, and does so on a number of attributes - i.e. not on travel times only. Note however, that Polydoropoulou & Ben-Akiva (1998) find that prescriptive

[60] Although Polydoropoulou et al. (1997) find that women perceive the benefits of the use of travel information services to be higher than men.
[61] Research concerning how information format influences travelers' need for and acquisition of the information is relatively scarce, but see Chorus et al. (2006d, f) for examples.

information to take transit has an effect on mode-choices, too. The findings of Polydoropoulou et al. (1996) may be used here as a summary: highest (short run) diversion rates among car-drivers are established by prescriptive information, followed by quantitative/predictive information on multiple alternatives, followed by quantitative/predictive information on the usual alternative. Qualitative information on the usual alternative results in the lowest diversion rates.

Before concluding this Section on the role of information format, we pay some more attention to the effect of advice, or prescriptive information. Let us first restate the argument made by Jackson (1996) that when longer term effects are taken into account, there is a case to be made against the provision of advice. Note that such a long-run perspective is rarely adopted in the studies encountered during our review. We agree with Jackson (ibid.) when he states that the provision of advice (in contrast with descriptive information such as the provision of travel time estimates or the presentation of previously unknown routes) prohibits learning and makes travelers dependent on the information service as it reduces a traveler's decision-making process from a true spatial choice to a binary choice of whether or not to follow the advice. We feel that it may even be argued that in the long run, through this choice-reduction process, providing advice may induce habitual behavior. Furthermore, we feel there is another reason to be cautious with the provision of advice: by giving advice, the information provider does part of the traveler's thinking, and by doing so, risks reaching other conclusions than the traveler would have reached. Take for example the case where one route is 2 minutes faster than another one, but where the other route is more attractive in terms of scenery, road conditions etc. Based on travel time comparisons, the information provider is likely to prescribe the traveler to take the former route, whereas the traveler might have chosen the latter. In combination with the earlier mentioned finding that travelers are very sensitive to 'wrong' information, there are many thinkable situations where such advice is harmful to the use and effect of travel information in the long run. In general, giving advice becomes a hazardous thing to do when more than one attribute determines a traveler's preference (e.g. in situations where fast but expensive toll-roads are available). As Golledge (1995, 2002) states, the information provider should always acknowledge that travelers may have a multitude of criteria for the selection of travel alternatives.

Concerning the role of medium type as a determinant of information use and effects, it is found that the radio is a preferred information medium among car-drivers (e.g. Haselkorn et al., 1989; Yim & Khattak, 2002; Targa et al., 2002); Chatterjee et al. (1999) however find that radio-information is often ignored. Many researchers propose the use of graphical information as the format that is most easily understood by travelers, arguing that vision is the spatial sense par excellence, especially in unfamiliar parts of the network (Hato et al., 1999; Yang & Fricker, 2001; Golledge, 2002). Yang & Fricker (2001) found that auditory information is very effective when conveying less detailed information, whereas visual information may help conveying more extensive messages (e.g. in unfamiliar parts of the network). Consistent with this argument, it is suggested that the internet is the ideal medium to provide in-depth comparisons between different modal options (e.g. Kreitz et al., 1999; Kenyon & Lyons, 2003). Variable Message Signs are found to induce rather high route-diversion rates, too (e.g. Zhao & Harata, 2001), although other studies mention that they are often overlooked (Wardman et al., 1997; Chatterjee & McDonald, 2004). In a more general sense, Polydoropoulou & Ben-Akiva (1998) find that pre-trip information from electronic sources has a higher impact on travelers' choices than comparable information from non-electronic sources. This might be due to the fact that electronic information suggests dynamism (i.e. that it is regularly updated), whereas non-electronic sources such as timetables and newspapers by definition provide only static information. Jou et al. (2005) find that travelers are generally most experienced with travel information provision through the radio and Variable Message Signs, and Emmerink et al. (1996) find that radio-information and Variable Message Signs induce comparable diversion levels. In conclusion, it is found that the medium to convey messages should be carefully chosen in accordance with the format and content of the information provided.

7.3 Ten summarizing insights into the potential and limitations of travel information

We will here present ten integrative, generic insights that may be derived from (combining elements from) the literature review and which may aid transport academics and policy makers appreciate the potentials and limitations of information provision as a means to change car-drivers' travel choices along the dimensions considered here. For clarity of presentation, no references will be made to literature underpinning these insights – they directly relate to findings presented in Section 7.2.2.

1. *Our expectations with respect to the effects of information provision on travel choices in general may be mildly optimistic, particularly for behavioral adaptation not involving changes in mode choice.* Many empirical studies suggest that information provision on alternative routes and modes to the one currently chosen or intended does lead to more changes towards these alternatives. However, several potential barriers exist that may hamper the provided information being searched for and processed by travelers in general and car-drivers in specific, and the processed information leading to choice adaptation: travelers may perceive their currently chosen travel option as satisfactory and are likely to perceive the quality of proposed alternative options negatively; they are likely to feel that their own knowledge is sufficient or that provided information is irrelevant or unreliable; they are likely to perceive the (non)-monetary costs of information acquisition and choice-adaptation as too high in relation to the expected benefits. Only when given a favorable mindset of the traveler, the availability and high quality of the information service and alternative travel options, and a favorable travel context, will a traveler search for and process travel information, and adapt her choice towards a different mode, route or departure time. Mode choices are found to be harder to change than other travel choices, as the former are often made in an habitual way, and are driven by soft factors such as status, rather than hard factors such as travel time gains. In the longer run, the effects of information provision, when presented to travelers in suitable formats, are likely to be stronger than the short term effects. Travelers that are repeatedly exposed to high quality information at relevant moments pre- and in-trip are likely to learn the value of information and become more aware of the availability and quality of alternative travel options. However, the barriers mentioned directly above are also likely to prohibit the emergence of substantial information effects on car-drivers' travel behaviour, especially their mode-choices.
2. *Provided information is used among travelers to the extent that its (non-) monetary costs are low.* Travelers' perceptions of information benefits are generally low or moderate. This means travelers will generally only acquire information when its perceived costs are low. Concerning monetary costs, it is found that a traveler's willingness to pay for information is very low, although substantial differences exist among travelers. Concerning non-monetary costs, it is found that travelers avoid spending time and attention on using information services. Those travel information services and devices that

are easily usable, and that provide information in ways that are readable and comprehensible while traveling, are far more likely to be used among travelers. It may be expected that these non-monetary costs of information acquisition will become more and more relevant as mobility among older travelers is projected to grow strongly over the next decades (although it might also be expected that the elderly will become more and more familiar with the use of high-tech devices and services).

3. *Information provision on the performance of the currently chosen alternative, also under normal circumstances, may help change car-drivers' choices in the long run.* Travel information can play an important role in a traveler's learning process as it has the potential to redress misperceptions of a normally or habitually chosen alternative. As such misperceptions may also exist under normal conditions, information provision on the currently chosen option under normal circumstances is likely to have a reducing effect in the long run on travelers' misperceptions of normally chosen travel alternatives.

4. *The effect of information provision on other than the currently chosen or intended option is conditional on the performance of these alternative options and the extent to which the information takes into account information acquisition costs and the costs of adaptation towards these alternative options.* It is found throughout the literature that providing information (especially advice) about alternative options when adaptation towards them is likely to cause regret, is a highly non-effective strategy. Information provision is effective, at least from the viewpoint of behavioural adaptation, to the extent that adaptation towards the other alternative, including potentially substantial information acquisition and choice adaptation costs, is more attractive than executing the currently chosen alternative. Information concerning other than the currently chosen alternative may benefit from a higher level of detail than information concerning the currently chosen alternative. This level of detail may concern two dimensions: firstly, it should be acknowledged that travelers may not know the alternative option as well as their currently chosen one. Therefore, the traveler may want to be informed about all the relevant attributes of the alternative- not only expected travel times. Secondly, information containing directions concerning how to reach the alternative option may lower the costs associated with choice adaptation towards the alternative.

5. *The long term effect of giving advice is likely to be limited.* Confronting travelers with advice may reduce the longer term learning potential that information provision has, and may therefore be of limited value in the long run, notwithstanding the relatively high diversion rates that may be established in the short run. This is due to the fact that advice reduces the complex spatial environment into a binary choice environment. When giving advice, presenting the argument behind the advice may help avoiding complete dependency on the received information. In general, the provision of advice is intrinsically difficult when it is acknowledged that travelers take into account more than one attribute dimension of alternatives, since it remains unclear on what weighing of attributes the advice is based.

6. *Young male travelers with high education and income levels that make a trip that differs from trips normally made in terms of destination, departure time, day of the week (weekday versus weekend) are most likely to use information provided to them and divert to other travel alternatives.* In travel situations that differ from a traveler's normal trip along some dimension, travelers that exhibit habitual behaviour for their usual trips may be expected to be more susceptible to the acquisition of travel information and to possible diversion to other than planned or intended travel alternatives. Furthermore, the mentioned socio-demographic group appears to be more prone than others to use information and

possibly divert, possibly due to the fact that people from these segments travel more than others. However, before using this finding as an underpinning of an information provision strategy that explicitly targets this segment of travelers, it should be acknowledged that in many cases targeting specific segments of travelers with information may be costly and even ethically troublesome. One acceptable way of doing so is to tailor marketing campaigns concerning travel information services towards this segment.

7. *In situations where a high variability of conditions exists in parts of the network the traveler is familiar with, information use and effect is likely to be relatively high.* When traveling through familiar parts of the transport network, travelers will be relatively prone to acquire information on other than the currently chosen option and potentially divert. Furthermore, when the attributes of travel alternatives are perceived as unpredictable, travelers will be relatively prone to search for the information provided to them, and they will be relatively prone to update their perceptions with received information and to divert to other alternatives. In parts of the network the traveler is unfamiliar with, it is recommendable that the information not only focuses on the attributes of alternatives (e.g. expected travel times), but also brings alternative travel options to the traveler's attention and guides the traveler towards them. If not, the traveler may perceive the potential costs of behavioral adaptation as too high, e.g. due to the risk of getting lost when changing routes in-trip.

8. *The effect of information provision is relatively high during long trips, complex trips and trips made for an important purpose.* These trips are likely to induce optimizing-behaviour in the traveler, leading to a higher likelihood of information acquisition (concerning both the intended alternative and other options) and choice adaptation. Examples of such a trip are a journey towards a holiday destination or a multiple stop-trip (e.g. home – kindergarten - business meeting - work).

9. *Making information services work well under incident conditions is likely to be cost-effective.* Generally, travelers perceive travel information services to be particularly unreliable under incident conditions. However, it is during these conditions that a need exists for detailed reliable information. Furthermore, as travelers, including the ones that chose their current alternative out of habit, perceive their own knowledge levels as particularly insufficient during such conditions, they are particularly likely to update their knowledge with received information and adapt their choices when the information gives reason for it. Such a diversion may be a first step in breaking a traveler's habit. Although the cost of improving the performance of an information service's performance (particularly in terms of their reliability) under incident conditions is bound to be high, it would be a cost-effective strategy from a behavioral adaptation point of view. Note that a traveler's willingness to pay for information will be relatively high under these circumstances.

10. *Providing travelers with information as early as possible is likely to increase its effectiveness in terms of behavioral adaptation.* Travelers generally find information useful to the extent that it may help them improve their choices. Before a trip is started, or at the beginning of a trip, far more choice adaptation possibilities exist than near the end of it, where information is of limited value to travelers. Furthermore, near the end of a trip a traveler's knowledge levels are much higher than at the beginning (e.g. regarding expected arrival times), so that information needs are lower and the inclination to update perceptions with received information decreases . When providing information to travelers just before a moment of choice may occur (e.g. advice to leave the highway, presented to

travelers right before a highway exit), it should be kept in mind that travelers may need time to think before they want to make a choice to divert.

7.4 Conclusions and discussion

This paper set out to provide insights that help transport academics and policy makers appreciate the potentials and limitations of information provision as a means to induce a modal shift from private car to public transport and/or changes in car-drivers' choices for departure times and routes towards a more even distribution of traffic within the available road network. It does so by providing a review of more than 15 years of literature concerning the use and effects of travel information among car-drivers. Based on the performed review, a number of generic, integrative insights is derived which are listed directly above and will not be repeated here, except for two main findings: it appears that our expectations with respect to the effects of information provision on travel choices in general may be mildly optimistic, particularly for behavioural changes not involving changes in mode-choice. In the longer term, the effects of information provision, when presented to travelers in suitable formats, are likely to be somewhat stronger than the short term effects, due to learning dynamics.

It should be acknowledged that for policy-makers considering the provision of travel information as a travel demand tool among car-drivers, this paper has only tried to answer a subset of the wide variety of questions that are relevant to them. We will list some of the most crucial ones here, without answering them: which transport externalities should the government try to reduce? How do these externalities relate to traveler behaviour? What travel demand management tools exist that may help reduce particular externalities caused by particular traveler behaviour? How does the provision of travel information compare to other travel demand management tools in terms of cost-effectiveness? Besides these effects in terms of travel demand management, what other effects might the provision of travel information have on traveler behaviour? What role should the government play in the process of gathering, integrating and distributing relevant travel information? How does this role relate to the potential role of private parties, such as technology-providers or transportation companies? Clearly, the answers provided in this paper only solve part of the complex puzzle that is faced by transport policy makers who consider attacking the externalities of passenger transport and possibly doing so by means of travel information provision. A clear research need exists concerning the other questions raised here.

Furthermore, where this paper has tried to capture a wide variety of rather *specific empirical* studies concerning the use and effect of travel information by means of a literature review, this is certainly not the only way to gain the needed insights into the potential and limitations of travel information as a travel demand management tool among car-drivers. More particularly, a clear need exists for an *integrative empirical* study effort. Such a study effort should consider simultaneously the use and effects of a variety of types of travel information in the context of multimodal travel choices, and it should simultaneously focus on the role of travelers' knowledge levels, information reliability and trip purpose. Preferably, data on revealed information acquisition and travel choices should be collected. However, a useful and less costly alternative data-collection method is to construct a multimodal travel simulator-experiment. Based on such an experiment, a forthcoming study has attempted to obtain some of these much needed integrative empirical insights (Chorus et al., 2006f). As a final reflection, it is felt by the authors that notwithstanding all our efforts in modeling the variation in behavioral response to information (and in reviewing the empirical application of these models), a substantial part of this variation will always remain unexplained: traveler behavior, and particular travelers' response to knowledge limitations and information provision, is too complex and nuanced to be fully understood by us analysts.

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Chapter 8

Chorus, C.G., Molin, E.J.E., van Wee, G.P., Arentze, T.A., Timmermans, H.J.P., 2006. Responses to transit information among car-drivers: regret-based models and simulations. *Transportation Planning & Technology,* 29(4), pp. 249-271. Copyright © *Taylor & Francis Inc.*

Abstract

This paper investigates the use and effects of transit information among non-habitual car-drivers, i.e. those that do consider transit as a mode-option in their choice set. It does so by first presenting a theoretical model of travel information use and effect, based on the integration of notions of Bayesian updating into a regret-based framework of travel choice. Subsequently, numerical simulation of the model provides insights into the mechanisms behind information use and effect in a mode-choice context where a traveler has both car- as well as transit-options in his choice set, and prefers traveling by car over riding transit. These simulations show that the perceived value of acquiring transit information is limited by a number of factors. Furthermore they demonstrate that, even in the case where transit information is acquired, and the message is favorable to transit, its impact on mode choices will also be limited. Given these results, obtained for non-habitual car-drivers, it is suggested that for car-drivers in general (thus including the large share of habitual drivers), conservative estimates regarding the impact of transit information provision on modal shift would be realistic.

8.1 Introduction

It is generally acknowledged that providing travelers with relevant information on travel options has the potential to change their behavior. An increasing interest has arisen in these information effects over the last years, as is indicated by a number of policy studies (e.g. Commission of the European Communities, 2001; Ministry of Transport, Public Works and Water Management, 2002; Department for Transport, 2004; Federal Transit Administration, 2003) and academic research papers (e.g. Kanninen, 1996; Abdel-Aty, 1996, 2001; Ouwersloot et al., 1997, Reed et al., 1997; Benjamin, 2006; Chorus et al., 2006a) on the topic. Some modal-shift policy initiatives have therefore included the provision of high quality travel information on transit, see the above mentioned policy-documents for examples. It is clear that, in order for transit-information to have any impact on the modal split between private car and transit, two conditions must be met: firstly, the information must be acquired by current car-drivers and secondly, the acquired information must lead to a change in their mode-choices. However, an abundant body of literature indicates that the propensity for car-drivers to acquire transit information and adapt their mode-choice behavior in favor of transit is rather low (e.g. Aarts et al., 1997; Verplanken et al., 1997; Neuherz et al., 2000; Lyons, 2001; Gärling et al., 2001, 2002; Kreitz et al., 2002; Kenyon & Lyons, 2003). A general finding in most of these studies is that this lack of willingness to acquire information and reconsider mode-choice behavior is predominantly due to the fact that car-drivers do not make their mode choices in a deliberate, conscious way, but instead appear to execute a habit: their choice set contains the car-option only, and transit options are not considered in the choice process in the first place[62]. This leaves two important questions unanswered: firstly, what would be the potential of transit information for mode-choice adaptation among those travelers that do have one or more transit options in their choice set, but generally favor their private car as a transport mode? Let us denote these travelers as non-habitual car-drivers. Secondly, what are the determinants behind these non-habitual car-drivers' choices whether or not to acquire available information, and whether or not to adapt their (intended) mode-choices?

This paper tries to answer these questions. In order to grasp the full complexity of the way in which non-habitual car-drivers deal with the information available to them, addressing all relevant mechanisms and the way they interact with each other, an extensive formal model of information use and effects is constructed. In order to capture the intuition that traveling may often be about avoiding negative emotions, more than deriving a maximum level of utility, we have adopted a framework of regret-based mode choice (Loomes and Sugden, 1982; 1983). This framework is based on the following two notions: 1) a traveler may be aware of the fact that, due to uncertainty in the transport network, he may end up having chosen a mode that turned out to be less attractive than a non-chosen mode. This induces regret on the side of the traveler. 2) this traveler anticipates this possibility of regret and aims to minimize expected regret when choosing from available modes. After having derived the model, it is applied through numerical simulations on a typical mode choice situation for the type of car-driver studied here, in order to gain insight into the predicted implications of a variety of potential determinants behind information use and effects. The derivation of the formal model and its illustration through a fictive mode choice situation form a contribution to the existing empirical literature on this topic in three ways: firstly, it presents and applies a coherent framework to systematically describe the mechanisms behind travel information use and

[62] Where other studies make a distinction between choice set and consideration set, we do not: we assume all alternatives that are element of ones choice set to be considered in the choice process. Alternatives that are not considered in the choice process are assumed to be outside the choice set.

effects. Current empirical literature on this issue, although having provided valuable insights, often lacks such a rigorous approach. Secondly, the paper provides insight into the way non-habitual car-drivers deal with travel information, thereby implicitly establishing an upper boundary for expectations concerning the impact of such information on car-drivers in general. Finally, whereas the concept of anticipated regret as a determinant of choice-behavior is well known in such areas as microeconomics, psychology and marketing (e.g. Simonson, 1992; Inman et al., 1997; Zeelenberg, 1999; Crawford et al., 2002; Hart, 2005), its application in the travel behavior domain is to the authors' knowledge virtually non-existing. This paper shows how the regret-concept may be applied to systematically and realistically describe travelers' behavior under uncertainty.

Section 8.2 presents the derivation of the formal model. The model is subsequently applied through numerical examples in Section 8.3 (discussing information acquisition) and 8.4 (discussing the effect of acquired information). Finally, conclusions on the design of transit-information services and modal split policies are derived in Section 8.5.

8.2 A regret-based model of information use and effect

This Section presents a regret-based model of how travelers in general may perceive the value of travel information, and may update their choice behavior using received messages[63]. For reasons of simplicity of presentation, and without any loss of generality, we here assume the highly simplified choice situation where a traveler's choice set contains one car-option and one transit-option, and where his preferences are based on an intrinsic mode-preference (for the car-option) and the modes' travel time. Travel times of both modes may be uncertain, and a traveler may acquire travel time information for either one of the two modes in order to reduce this uncertainty. In notation: suppose that a traveler faces a choice set S of two travel considered alternatives Y_i and Y_j, for example i representing a transit option, and j a car option:

$$S = \{Y_i, Y_j\} \tag{1}$$

Each of these travel modes can be thought of as being a bundle of attributes, or in the present case, as being nothing more than one attribute, a travel time X_i or X_j:

$$Y_i = \{X_i\},\ Y_j = \{X_j\} \tag{2}$$

The traveler is aware of the fact that his estimates of the characteristics of the two mode-alternatives may be imprecise. His perception X_i^p of travel time X_i may therefore be represented by a random continuous variable, having a distribution $f_i^p(x_i)$. Throughout this paper, the normal distribution will be adopted to this aim, although many other distributions may prove suitable for the arguments made:

$$X_i^p \sim f_i^p(x_i) = N(\hat{x}_i^p, \sigma_i^p) \tag{3}$$

63 This Section draws from Chorus et al., 2006c.

These perceptions are characterized by a mean travel time $\hat{x}_i^p$ and a standard deviation σ_i^p. The mean represents the traveler's 'best guess' for a certain characteristic, the standard deviation represents the perceived unreliability of that estimate. The utility of a particular state of a perceived alternative, as a function of the intrinsic mode preference and the mode's travel time may now be expressed as $u(x_i)$. A traveler that is confronted with perceived incomplete knowledge about the travel times of the alternatives known to him faces an expected regret as he is not certain that a considered mode alternative Y_i will turn out to be the best of the two considered alternatives. Given this conceptualization, the regret a traveler expects to be induced by choosing alternative Y_i can now be formulated as the sum of possible realizations of states (travel times) for which the realized utility of a considered alternative Y_i is lower than that of the other known alternative Y_j or the unknown alternative Z, weighed by the probability of occurrence of these states of known and unknown alternatives and the difference between the realized levels of utility.

$$ER(Y_i) = \int_{-\infty}\int^{+\infty}\left[\gamma_{ij}\cdot\left(u\left(x_j\right)-u\left(x_i\right)\right)\right]\cdot f_j^p\left(x_j\right)f_i^p\left(x_i\right)dx_j dx_i \qquad (4)$$

where[64]: $\gamma_{ij} = \begin{cases} 1 \Leftrightarrow u(x_j) > u(x_i) \\ 0 \Leftrightarrow u(x_j) \leq u(x_i) \end{cases}$

Note here that the amount of expected regret is measured in utils. As the traveler is assumed to choose the alternative which induces the lowest level of expected regret, the following represents the expected regret induced by a choice situation:

$$ER = \min_{k=i,j}\left(ER(Y_k)\right) \qquad (5)$$

Note that we have thus expressed the expected regret of the choice situation in terms of the utility of the travel alternatives under evaluation. This Section has presented mathematical formulations of how expected regret may determine a traveler's mode-choices. Based on these formulations, we will now derive formulations for the perceived value of travel time information acquisition for, say, the transit option Y_i. First, we need to specify what messages the traveler may expect when acquiring information and secondly, we need to establish the effect of received messages.

At first, it may seem somewhat strange to assume that a traveler that is uncertain about the actual value of a characteristic, does have expectations concerning what message to receive when asking an information service for an estimate: if a traveler knows what messages to expect when acquiring information, why should he make the effort to acquire the information at all? It should be noted however, that it is meant here that the traveler has *some* expectations concerning the information to be received, based on his initial perceptions concerning the value of the travel time, reflected in $X_i^p \sim f_i^p(x_i)$ and the perceived unreliability of the information service, reflected in $f\left(x_i^I \middle| x_i\right) \sim N(x_i, \sigma_i^I)$. Formally, we can express the travelers

[64] The notion γ_{ij} will be used throughout this paper, with varying indices, to denote the situation where the utility of the alternative represented by the first index is surpassed by the utility of the other alternative.

expectations concerning travel time messages in the form of $x_i = x_i^I$ (e.g. "travel time by transit equals 40 minutes") to be received when acquiring information as:

$$X_i^I \sim f_i^I(x_i) = \int_{-\infty}^{+\infty} f(x_i^I \mid x_i^p) \cdot f(x_i^p) dx_i^p \tag{6}$$

When a traveler receives a message from the information service, he uses it to update his earlier perception into a new one. While doing so, he must deal with the fact that both his initial perception concerning the mode's travel time, as well as the message received, are only partly reliable –this is reflected in σ_i^p and σ_i^I respectively. An updating mechanism that takes into account these two sources of unreliability, is that of Bayesian perception updating, where probabilities are updated using Bayes' law. A widely used concept throughout psychological research (e.g., Edwards et al., 1963; Phillips and Edwards, 1966), Bayes' law has been recently adopted in travel demand contexts to explain updating processes concerning for example unreliable travel-time estimates (Kaysi, 1991; Chen & Mahmassani, 2004; Arentze & Timmermans, 2005a; Chorus et al., 2006b). Under the assumption of a normally distributed[65] initial perception of both the travel times X_i^p as well as messages received X_i^I, we can, applying Bayes' law for continuous variables (see Edwards, et al., 1963), derive the traveler's updated perception X_i^u as follows:

$$X_i^u \sim f_i^u(x_i) = N(\hat{x}_i^u, \sigma_i^u) \tag{7}$$

where:

$$\hat{x}_i^u = \left(\frac{1}{\sigma_i^p}\right)^2 \cdot \hat{x}_i^p + \left(\frac{1}{\sigma_i^I}\right)^2 \cdot x_i^I \Bigg/ \left(\frac{1}{\sigma_i^p}\right)^2 + \left(\frac{1}{\sigma_i^I}\right)^2 \tag{8}$$

$$\sigma_i^u = \sqrt{\left(\sigma_i^{p\,2} \cdot \sigma_i^{I\,2}\right) \Big/ \left(\sigma_i^{p\,2} + \sigma_i^{I\,2}\right)} \tag{9}$$

Note that, completely in line with intuition, the more reliable the information service is believed to be (i.e. the lower is σ_i^I), the more the updated perception resembles the message that is received through the information service. Note also that the more reliable the information is believed to be, the more confidence the traveler will have in his updated perceptions (reflected in a lower σ_i^u). These notions are key to the reduction in expected regret that may occur through acquiring information.

It is important to note that the expected regret of the mode for which travel time information is acquired may be influenced by a received message in several ways. First, due to the message received, the traveler's best estimate for the alternative's travel time may be altered, which directly leads to an increase or a decrease in expected regret that may be induced by the alternative (take for example the traveler who finds out that the travel time of a mode he is

[65] This assumption is often made, and often criticized for being a less valid representation of perceptions from a behavioural point of view (e.g., Bonsall, 2001). However, the assumption is non-critical for the argument made here, and is only made for reasons of simplicity: the normal distribution can be replaced by other distributions, as long as these are conjugate priors, i.e. priors that are conjugate to the distribution representing the perceived unreliability of the information service.

considering is twice the normal travel time, due to an incident). Secondly, as the confidence in his estimate for some mode's travel time increases due to the reception of a message, or in other words as the spread of the perception decreases, the tails of the distribution reflecting this perception is less likely to interfere with the utility distributions of other alternatives, leading to changes in expected regret. Next to these aspects that refer to the expected regret of the alternative a message is received for, the expected regret of an entire choice situation may be diminished by receiving an estimate for some characteristic, as the traveler is given the possibility to capitalize on the improved accuracy of his choice: even the perspective of possibly receiving a disappointing message may reduce the regret that is expected to remain in the choice situation, as the traveler knows that, based on the received message, he has the possibility to not choose the alternative for which the disappointing message was received.

Based on the above conceptualization of what messages may be expected to be received when asking an information service for an estimate for the travel time of alternative Y_i, and of what may be the expected effect of such a received message in terms of perception updating, the expected regret that is perceived to remain after having asked the information service for an estimate concerning this characteristic for Y_i can now be formulated. For every message that may be expected to be received through the information service, weighed by the probability of receiving $f_i^I(x_i)$, an updated perception $f_i^u(x_i)$ is formed using Bayes' rule, taking into account the traveler's beliefs about the level of reliability of his initial estimate and that of the information service. This updated travel time perception is subsequently used to re-evaluate the choice situation. Thus, the expected regret of the alternative travel time information is acquired about, $ER^+(Y_i)$, can be written as:

$$ER^+(Y_i) = {}_{-\infty}\int \int^{+\infty} \left[\gamma_{ij} \cdot \left(u(x_j) - u(x_i)\right)\right] \cdot f_j^p(x_j) f_i^u(x_i)\, dx_j dx_i \tag{10}$$

The traveler's expectations of regret induced by the choice situation as a whole, based on the notion that the traveler anticipates, and aims to minimize, expected regret, may be formulated as follows:

$$ER^+ = {}_{-\infty}\int^{+\infty} \left[\min \left\{ \begin{aligned} &\left({}_{-\infty}\int \int^{+\infty} \left[\gamma_{ij}\left(u(x_j) - u(x_i)\right)\right] f_j^p(x_j) f_i^u(x_i)\, dx_j dx_i \right), \\ &\left({}_{-\infty}\int \int^{+\infty} \left[\gamma_{ji}\left(u(x_i) - u(x_j)\right)\right] f_i^u(x_i) f_j^p(x_j)\, dx_i dx_j \right) \end{aligned} \right\} \right] f_i^I(x_i)\, dx_i$$

(11)

Now we can write the perceived value of acquiring travel time information as the anticipated difference in expected regret induced by the choice situation before and after the acquisition of information:

$$PIV = ER - ER^+ \tag{12}$$

Note that we have thus expressed the value of information in terms of the utility of the travel alternatives under evaluation. The traveler may now be assumed to compare this perceived information value to perceived information costs, which may be composed out of monetary costs and, among other things, costs in terms of time, effort and attention, and the possibility of foregoing an interesting alternative during the acquisition of information (Simon, 1978; Weibull, 1978; Shugan, 1980; Richardson, 1982). We thus assume that, should the perceived information costs outweigh the perceived value as expressed in Equation (12), the traveler will acquire information. If this is the case, and a message $x_i = x_i^I$ is received (e.g. "Travel time by transit equals 40 minutes"), the impact on the traveler's perceptions, utility and mode choice follows the application of expressions (7) through (9), followed by (4) and (5). In words, the role of information in a mode choice context may be put as follows: depending on its perceived reliability, information may lead to an *update of perception*. Depending on the relevance or utility function of the informed attribute, information that has led to an update of perception may lead to an *update of utility* for a given mode. Finally, depending on the utility for all other attributes of a given mode (a traveler's base preference for a mode), information that has led to an update of utility for a given mode may lead to an *update of mode choice*, or choice adaptation. Moreover, a traveler knows that this is the case before he acquires information, and thus will base his decision of whether or not to acquire information on his belief in the potential of information to update his perceptions, utilities and eventually his mode choices.

Although the model presented is mathematically somewhat tedious, it presents one clear and important advantage over more ad-hoc modeling approaches: it presents the perceived value of information acquisition in terms of the utility derived from the attributes of the alternatives considered in the choice, which provides a highly straightforward and coherent interpretation of the concept of information value. Using this feature, interpretation of the absolute changes in predicted information use and its effects are meaningful for a specific choice context and specific utility function of the alternative's attributes. Predicted trends or relative changes in information use and effects, however, are even more generic, providing a meaningful interpretation for all choice-contexts where the same utility functions for attributes apply. We will exploit this latter characteristic in the subsequent Sections in order to derive insights regarding the relative impacts of several determinants on the use (Section 8.3) and effects (Section 8.4) of transit-information among non-habitual car-drivers.

8.3 The acquisition of transit-information among car-drivers: simulations

Although it would be possible to discuss the determinants of information acquisition based directly on a discussion of the derivations made above, this would complicate things unnecessarily. We have chosen here to use a fictive, though plausible, mode choice situation and simulate the relevant mechanisms described above as illustration. This Section, as mentioned earlier, focuses on information *acquisition* among those travelers that do have the transit option in their choice set, but generally prefer traveling by car.

The following purely fictive example of a mode choice situation is proposed: take a car-driver that faces a trip that can be performed using car or transit. He is assumed to only be uncertain about the modes' travel times, which he perceives as normally distributed variables with equal means $\mu_{car} = \mu_{trans} = 50$ and standard deviations $\sigma_{car} = \sigma_{trans} = 10$. In case of equal travel times, he would take the car, implying that the base-utility he derives from all non-travel time related attributes of the car exceed those of transit: $u_{car}^{base} > u_{trans}^{base}$. We take these base preferences to take on the following values: $u_{car}^{base} = 65$ and $u_{trans}^{base} = 55$. Suppose furthermore that the traveler attaches a disutility to travel time by either car or train of $u(tt) = -\beta \cdot (tt)$ with $\beta_{base} = 1$. The traveler now bases his choice on the expected regret for both modes, which itself is a function of the intrinsic mode preferences and the modes' uncertain travel times. Applying Equations (4) and (5), we can compute that in this base case, $ER_{car} = 2.14$, $ER_{trans} = 12.02$ and the expected regret of the choice situation as a whole equals therefore $ER = 2.14$. Furthermore assume that the traveler also knows he can acquire travel time information for the transit option using an information service, the unreliability of which is represented by $\sigma_{trans}^{info} = 1$. Using these values as input for Equations (11) and (12), we can compute the perceived value of information: in this base case, $PIV = 1.10$.

As mentioned earlier, from our model's perspective, the role of information in a mode choice context depends on its perceived potential to update perceptions, utilities and eventually choices. We will use these three conditions to identify the determinants of information acquisition. We start with the first condition, referring to the traveler's expectation that the information she will receive should help her *update her perceptions of modal characteristics*. As derived in Section 8.2 (Equation (8)), this will only be the case when the perceived reliability of the information is high enough relative to the traveler's perceived reliability of her initial knowledge. This importance of this perceived –relative- unreliability is found in several empirical studies (e.g. Polydoropulou & Ben-Akiva, 1998; Hato et al., 1999; de Vries et al., 2003, Fayish & Jovanis, 2004).

It is generally known that travel information in general, and travel time information in specific, is always perceived to be unreliable to some extent. Using our conceptual model we can study how the notion of relative unreliability of transit-information affects the value that a conscious traveler expects to derive from information acquisition: the information unreliability is varied from $\sigma_{trans}^{info} \approx 0$ to $\sigma_{trans}^{info} = 10$, keeping $\sigma_{trans} = 10$ constant, so that relative unreliability $\sigma_{trans}^{info} / \sigma_{trans}$ is increased from 0 to 1, step size 0.2. Figure 1 shows us that, as expected, such a traveler's perception of information value decreases as the perceived relative unreliability of the information service increases[66]: the traveler perceives that any information service with a high perceived relative unreliability will not be able to substantially update her initial perception of transit's travel time, and thus, by definition, will not be able to reduce the expected mistake she faces. Formulated differently, the traveler knows that she will discard messages received from the information service if the source is perceived as unreliable.

An additional insight can be derived by observing that the traveler's perception of information value decreases rather slowly when the increase in relative information unreliability is small. However, as the perceived unreliability of the information starts to approach the traveler's perception of the unreliability of his own knowledge, the perceived value of acquiring the information rapidly fall with increasing unreliability. This mechanism thus stresses the paramount importance of maintaining an acceptable level of reliability of transit-information services. In the light of this analysis it is also quite disturbing that car-drivers find their own knowledge concerning transit-characteristics fairly reliable (Bonsall et al., 2004), although in reality they are severely biased against transit (Li, 2003; Bonsall et al., 2004).

[66] Please note that the Appendix contains the numerical values that enter Figures 1, 2 and 3 in Table 1, those that enter Figures 4,5 and 6 of Section 4 in Table 2.

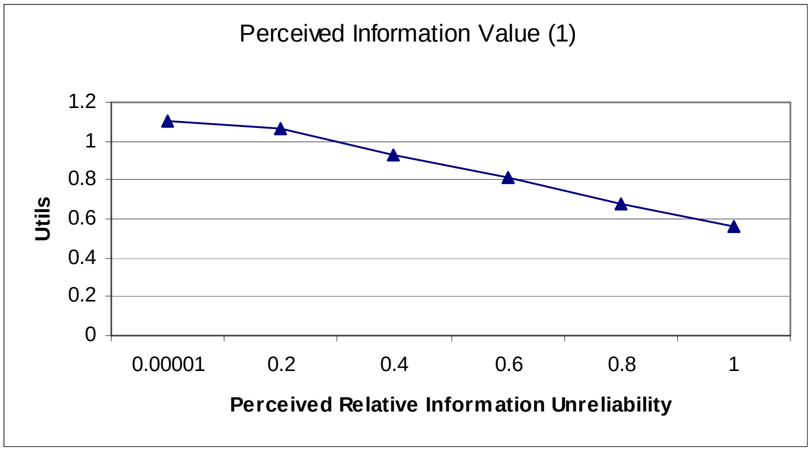

Figure 1: Influence of relative information unreliability on information value

Let us now play advocate of the devil and assume the highly unrealistic situation in which the transit information service is perceived among car-drivers to be completely reliable. Will this lead to a substantial usage of such information on transit among them? Assuming that the condition of perception updating has been met – so that the traveler knows that he will always be able to completely update or replace her perceptions based on the information acquired - let us examine the second condition, which states that the traveler should feel that the information that might be received may help her *update the utility she may derive from the transit-option*. Intuitively, it can be seen that information, although completely reliable, is of limited value to anyone when it concerns features of alternatives that the traveler does not care about. From the micro-economic perspective used in our model, this means that the individual expects that the utility he derives from an alternative will not substantially change after receiving the information. Now this is exactly what might happen when car-drivers are faced with the availability of transit-information: this information mostly concerns transit travel times and costs, whereas travelers in general, and car-drivers in particular, appear to find other features of travel modes more important. Such features are often called symbolic characteristics (Hague Consulting Group, 1991; Steg et al., 2001; Thogersen, 2001; Ellaway et al., 2003; Steg, 2005; Anable & Gatersleben, 2005), and include perceived individuality and freedom, image, perceived environmentally friendliness, etc. Other features of travel alternatives such as comfort and convenience, which are difficult to define, also appear to play an important role in travelers' mode choice process (Kenyon & Lyons, 2003).

Let us look at Figure 2 for a view on the impact on information value among non-habitual car-drivers of the fact that the feature that the traveler is informed about (travel times), may not be highly relevant to them. In other words, the importance of the travel time characteristic relative to all other characteristics is varied, maintaining complete perceived reliability of the information, ceteris paribus, from $\beta = 0.5$ to $\beta = 1.75$. It can easily be seen that as the relative importance of other characteristics increases, the perceived value of acquiring information concerning transit's travel time decreases as it refers to a characteristic whose relevance decreases. Furthermore, it can be observed that increases in small values of β have a far more limited impact on perceived information value than the same increases in larger values of β. For relatively large values of β, the perceived information value appear to increase linearly with increasing values of β. To summarize, as car drivers become more interested in characteristics such as image and convenience, they know that travel time information, whether or not completely reliable, will only have a very limited updating impact on the utility they expect to derive from choosing transit.

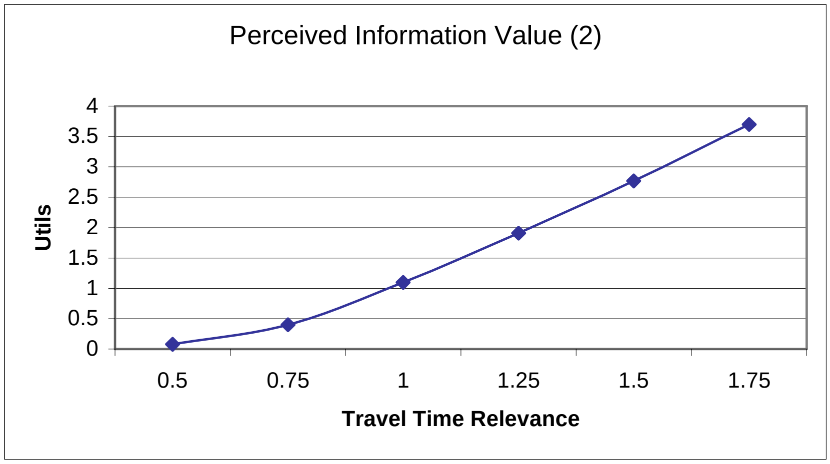

Figure 2: Influence of travel time relevance on travel time information value

Let us now assume the even more unrealistic situation in which the information service is perceived to be completely reliable, and the feature it concerns (transit-travel time) is considered to be very important by our car-driver (i.e. $\beta = 1.75$ in our example). Will this lead to a substantial usage of such information on transit? The conditions of perception and utility updating are met, as the traveler knows that he will take received messages serious, and that she may substantially update her utility of the transit-alternative based on the update of her travel time perception. One condition remains however: *updating of mode choice*. Intuitively, it is clear that when an individual perceives an alternative as being very unattractive in general, the traveler will not expect to derive value from being informed about the alternative's features, even if this information is completely reliable and addresses important features. The reason for this in a micro-economic sense is that the individual knows that even a substantial update in utility of the unfavorable alternative will not make her change her mind, i.e. make her update her choice, as other alternatives available will remain the more attractive ones anyhow. In the model presented here, this notion is captured through the concept of expected regret: a very unattractive alternative does not cause any expected regret, notwithstanding the uncertainty the traveler faces concerning one or more of its attributes, whether these are important or not. Highly reliable and relevant information will then not be able to make a substantial difference in that situation.

In a mode choice context, exactly this situation appears to apply among conscious car-drivers, as they by definition prefer their car to the transit-alternative. More specifically, it appears that those car-drivers that do consider the transit-option (non-habitual ones in our terminology) generally consider the potential (e.g. Ibrahim, 2003) and the availability (Hague Consulting Group, 1991; de Palma & Rochat, 1999) of transit as being far lower than that of their car, making transit a non-preferable option in their eyes. Applying our model of a non-habitual traveler, we indeed find a strong effect in the difference in base preferences for the two modes on their susceptibility to acquire information on the least preferred mode (transit in our example). Figure 3 shows our model's calculations of the perceived benefit of acquiring information concerning transit, while increasing u_{car}^{base} from 55 utility points up to 75 utility points, keeping u_{trans}^{base} constant at 55.

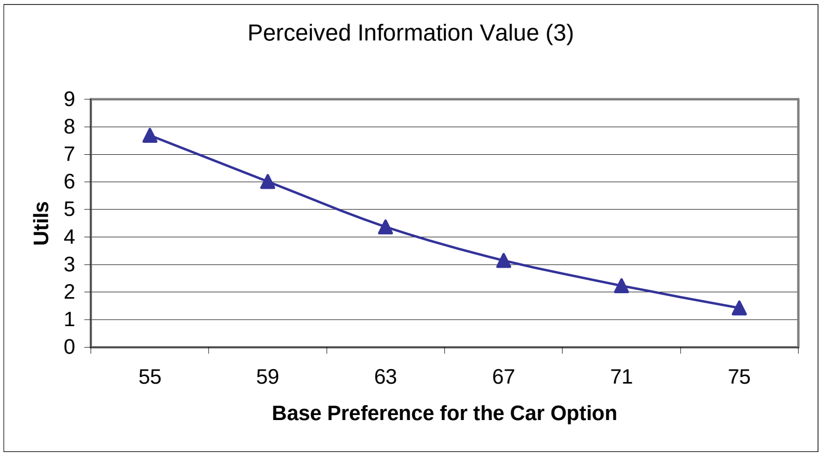

Figure 3: Influence of a base preference for the car on transit-information value

For those cases where the intrinsic preference for car over mode is non-existing (i.e. travelers are indifferent between the two modes in general) or small, perceived information value is large. This signals that in those situations, travelers may want to brake the tie by looking at the modes' attributes. However, it becomes clear that an increase in differences in base preference for the car option strongly affects a traveler's propensity to acquire transit information: perceived information value exponentially decrease with increasing differences in base preferences. Although the information is completely reliable, and addresses an important feature, the traveler does not expect that she will adapt her choice following the reception of information: the preference gap is simply too big. This argument stresses the role of base preferences and complements empirical literature that suggests that travelers mostly look for information regarding an option they plan to choose in the first place (Polak & Jones, 1993; Srinivisan et al., 1999; van der Horst & Ettema, 2005).

Summarizing the analyses of this Section it appears that even among those car-drivers that do consider transit as a mode option, the perceived value of acquiring information about the transit-option (transit travel time in our example) in real-life mode choice situations may be severely limited by a number of factors: firstly, a traveler may feel that the fact that the travel information will generally not be completely reliable will prohibit a full *updating of perception*, especially in those frequent cases where a traveler perceives himself as relatively knowledgeable on transit-features. Secondly, he may feel that the fact that the information addresses features (such as travel time and costs) that are surpassed in importance by other non-informable features (such as convenience, status, or freedom), will prohibit a substantial *updating of utility* derived from transit. Thirdly, he may feel that the fact that there is a difference in base preference between the transit and the car option (which is generally the case for car-drivers) may prohibit an *update of mode choice*. The analyses thus suggest that even non-habitual car-drivers will often be prepared to bear only very little costs in terms of effort, attention and money for acquiring information about transit.

8.4 The effect of received transit-information on mode choices: simulations

After having discussed several issues surrounding the acquisition of transit-information among non-habitual car-drivers, let us now look at the potential impact of such information, should it be acquired by them. That is, let us assume that the costs of information acquisition (both in terms of effort and money) are low enough to induce acquisition of transit-information among these car-drivers, and investigate the effect of the messages received on their mode-choices, driven by minimization of ER_{trans} and ER_{car}. We will use the example from Section 8.2, the settings of which in the base case are as follows : $\mu_{car} = \mu_{trans} = 50$, $\sigma_{car} = \sigma_{trans} = 10$, $u_{car}^{base} = 65$ and $u_{trans}^{base} = 55$, $u(tt) = -\beta \cdot (tt + \ln(tt))$ with $\beta_{base} = 1$, giving $ER_{car} = 2.14$ and $ER_{trans} = 12.02$. Information unreliability is set $\sigma_{trans}^{info} = 1$. It should be acknowledged that car drivers in general have a too negative perception of transit characteristics, such as transit travel times (e.g. Li, 2003; Bonsall et al., 2004). Let us assume that this is also the case for non-habitual car-drivers, and thus assume that a car-driver acquiring transit travel time information will receive a travel time estimate from the service that is lower than his initial expectations. In our mode choice example, the travelers having initial mean travel time estimates of $\mu_{car} = \mu_{trans} = 50$, we assume that he receives the following message: "transit travel time equals 38 minutes", meaning that his initial estimate for transit's travel time was 12 minutes off in favor of the car-alternative. Table 2 in the Appendix shows the actual computed values of ER_{trans} and ER_{car}, having applied Equations (7) through (9), followed by (4) and (5), as presented in Section 8.2. Note that we assume here that the individual traveler will always choose the mode that he perceives to have the lowest expected regret. Again, the perspective of updating perceptions, utilities and choices will be used to study the effect of this message on the car-driver's mode choice. We will use the same line of argument used in the previous Section to identify the roles of several determinants of the effect of information. Starting with the issue of *perception updating*, or relative information reliability, Figure 4 clearly indicates that the favorable message only causes a substantial decrease in expected regret to be derived from the transit-option when the car driver attaches enough credibility to the information source, relative to his initial knowledge.

More specifically, any perceived relative unreliability of the service higher than 0.4 (perceived relative information unreliability operationalized as $\sigma_{PT}^{info} / \sigma_{PT}$) will lead to a discounting of the received message to such an extent that the traveler will still prefer his car as travel mode, notwithstanding having received the positive message regarding transit travel time. Only a message that is perceived as being very reliable, compared to the traveler's initial knowledge, will lead to a change in mode choice. In general, it can be seen that the message's perceived capability of updating a traveler's expected regret rapidly decreases once its perceived unreliability exceeds about one third of the traveler's perception of the unreliability of his own knowledge (being $\sigma_{PT} = 10$ in our example). Again, the fact that car-drivers find their own knowledge concerning transit-characteristics fairly reliable (Bonsall et al., 2004), in combination with the perceived unreliability of travel information services in general, appears to form a formidable barrier for the impact of transit-information on modal split.

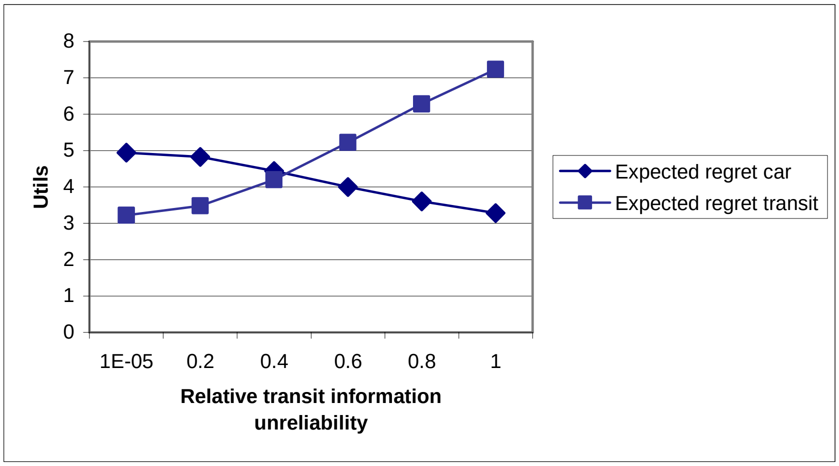

Figure 4: Influence of relative info unreliability on the impact of info on exp. regret

Let us now assume the unrealistic situation in which the information service is perceived as being approximately completely reliable, meaning that the traveler's initial transit travel time perception ($\mu_{PT} = 50$, $\sigma_{PT} = 10$) is replaced with the service's message that transit travel time equals 40 minutes. Doing so, we can investigate the issue of *utility updating*, or information relevance using Figure 5: it is immediately clear that in those cases where the importance attached to travel time (operationalized through parameter β) is less than some value, in this case appr. 0.875, the message received will not lead to a change in mode choice, due to the fact that the complete update of travel time perceptions does not lead to enough update in utility to be derived from the transit option as a whole.

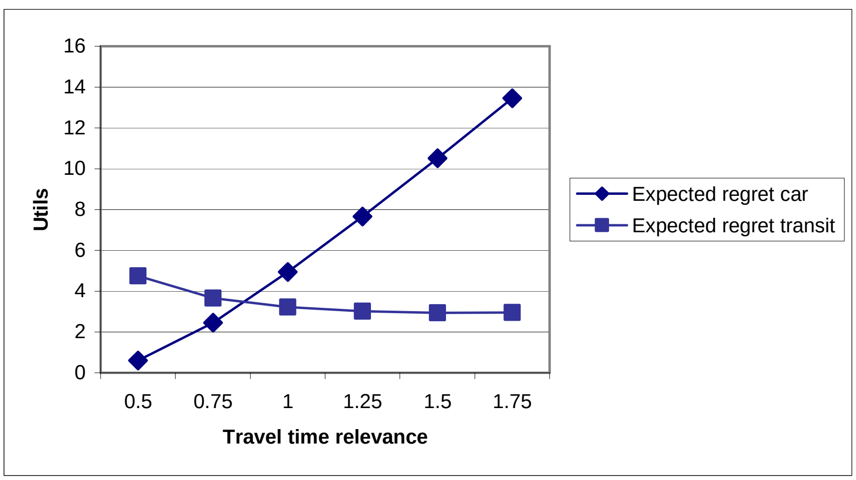

Figure 5: Influence of travel time relevance on the impact of information on exp. regret

In order to investigate the issue *of choice updating*, or the influence of base preferences, let us assume the highly unrealistic situation where the information is perceived as being completely reliable, and travel time is of paramount importance to the traveler ($\beta = 1.75$). Figure 6 indicates that in this situation, where the received message leads to a substantial positive update in the utility of the transit option, a large intrinsic base preference for the car option might still prohibit choice updating.

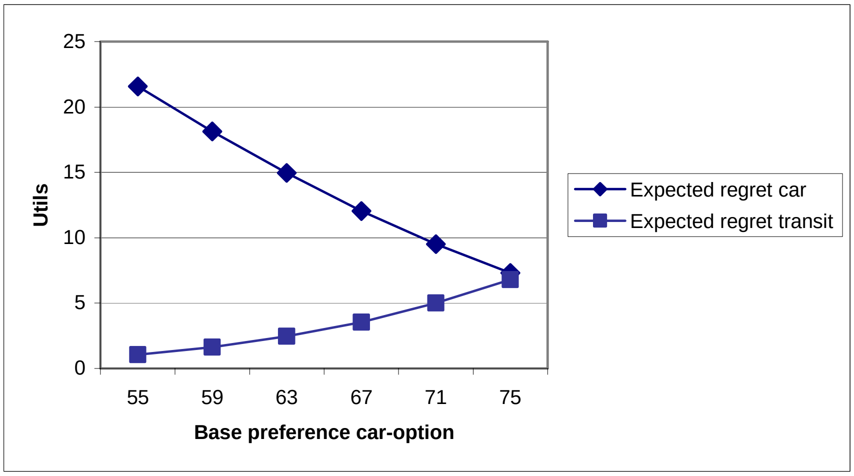

Figure 6: Influence of base preferences on the impact of information on expected regret

Summarizing the analyses of this Section it can be said that even in those situations where non-habitual car-drivers do acquire information concerning the transit-option and receive a message that favors the transit-option, the impact of this message on the traveler's mode choice will still be limited by the same issues arising in real-life mode choice situations that might prohibit information acquisition in the first place. Perceived relative unreliability of the information source prohibits full *updating of perceptions*, information irrelevance due to the existence of important other utility-drivers than travel times and costs may prohibit substantial *updating of utility* and the fact that there apparently exists a base preference for the car option may prohibit an ultimate *updating of mode choice* in favor of the transit option. Generally, the impacts of these determinants on the expected utility of the informed alternative exhibit a linear trend.

8.5 Conclusions

This paper investigated the use and effects of travel information about transit among a group of travelers that is often overlooked in the literature on mode-choices: car-drivers that do consider transit as a mode-option, but generally prefer traveling by car. Where recent research efforts have empirically investigated issues concerning the actual use and effects of travel information in mode choice contexts, this paper aimed to add to the existing insights by introducing a theoretical, regret-based model of information use and effects illustrated by examples that are based on synthetic data. The contribution of this approach to literature is that it allows one to systematically and coherently discuss the working of several complex mechanisms behind information use and effects, and that it allows for the establishment of an upper boundary in information use and effects by explicitly representing non-habitual travelers. The performed calculations show that, even among this group of car-drivers that do consider transit as a potential alternative to their car, the value of acquiring travel information concerning the transit option (in our example travel time information) may be severely affected by three distinct factors: the traveler knows that information unreliability prohibits a full updating of perceptions, information irrelevance prohibits a full updating of transit-utility and her base preference for the car-option may prohibit a change in mode choice. These trends are mostly non-linear. Furthermore it is identified that even in those situations where travel information is acquired among these car-drivers and the message is highly favorable to the transit option, then exactly the same factors as mentioned above will severely limit the impact of the received information on mode choice towards transit among the group of conscious car-drivers. Their impact on information appear to follow linear trends. Given these results, obtained for those car-drivers that do consider transit in their choice process, this study suggests that for car-drivers in general, thus including the substantial share of habitual drivers that are not at all inclined to acquire information on other modes' characteristics nor have their mode-choice changed as a result of received messages (e.g. Aarts et al., 1997; Verplanken et al., 1997; Neuherz et al., 2000; Lyons, 2001; Gärling et al., 2001, 2002; Kreitz et al., 2002; Kenyon & Lyons, 2003), conservative estimates regarding the impact of transit information on modal shift towards transit appear to be realistic. This study is thus consistent with conservative estimates (Kanninen, 1996; Kenyon & Lyons, 2003; Fujiwara et al., 2004), rather than with more optimistic views (Abdel-Aty, 1996, 2001; Ouwersloot et al., 1997, Reed et al., 1997).

Now what can be learned from these results with respect to the design of transit information services? In the first place, the minimization of costs of information acquisition seems to be a necessary condition for their use among non-transit travelers. This should be interpreted from an 'all costs' perspective: it seems that only transit-information that is provided for free, and that is very easily accessible has any chance of being often used among car-drivers. Secondly, it appears that information reliability is also of paramount importance: if very reliable transit-information appears unattainable, then its use and effect among car-drivers will be severely limited. This signals firmly the need for dynamic, rather than static, travel information on transit options. The information should furthermore also refer to aspects of comfort, convenience and perhaps environmental friendliness of the transit option, as the traveler might place importance on such attributes. Such low-cost, high-quality information might be used by a non-habitual car-driver, and when used, might have an effect on their mode choices, but only when her base preference for the car-option is limited, and attractive transit-alternatives to her private car are available. In all other cases however, it seems more efficient and effective to inform car-drivers about their car's limited attractiveness in some situations (e.g. large travel time increases due to bad weather or accidents): such information has a much higher chance of actually being acquired and used in the car-drivers mode-choice process.

Finally, it can be concluded that it appears that the proposed regret-based model of information acquisition and effects provides insightful results that are at the same time consistent with empirical literature on the topic. It complements earlier empirical findings concerning the topic as it appears to offer a structured way of discussing the use and effects of information, especially in those situations where deliberate choices are made. We would encourage further regret-based applications in travel behavior literature, as they promise to provide realistic accounts of travelers’ behavior under uncertainty. Currently, validation and estimation of the model is taking place, based on empirical data that is obtained in an interactive travel environment (Chorus et al., 2006c). This will make possible even more rigorous investigations of the determinants of travel information use and effects.

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Appendix

Table 1: Figures 1, 2, 3 ($\mu_{car} = \mu_{trans} = 50$, $\sigma_{car} = \sigma_{trans} = 10$, $u_{trans}^{base} = 55$)

*PIV **				β					
				0.5	*0.75*	*1*	*1.25*	*1.5*	*1.75*
u_{car}^{base}	*55*	σ_{trans}^{info}	*0*	-	-	-	-	-	7.69
	59	σ_{trans}^{info}	*0*	-	-	-	-	-	6.01
	63	σ_{trans}^{info}	*0*	-	-	-	-	-	4.37
	65	σ_{trans}^{info}	*0.0001*	0.08	0.40	1.10	1.91	2.77	3.70
			2	-	-	1.06	-	-	-
			4	-	-	0.93	-	-	-
			6	-	-	0.81	-	-	-
			8	-	-	0.68	-	-	-
			10	-	-	0.56	-	-	-
	67	σ_{trans}^{info}	*0*	-	-	-	-	-	3.15
	71	σ_{trans}^{info}	*0*	-	-	-	-	-	2.23
	75	σ_{trans}^{info}	*0*	-	-	-	-	-	1.43

Table 2: Figures 4, 5, 6 ($\mu_{car} = \mu_{trans} = 50$, $\sigma_{car} = \sigma_{trans} = 10$, $u^{base}_{trans} = 55$, $TT^{1}_{trans} = 40$)

ER_{car} * (upper row), ER_{trans} * (lower row)				β 0.5	0.75	1	1.25	1.5	1.75
u^{base}_{car}	55	σ^{info}_{trans}	0	-	-	-	-	-	21.57 1.06
	59	σ^{info}_{trans}	0	-	-	-	-	-	18.14 1.63
	63	σ^{info}_{trans}	0	-	-	-	-	-	14.96 2.45
	65	σ^{info}_{trans}	0	0.61 4.75	2.45 3.66	4.94 3.22	7.66 3.01	10.52 2.94	13.46 2.95
			2	-	-	4.83 3.48	-	-	-
			4	-	-	4.44 4.20	-	-	-
			6	-	-	4.00 5.22	-	-	-
			8	-	-	3.60 6.28	-	-	-
			10	-	-	3.28 7.23	-	-	-
	67	σ^{info}_{trans}	0	-	-	-	-	-	12.05 3.54
	71	σ^{info}_{trans}	0	-	-	-	-	-	9.51 5.00
	75	σ^{info}_{trans}	0	-	-	-	-	-	7.31 6.80

Chapter 9

Chorus, C.G., Arentze, T.A., Timmermans, H.J.P., 2007. Information impact on quality of multimodal travel choices: conceptualizations and empirical analyses. *Submitted for publication* [67]

Abstract

This paper investigates the impact of travel information on the quality of travel choices. It distinguishes itself from earlier studies on this topic by empirically investigating the impact of a variety of travel information types on the quality of observed multimodal travel choices. Choice quality is measured by comparing observed choices made under conditions of incomplete knowledge with predicted choice probabilities under complete knowledge. Furthermore, the potential impact of travel information is considered along multiple attribute-dimensions of alternatives, rather than in terms of travel time reductions only. Data is obtained from a choice experiment in a multimodal travel simulator in combination with a web-based mode-choice experiment. A Structural Equation Model is estimated to test a series of hypothesized direct and indirect relations between a traveler's knowledge levels, information acquisition behavior and the resulting travel-choice quality. The estimation results support the hypothesized relations, which provides evidence of validity and applicability of the developed measure of travel-choice quality. Furthermore, found relations in general provide some careful support for the often expected impact of information on the quality of travel choices. The effects are largest for information services that generate previously unknown alternatives, and lowest for services that provide warnings in case of high travel times only.

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9.1 Introduction

The interest in Advanced Traveler Information Services (ATIS) has grown rapidly over the last years, already culminating in a large body of academic literature on this topic (see for some notable contributions Ben-Akiva et al. (1991), Polak & Jones (1993), Emmerink et al. (1995), Hato et al. (1999), Denant-Boèmont & Petiot (2003) or for a review Chorus et al. (2006a)). Furthermore, a stream of policy initiatives has been built on the deployment of ATIS in transport networks (e.g. Commission of the European Communities, 2001; Ministry of Transport, Public Works and Water Management, 2002; Department for Transport, 2004). A main underlying justification for this large and growing interest, and for the huge investments needed for the development and deployment of such services, is the following line of argumentation: multimodal urban transport networks become more and more complex and unreliable, so that it becomes practically impossible for travelers to attain complete knowledge of all relevant factors influencing travel choice. This lack of knowledge predominantly exists along two dimensions (Bonsall, 2004a; Chorus et al., 2006b): firstly, travelers may not know all available and feasible travel alternatives (in terms of mode-route combinations) that may bring them to their destination (e.g. Ramming, 2002; Hoogendoorn-Lanser & van Nes, 2004). Secondly, of the alternatives they do know, they may not know their precise attributes in terms of travel times, costs and other relevant factors (e.g. Ouwersloot et al., 1997; Bonsall, 2001; Rietveld et al., 2001; Bates et al., 2001; Avineri & Prashker, 2003). In this paper, a reference to (in)complete knowledge means a reference to (a lack of) knowledge along both these two dimensions. These conditions of incomplete knowledge are assumed to lead to decreasing quality of travel choices. It is hoped for, and by many expected, that travel information provision may assist travelers in making better choices in these increasingly uncertain and complex multimodal travel networks by increasing travelers' knowledge levels (e.g. Khattak et al., 1993; Walker & Ben-Akiva, 1996; Adler & Blue, 1998; Golledge, 2002; Abdel-Aty & Abdalla, 2004; Jou et al., 2005).

One would expect that a substantial body of knowledge has been acquired over the years to test whether these expectations are correct. A first body of research, based on empirical data obtained from surveys or choice experiments, has focused on travelers' subjective perceptions of the potential of information to improve their choices. These research efforts either studied travelers' willingness to pay for information (e.g. Polydoropoulou et al., 1997; Khattak et al., 2003; Denant-Boèmont & Petiot, 2003; Molin & Chorus, 2004) or their ex-post judgments of how available information helped them make better choices (Chatterjee & McDonald, 2004; Benjamin, 2006). These approaches, notwithstanding the valuable insights they present, lack an objective measurement[68] of information impact on choice quality. This disadvantage is addressed in a second body of research, that studies the potential of information to improve travelers' choices by deriving theoretical models and illustrating these with numerical examples based on synthetic data (e.g. Mahmassani & Jayakrishnan, 1991; Arnott et al., 1991; Al-Deek et al., 1998; Levinson, 2003; Gentile et al., 2005; Szeto & Lo, 2005). This latter approach allows the objective measurement of information impact on choice quality (e.g. in terms of mean travel time reductions), but suffers from an inherent lack of external validity as

[68] With the term *objective measurement* we refer in this paper to a measurement that is based on a comparison by the analyst of choices made with, and those made without, travel information. Such measurements contrast with *subjective measurements*, where choice makers themselves are asked to state the expected or experienced impact of information on the quality of their choices.

no real life behavior is observed. Exceptions are found in Adler (2001) and Bogers et al. (2005), where the impact of information on travel times is studied empirically. All these research efforts have focused on either travel by car (predominantly) or by transit, and were predominantly concerned with travel time information only, and its effect on travelers' realized travel times. This limited scope fails to acknowledge that travelers generally make their choices in a multimodal environment where a variety of travel information types might be available to them, and that they generally base their choices on many more attributes than travel times only.

This paper presents a study that aims at i) combining the advantages of the different streams of research presented above, and at ii) providing a broader scope of research, one that better fits the full dimensionality of traveler behavior. This is done by *empirically* investigating the impact of a *variety of travel information types*, including the assessment of known alternatives and the generation of unknown alternatives, on the quality of observed *multimodal travel choices*. Furthermore, an o*bjective measurement of choice quality* is applied that is based on the following general notion: a traveler's choice for an alternative (e.g. a mode-route combination), made under incomplete knowledge, is of a high quality if the traveler, given complete knowledge, would choose the same alternative. Finally, the potential impact of travel information is considered along *multiple attribute-dimensions* of alternatives, such as travel times and travel costs of car and transit alternatives, as well as seat probabilities in transit. Data needed for empirical analysis is obtained from a choice experiment in a multimodal travel simulator with information provision, where 261 participants together made 4536 travel choices under conditions of incomplete knowledge, in combination with a web-based mode-choice experiment where the same participants made choices under conditions of complete knowledge.

The remainder of the paper is structured as follows: in Section 9.2 we briefly illustrate the proposed general notion of travel choice quality with an example. Subsequently, hypotheses are formulated that are to be tested in this study; they relate to the determinants of travel choice quality in general and the role of information acquisition in specific. Section 9.3 discusses data requirements that follow from the hypotheses to be tested and the general notion of choice quality proposed here. Subsequently, the data-collection effort is presented. Section 9.4 derives from the proposed general notion an operational measure of travel choice-quality that is compatible with the obtained data. Section 9.5 presents the empirical analysis of the impact of travel information on travel choice quality by estimating a structural Equation model that is based on the obtained choice data and the derived choice quality measure. Estimation results are discussed in depth. Finally, Section 9.6 presents conclusions and directions for further research.

9.2 Hypotheses on travel choice quality and the role of travel information

Before formulating hypotheses concerning the determinants of travel choice quality, let us briefly discuss the general notion of travel choice quality that is presented in the introduction. We conceptualize travel choice quality as the extent to which a traveler's choice is the same under conditions of incomplete knowledge and complete knowledge. The following brief example may illustrate this conceptualization: take a traveler that faces a choice under conditions of incomplete knowledge. That is, she knows of only some of the available alternatives (e.g. routes for a particular mode) and for the alternatives she knows of, she does not know their exact attributes (e.g. travel times and costs). Based on this incomplete knowledge, she chooses a mode-route combination from the set of known alternatives. Given our conceptualization, this choice has a high quality when the traveler, would she have known all available alternatives as well as the exact value of their attributes, would choose the same route. Otherwise, her lack of knowledge has resulted in a choice of relatively low quality. Note how the adopted notion accounts for a travelers' preferences: assume that the traveler of our example has a very low value of time, and is uncertain about alternatives' travel times but not about their costs. In that case travel time uncertainty will not lead to large reductions in the quality of her choices, as conceptualized here, since these choices are not strongly influenced by travel times. Therefore, the probability that she would have chosen a different mode-route combination under the hypothetical condition of travel time certainty is relatively low. Due to its generality, this notion is well suited for testing hypotheses concerning the impact of a wide variety of factors on travel choice quality, along multiple attribute dimensions. We will specifically address in this study the following hypotheses:

1. *The more alternatives a traveler knows of, the higher will be her travel choice quality*
   Not only is this an intuitive relation, it in fact is implied by the adopted general notion of choice quality, as it is presented in the introduction: the more alternatives a traveler knows of, the lower will be the probability (ceteris paribus) that one of the remaining unknown alternatives is in fact the best one available, and would be chosen under conditions of complete knowledge. A test of this hypothesis therefore foremost forms a test of the validity of the general notion of choice quality proposed here.

2. *The less uncertainty is attached to the attributes of known alternatives, the higher will be a traveler's choice quality (given that there is no structural bias in perceptions)*
   Similar to hypothesis 1, this one is also implied by the adopted notion of choice quality: the more certain the choice-maker is about the actual value of the attributes of known alternatives, the less likely she is to choose an alternative from this set that she would not have chosen under conditions of complete knowledge. A test of this hypothesis therefore also forms a test of the validity of the general notion of choice quality proposed here.

3. *The more travel information is acquired, the higher will be the travel-choice quality*
   This expected relation is the central hypothesis of the study presented here. Although this notion may appear evident to some, there is in fact little empirical evidence to support this expectation, as was argued in the introduction. It may be expected that different types of information may have different impacts on the quality of travel choices.

4. *The more complete a traveler's knowledge, the less information will be acquired*
   Much empirical work has been done on this topic (e.g. Hato et al., 1999; Yim & Khattak, 2001; Denant-Boèmont & Petiot, 2003; Targa et al., 2003; Petrella & Lappin, 2004; Peirce & Lappin, 2004; van der Horst & Ettema, 2005; Chorus et al., 2006d). Generally, these studies point out that lack of knowledge does drive information acquisition, but that subtle effects may exist in the opposite direction. An example of such a subtle mechanism is that the more alternatives a traveler knows of, the more inclined she might become to assess the attributes of these known alternatives.

5. *For business trips, travelers acquire more information and, controlled for the acquired information, make travel choices of relatively high quality.*
   The first part of this hypothesis is well established in empirical literature on travel information acquisition for arrival time sensitive trips (e.g. Emmerink et al., 1996; Polydoropulou & Ben-Akiva, 1998; Hato et al., 1999; Srinivisan et al., 1999), and makes sense intuitively. The second part is based on the notion that when the stakes are high (in this case: the penalty of late arrival is high), individuals may put more effort in their decision making process which in turn may help them make better choices (e.g. Payne et al., 1993).

6. *The more unreliable the information, the less it is acquired and when it is acquired, the less will be its positive impact on travel choice quality.*
   The importance of (perceived) information reliability as a determinant of information use is well grounded in empirical literature (Polydoropulou & Ben-Akiva, 1998; Hato et al., 1999; Fayish & Jovanis, 2004). The second part of the hypothesis is based on the notion, found in theoretical studies of travel information effect (e.g. Arentze & Timmermans, 2005; Chorus et al., 2006b), that due to unreliability of the information, travelers may only partly reduce the uncertainty of their initial perceptions.

9.3 Data-requirements and -collection

9.3.1 Derivation of data-requirements

Given the adopted conceptualization of travel choice quality and the formulated hypotheses, a range of data requirements can be derived: firstly, we need to observe travel choices made under conditions of various levels of incomplete knowledge, in terms of both small numbers of known alternatives and large levels of uncertainty with respect to their attributes. In this context of incomplete knowledge, a wide range of travel information should be available to the traveler. Furthermore, we as an analyst need to be able to observe the set of available alternatives and the true values of their attributes. The needed level of experimental control (i.e. the need to be able to control travelers' knowledge levels) in combination with the need to provide a variety of travel information options led us to the deployment of a multimodal travel simulator with information provision, see Section 9.3.3. Finally, we need to infer what choices travelers would have made if they would have had complete knowledge in the same choice situations. Given the hypothetical nature of the condition, the latter choices cannot be directly observed. Therefore, we predict them based on estimated preferences of travelers for alternatives and their attributes and assuming complete knowledge. A web-based stated mode-choice experiment under conditions of complete knowledge is held *among the same group of respondents that participated in the simulator experiment, during the same session,* to derive estimates for their preferences (Section 9.3.4).

9.3.2 Response group characteristics and outline of the experiment

Participants were recruited through placement of advertisements in a campus newspaper and a free newspaper. Also an email was sent out to ± 500 students. Criterion for participation was that participants had some experience with traveling by both car and train. A 20 euro reward was offered for participation. In total, 261 individuals were recruited this way. Table 1 presents some response group characteristics and shows a rather heterogeneous group in terms of socio-economic characteristics. However, it should be noted that the participants were not average travelers due to the above mentioned selection criterion. This should be taken into account when interpreting the results of the analysis presented further below, although it is not directly clear what potential biases our sample-selection might induce. The sessions each followed the same program. After a brief introduction, an extensive web survey was filled out concerning among other things the participant's actual travel behavior and her or her acquisition of travel information through different media. Following this web survey, a stated choice experiment was performed (see Section 9.3.4), after which the participants were given a rather extensive introduction in the travel simulator's workings (see Section 9.3.3).

Table 1: response group characteristics (N = 261)

Variable	Frequency %	Cumulative %
Gender		
female	49	49
male	51	100
Age		
< 25	45	45
< 40	27	72
< 65	27	99
> 65	1	100
Completed education		
lower education	2	2
secondary school	67	69
higher education	31	100
Main out-of-home activity		
paid work	41	41
education	45	86
other	14	100
Car availability		
always	39	39
usually	18	57
sometimes	26	83
less than sometimes	17	100
Public Transport (PT) season ticket		
some form of	62	62
none	38	100

Following this, the participants were given a rather extensive introduction in the simulator. Participants were asked very explicitly to not regard the experiment as some form of a game (e.g. by trying to travel as fast as possible, or spending as much or as little money as possible), but rather to try to identify with the travel situations presented and make choices that they would make, would they be confronted with such a situation in real life. It is known that in simulated travel situations like the ones presented in this experiment, the issue of motivation is a difficult one. See Carson et al. (2000) and Bonsall (2002) for overviews of possible incentive-caveats. In order to increase the motivation of participants to put effort in identifying themselves with the simulated travel environment, the following approach was chosen: participants were told during the introduction that they could win a 7,5 euro bonus, to be awarded to about half of the respondents, based on the success of their identification effort. It was mentioned that the correspondence of their choice-behavior as observed in the simulator experiment with the choice-behavior observed in the stated mode choice experiment and the answers to web-survey questions concerning revealed behavior would be used to measure the degree of identification. However, it was made clear to the participants that they would probably be most likely to obtain the bonus by simply making a real effort to identify with each of the travel situations presented. After this introduction, participants all made four test-rides, two with and two without the availability of travel information. Subsequently, a number of trips (maximum 25) were made in the travel simulator environment and recorded, all in the presence of information services.

9.3.3 Travel simulator experiment (observation of choices under incomplete knowledge)

Figure 1 shows a screen plot of an arbitrary travel situation a participant may be confronted with. The workings of the simulator will be discussed by going through this Figure. The screen consists of 4 parts: lower left presents the trip context, upper-left shows the transport network, upper right presents the information service and lower right shows a visual aid.

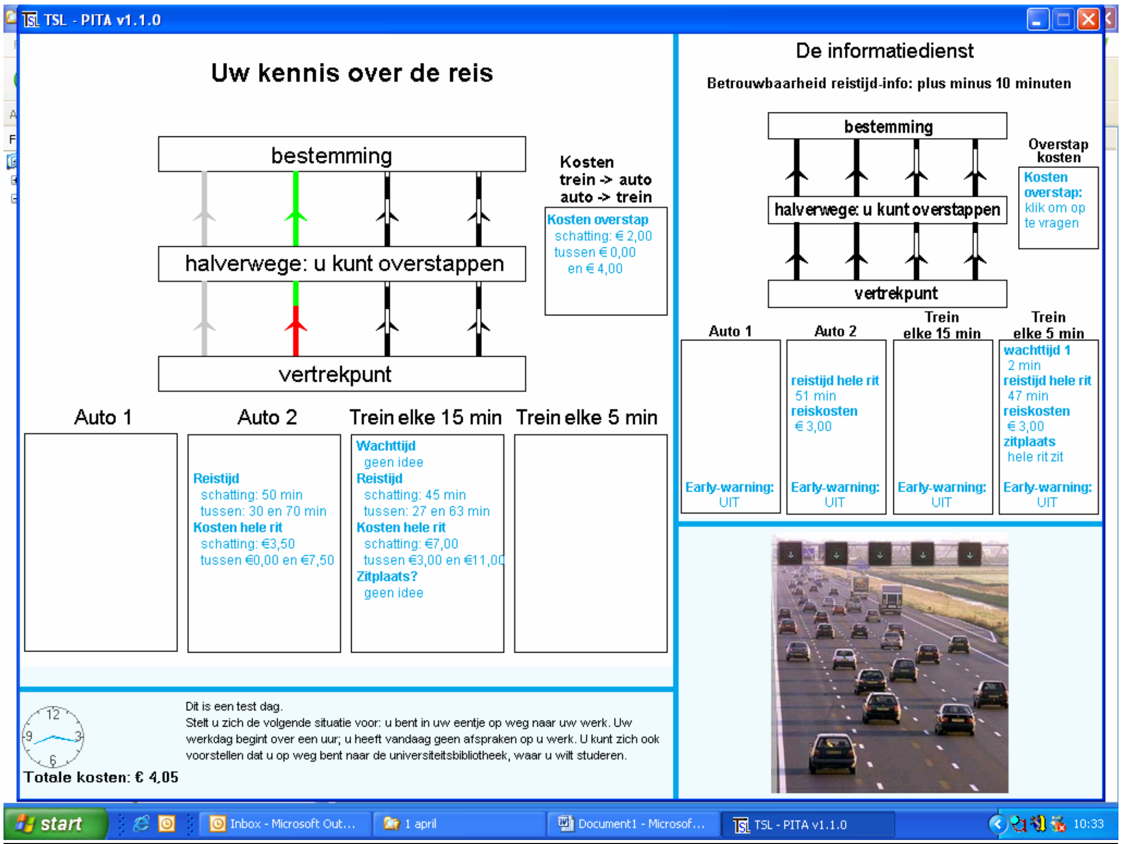

Figure 1: screen plot of the simulator *(in Dutch)*

Trip purpose

The trip purpose consists of a story line describing trip purpose and possibly preferred arrival times, generated at random for each trip from a set of predefined options. These story lines were presented at the beginning of each new trip through pop-up windows, after which they were located at the lower left of the screen during the completion of the trip. Trip purpose could be either *business*, *commute*, *social* or *leisure*. Next to the story line, the trip context displays a clock, presenting accelerated time. It ticks away one minute waiting time or in-vehicle time per actual second, after a travel alternative is executed. Finally, beneath the clock, a money counter registers the amount of money spent so far on a given trip, including both travel costs and costs of information acquisition.

The transport network

A purely fictive O-D pair was created, connected by four paths displayed as arrows and an interchange facility halfway; as our current analyses do not deal with in-trip choice adaptation, we will not discuss here the interchange possibilities. The two left arrows symbolize two car-options, i.e. highway routes. The two routes are equivalent except that they may differ in terms of travel times and costs. Next to these two car-options, two intercity train options exist which are also equivalent, except that they may also differ in travel time and cost, as well as seat availability. Furthermore, the left one of the two trains departs once every 15 minutes, the right one once every 5 minutes, thus inducing a lower expected and maximum waiting time. The number of a priori alternatives 'known' to the traveler varies per trip. 'Unknown' alternatives are marked grey instead of black, and the traveler initially has no knowledge concerning their characteristics. These alternatives are inactive, and cannot be executed by the traveler. For the trip displayed in Figure 1, one car-option and the 15 minute train option are known a priori. The other train alternative is activated by the information service (see further below).

The participant's initial knowledge of the alternatives (i.e., before acquiring any information) is presented in the boxes below the black arrows. The following a priori knowledge is provided to the traveler for the known alternatives: for both car and train options, i) *best guesses* for travel times and travel costs[69] are provided, as well as ii) '*confidence' intervals*, i.e. ranges of times and costs within which the participants are told (correctly) that actual values will fall almost certainly. A priori, train travelers do not know the exact departure times (although they do know the service's frequency), neither do they know whether or not a seat is available for them. Let us focus first on the situation where a traveler decides not to acquire information, but to directly embark on a trip by executing one of the known travel alternatives: a participant may start his journey by clicking one of the arrows, and subsequently confirming his choice in the appearing pop-up window. By confirming his or her choice, there is no possibility of adaptation until the interchange point is reached. Directly after confirmation, the traveler is confronted with the actual costs of the alternative, and train travelers were also informed whether or not they had a seat. As the trip commences (Figure 1 shows the situation where a car option is chosen), the clock starts ticking and the arrow that represents the chosen alternative incrementally turns red, indicating the amount of distance traveled so far. These actual travel costs were drawn from a normal distribution, having the best guess as mean, and a quarter of the length of the 'confidence' interval as standard deviation, so that 95% of the drawn actual values would indeed fall within the 'confidence' interval. The same applies to the generation of actual travel times. Seat availability was randomly drawn from a discrete distribution (50% chance of having a seat), waiting times from a uniform distribution between 0 and the headway (either 5 or 15 minutes).

The information service

Let us focus now on the information acquisition options: as can be seen in Figure 1, the information service's layout is an exact copy of the transport network. In the sample used for our current analyses all provided information was fully reliable, meaning that every received message corresponds to the actual value of that particular attribute. Participants were told about this complete reliability. The service presents three ways of acquiring information: firstly, a traveler may acquire information concerning one or more particular attributes of a known alternative, be it travel times and/or costs for a car or train option, and/or waiting times and seat availability for train options. This is done by first clicking on the arrow of a 'known' alternative and subsequently checking the boxes for those attributes for which information is needed (the information price is listed at every box, and varies between .15, .30, .45

[69] Travel times were framed as door to door for car-trips, and door-to-door minus waiting times for train-trips. All 'best guess' travel times were randomly varied beforehand and could take the values of 50 and 60 minutes for the car-option and 45 and 55 minutes for the train option (since to the latter also waiting times had to be added to get the total travel time). Travel costs were framed as fuel expenditures + parking costs for car-trips, and ticket tariffs for train-trips. Travel costs were randomly assigned beforehand the values of 3.5 euro or either 7 euro.

eurocents). After the boxes are checked, the service displays the information in the information box. Figure 1 presents the situation where for one of the car-options, both travel time and costs are informed about by the information service. Secondly, a traveler can ask the service to generate or activate one or more alternatives that are currently 'unknown' to him or her. This is done by clicking on an arrow within the information service screen that corresponds to an unknown alternative in the transport network. After this is done, a pop-up window appears that states the price of the information acquisition (being varied between .45, .60 and .75 eurocents) and asks for a confirmation. After confirmation, the alternative is made active, that is, its color turns black in the transport network, and the alternative can be executed from now on. Furthermore, the information service provides estimates for all the alternative's characteristics. These estimates are displayed in the box below the activated alternative in the information service screen part. Figure 1 presents such an information acquisition for the 5 minute train option. Thirdly, a traveler may activate the so-called early-warning function. This function notifies a traveler when an alternative that is about to be chosen has an actual travel time that is substantially larger than the traveler's best guess (no strict level of travel time differences that triggers these messages is mentioned to the travelers). This type of information is acquired by clicking on a known alternative and checking the early warning box. Note that all these types of information can be acquired either pre-trip, as well during the trip or at the interchange point, which makes the information service 'mobile'. However, we focus on pre-trip information acquisition here. Note furthermore that the choice set size of information options depends on the choice set size of travel options: when a travel alternative is unknown, it can not be assessed in terms of its attributes; when it is known, it cannot be generated by the information service. Since there are more assessment options per known alternative than there are generation options per unknown alternative, the size of the information choice set is positively correlated with the size of the travel choice set. The early warning function is always available, irrespective the number of available travel alternatives in the traveler's travel choice set.

The visual aid

In the lower right, pictures are placed that help the traveler identify with the situation at hand: several pictures were available to describe a number of possible pre- and in-trip situations for car (e.g. with and without congestion) as well as train (e.g. waiting at the station, being underway).

Observed choices

In total 4536 recorded trips were made in the simulator in the presence of travel information. Of these trips, 2454 were executed by car (54%); the rest of times, train was chosen as a travel mode. In total, 5298 unknown alternatives were generated (on average 1.17 times per trip). Travel time information was acquired 2653 times (0.58), travel costs 1023 times (0.23). Train departure time information was requested about 849 times (0.19), seat availability 303 times (0.07). The early warning function was activated for 1252 trips (0.28).

9.3.4 Stated mode-choice experiment (observation of choices under complete knowledge)

This experiment consisted of a series of binary car-train mode-choices. Also here, trip purposes (the same ones as used in the simulator) were randomly assigned to trips. Car-alternatives were specified in terms of their travel times and costs, train alternatives additionally in terms of their waiting times and seat availability. Attribute values were varied systematically across alternatives. In order to avoid fatigue effects, a fractional factorial experimental design was applied that resulted in 16 binary choice tasks per individual. Attribute values were presented to participants as being certain. In total, 261 * 16 = 4176 stated mode-choices were observed, of which 2366 were choices for car (57%), the remainder being train-choices. These observed choices were used to derive travelers' alternative-specific preferences as well as their valuation of travel and waiting times, costs and seat availability in trains.

9.4 A measure of travel choice quality

This Section derives a measure of travel choice quality that, although it may be applied in a number of other settings, is geared for compatibility with our general notion of travel choice quality, the formulated hypotheses and the obtained dataset. Subsequently, the measure is applied to compute choice quality for the observed travel choices made under conditions of incomplete knowledge in the travel simulator environment.

9.4.1 Derivation of a measure of travel choice quality

Assume a traveler i facing a set of available alternatives S^{avail}, containing J alternatives Y_j (say, mode-route combinations). Each of these alternatives consists of a bundle of relevant observed attributes. Assume for simplicity of presentation and without loss of generality that these attributes are invariable across travelers: $Y_j = \{x_{j1}, x_{j2}, ...\}$. Assume furthermore that the traveler has incomplete knowledge as she is only aware of a subset of alternatives ($S_i^{known} \subset S^{avail}$), and does not know the exact true values $\{\overline{x}_{j1}, \overline{x}_{j2}, ...\}$ of the bundle of relevant attributes $\{x_{j1}, x_{j2}, ...\}$. Rather, she perceives the bundle as a joint probability distribution $f_i(x_{j1}, x_{j2}, ...)$. Note that many other conceptualizations of the traveler's uncertain perception of these attributes would fit the argument being made here. We observe that a traveler, faced with this incomplete knowledge, chooses an alternative, say $Y_i^{chosen} = Y_m$, from S_i^{known}. To infer what alternative would have been chosen under hypothetical conditions of complete knowledge, take the same traveler, but assume now that she does know all available alternatives (i.e. $S_i^{known} = S^{avail}$), as well as the exact values of their relevant attributes (i.e. $f_i(x_{j1}, x_{j2}, ...) = 1$ for $\{x_{j1}, x_{j2}, ...\} = \{\overline{x}_{j1}, \overline{x}_{j2}, ...\}$, 0 otherwise). We assume that her choice under complete knowledge will be based on a compensatory utility structure, using her valuations $\beta_{ij0}, \beta_{ij1}, \beta_{ij2}, ...$ of the true values $\{\overline{x}_{j1}, \overline{x}_{j2}, ...\}$ of the attributes of available alternatives:

$$V_i\left(Y_j \in S^{avail}\right) = \beta_{ij0} + \beta_{ij1}\overline{x}_{j1} + \beta_{ij2}\overline{x}_{j2} + ... \quad (1)$$

Although it will often be practically infeasible to infer the exact values $\beta_{ij0}, \beta_{ij1}, \beta_{ij2}, ...$ of travelers' preferences for alternatives and their attributes in the hypothetical situation of choice under complete knowledge, we may estimate proxies $\hat{\beta}_{ij0}, \hat{\beta}_{ij1}, \hat{\beta}_{ij2}, ...$ for these preferences from other observed travel choices, made by the same travelers.[70] Let us assume

[70] Note that the availability of individual-level parameters is not critical for the argument made here, nor for the development of the measure of travel-choice quality that is proposed below. Obviously, parameters estimated at

that this estimation process is performed within a random-utility framework, and that the variances of the i.i.d.-extreme value random utility components ε_{ij} equal $\pi^2/6$, i.e. that the scale of the utility is normalized to 1. Under the requirement that i) the choices used for preference-elicitation are observed in a choice-context that closely resembles the context within which the quality of travel-choices is evaluated, and ii) that both the observations made for parameter estimation, and the evaluation of travel-choice quality are made at very nearby moments in time, we assume that the scale of estimated proxies $\widehat{\beta}_{ij0}, \widehat{\beta}_{ij1}, \widehat{\beta}_{ij2},...$ equals the scale of true preferences $\beta_{ij0}, \beta_{ij1}, \beta_{ij2},...$ so that the deterministic utility of Equation (1) can be rewritten into its random utility counterpart (2), where $\text{var}(\varepsilon_{ij}) = \pi^2/6$:

$$U_i\left(Y_j \in S^{avail}\right) = \widehat{\beta}_{ij0} + \widehat{\beta}_{ij1}\overline{x}_{j1} + \widehat{\beta}_{ij2}\overline{x}_{j2} + ... + \varepsilon_{ij} \tag{2}$$

This random-utility specification thus reflects the observational deficiencies of the analyst in terms of observing and predicting utilities of travel alternatives. Given this representation of a traveler's preferences (up to a random error), the analyst can predict choice probabilities for alternatives under conditions of complete knowledge by specifying the functional relationship between utility and choice, in this case resulting in a straightforward MNL-model. These choice probabilities represent the probability in the eyes of the analyst that the traveler, would she have complete knowledge, chooses an alternative, and is denoted $P\left(Y_j \middle| S^{avail}; \{\overline{x}_{k1}, \overline{x}_{k2},...\} \forall k \in S^{avail}\right)$. The assessment of travel-choice quality, in terms of whether the observed chosen alternative under incomplete knowledge corresponds to the predicted choice probabilities under complete knowledge, now takes the form of the following likelihood function:

$$L_i = \prod_{S_i^{known}} \left[P\left(Y_j \middle| S^{avail}; \{\overline{x}_{k1}, \overline{x}_{k2},...\} \forall k \in S^{avail}\right)^{y_j \left| S_i^{known}; f_i(x_{k1}, x_{k2},...) \forall k \in S_i^{known} \right.} \right] \tag{3}$$

Where $y_j \left| S_i^{known}; f_i(x_{k1}, x_{k2},...) \forall k \in S_i^{known} \right. = 1$ if alternative j is chosen under conditions of incomplete knowledge, and 0 otherwise. L takes on values anywhere between 0 (poorest quality – the probability that the traveler would have chosen his current alternative had (s)he had complete knowledge is zero) and 1 (highest quality – the probability that the traveler would have chosen *another* alternative had (s)he had complete knowledge is zero). This range implies that our measure of travel choice quality is standardized with respect to a base-case and an upper bound.

It is important to note here, that the measure presented in Equation (3) not only captures travelers' capability - under conditions of incomplete knowledge - to choose an alternative they would also choose had they had complete knowledge, but also the analyst's ability to approximate travelers' true preferences. This point can be clarified supposing that the analyst that has not been able at all to capture travelers' true preferences, i.e. signs and magnitudes of

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the individual level $\widehat{\beta}_{ij0}, \widehat{\beta}_{ij1}, \widehat{\beta}_{ij2},...$ may provide a more reliable inference of an individual traveler's choice under hypothetical conditions of complete knowledge than group-level parameters $\widehat{\beta}_{j0}, \widehat{\beta}_{j1}, \widehat{\beta}_{j2},...$, as the latter do not account for preference heterogeneity in the sample. However, substantial parts of this heterogeneity may be accounted for indirectly by having a number of socio-economic characteristics enter the utility functions.

estimated parameters are completely off mark. As a result, the predicted choice probabilities are not representative of the choices of travelers under the hypothetical conditions of complete knowledge. Based on these erroneous predictions, low values of L are likely to be found; these low values do not signal a low choice-quality from the side of the traveler, but rather inability from the side of the analyst. The same reasoning holds for the situation where the analyst does not find significant parameters in the first place, leading to insensitivity of predicted choice probabilities to changes in attribute values. The measure proposed in Equation (3) therefore only has meaning within the context of the adopted theoretical framework, assuming that it provides a valid representation of actual choice processes. This is however not unique to the present measure: for example welfare-based accessibility measures also only have meaning within the context of the estimated model.

Furthermore, note that for analyses that do not focus on choice quality in an absolute sense, but rather in a *relative* one (such as analyses concerning the impact of information on choice quality), the measure presented in Equation (3) does not require that the analyst knows all alternatives S^{avail}: a minimum requirement for the application of the measure is then that the analyst knows one more available alternative, besides the one chosen by the traveler. A fictive choice set $\breve{S}^{avail}$ can then be constructed that contains the chosen alternative as well as the non-chosen but available alternative, and may be denoted $\breve{S}^{avail} \subset S^{avail}$. Equation (3) then gives a travel-choice quality measure based on the predicted probability that the chosen alternative would also be the chosen one in the constructed subset $\breve{S}^{avail}$. Finally, note that it is not necessary to assume that the analyst knows the true values $\{\bar{x}_{j1}, \bar{x}_{j2}, ...\}$ of all relevant attributes in $\breve{S}^{avail}$ or S^{avail}. Rather, the analyst should know the true values of those attributes that she wishes to enter the analyses. Of course, the inclusion of only a very limited number of attributes in the analysis might lead to a less reliable measure of travel-choice quality.

9.4.2 Applying the measure of travel choice quality on the obtained dataset

Recall that (to avoid fatigue effects) it was decided to have participants make a number of 16 binary mode-choices under conditions of complete knowledge. As estimation of meaningful individual-level parameters $\hat{\beta}_{ij0}, \hat{\beta}_{ij1}, \hat{\beta}_{ij2}, ...$ is not possible based on these 16 observations per individual, group level parameters $\hat{\beta}_{j0}, \hat{\beta}_{j1}, \hat{\beta}_{j2}, ...$ were estimated and a number of socioeconomic characteristics were entered in the utility-specification in order to capture a substantial share of preference-heterogeneity in the sample. Table 2 presents the estimation results, obtained by estimating a binary logit model using the BIOGEME statistical package[71].

Note that the scale-parameter is normalized to 1, i.e. $\text{var}(\varepsilon_{ij})$ is set to $\pi^2/6$. We will only briefly touch upon these results, as this study is not concerned with mode-choices. All parameters are of the expected sign, and significant. The car-constant implies that the average traveler in our sample prefers traveling by car over traveling by transit, all else being equal. The implied value of travel time is 10.89 euro per hour car travel time, and 7.95 euro per hour

[71] Note that, although multiple choices were observed per individual, we did not directly apply this panel structure in estimation. Acknowledging the panel structure through random agent effects and subsequent incorporation of these agent effects in our subsequent Structural Equation Model of the determinants of travel choice quality would greatly increase that model's complexity. For the present study, we have, for reasons of simplicity of presentation and for reasons of space limitations, chosen to indirectly acknowledge the panel structure by using robust t-statistics. Also, we have incorporated a number of sociodemographics in our models in order to increase our grasp of variation due to observed, rather than unobserved factors.

transit travel time (which itself is a sum of waiting time and in-vehicle time). For business trips, these values are 19.37 and 16.43 respectively. Seat availability in transit is positively valued, as expected. Concerning socio-economic characteristics, it appears that older travelers are more inclined to choose transit than younger ones, and have higher values of time as they value travel costs less negative than younger ones. Higher education (coded from 1 to 5 for increasing levels in the Dutch education system) leads to more transit use.

Table 2: estimation results (travel choices under complete knowledge)

Variable	**Parameter**	**t-Statistic (robust)**
Attributes of travel alternatives		
Car constant	2.139	5.257
Travel time car (minutes)	-0.063	-15.088
Travel time train (minutes)	-0.046	-12.130
Travel costs (euros)	-0.347	-13.063
Travel time * Business	-0.049	-5.464
Seat availability (on train)	0.862	9.667
Socioeconomic variables		
Age dummy (on car)	-0.027	-7.461
Age dummy (to be added to travel costs parameter)	0.002	3.243
Number of days car use in real life (on car)	0.156	6.998
Number of days transit use in real life (on car)	-0.062	-2.666
Education (on car)	-0.126	-2.978
Dummy for “car is most important mode for me” (on car)	0.524	4.006
Car license (on car)	0.417	2.433
Model statistics		
0-Log-Likelihood	-2894.58	
Log-likelihood at convergence	-1716.46	
Adjusted rho-square (13 parameters)	0.403	
Number of cases	4536	

In order to obtain optimal congruence between on the one hand the contexts of the choices observed in the simulator (incomplete knowledge) and on the other hand the binary choices observed in the stated mode-choice experiment (complete knowledge), as was advocated in Section 9.4.1, it was decided to construct per observed choice in the simulator an artificial choice set $\breve{S}^{avail}$. This set contains the chosen alternative from S_i^{known}, as well as a randomly drawn alternative route *from a different mode*. That way, i.e. by making sure that the constructed set as well as the stated mode-choice set contain both one car and one rail alternative, we can apply the parameters estimated in a binary mode-choice context in order to predict choice probabilities in a similar binary mode-choice context, as much as possible avoiding potential incompatibilities with the scale of the utilities and the correlation structure of error components (IIA assumption). Together, this enables us to calculate the quality of each of the 4536 travel choices made in the simulator, as defined in Equation (3) (note that we applied scale-factor 1 for the prediction of choice-probabilities, in congruence with the scale factor used in the estimation process of $\hat{\beta}_{ij0}, \hat{\beta}_{ij1}, \hat{\beta}_{ij2},...$), and proceed with our analyses concerning the determinants of choice quality. Note that from an *absolute* point of view, this artificial choice set composision presents a bias in the measurement of choice quality. However, as elaborated on above, since we are here interested in choice quality in a *relative* sense, this bias does not affect our ability to study the *relations* between information use and quality of travel choices in an unbiased way.

9.5 Empirical analysis of the impact of travel information on travel choice quality

As can be seen in Section 9.2, we hypothesize that the effects of a range of factors on travel choice quality may consist of direct and indirect effects. Take for example the factor ‘uncertainty’: it is hypothesized that the direct effect of this factor on choice quality is negative (relation 2). However, as we also hypothesize that travelers with limited knowledge will be relatively inclined to acquire information (relation 4) and that information acquisition leads to better choices (relation 3), we also hypothesize a positive indirect effect to exist (relation 3 + 4). A confirmatory modeling technique that is well suited to deal with such a combination of direct and indirect effects is *Structural Equation Modeling* (SEM). As this linear-in-parameters multivariate statistical modeling technique is fairly well known in transportation academia, and excellent in-depth treatments of the technique exist (e.g. Golob, 2003), we will not discuss it in any details here. Table 3 presents the actual variables that enter our model.

The result of the model estimation, using the LisRel package, is presented in Figure 3. For simplicity of presentation, the error terms for the independent variables as well as the correlations between variables are suppressed in this Figure. Estimated effects are mentioned, followed by their t-values. Effects with t-values of less than 1.96 (a two-tailed significance level of 0.05) are given dotted lines. The model's χ^2 totaled 4.61, for 3 degrees of freedom, signaling a reasonable model fit ($p = 0.203$). Furthermore, most hypothesized relations appear significant and as will be discussed below, are of the expected sign. Note however, that only 4% of the variation in travel choice quality has been explained by variation in the independent variables, which is a rather low percentage. There are two reasons why this limited explanatory power of the model is not surprising: firstly, as elaborated on in Section 9.4.1, it should be acknowledged that a substantial part of the variation in the applied likelihood measure might stem from the fact that proxies for the travelers’ true preferences were used in predicting choice probabilities under the hypothetical conditions of complete knowledge, as true preferences could by definition not be derived under these hypothetical circumstances. Therefore, the analyst is by definition unable to determine exactly what alternative would have been chosen under conditions of complete knowledge, due to variation in the random error component in the utility function. This imperfect ability of the analyst results in an inherent measurement error with respect to the measurement of travel choice quality. This measurement results in additional variation in measured travel choice quality that cannot be explained by the reported hypothesized relations. Secondly, we only considered a limited number of explanatory variables, as our study is *confirmatory* in nature (how valid is the proposed measure of choice quality? And: does information acquisition lead to better travel choices?), rather than *explanatory* (what are the determinants of travel choice quality?): we are interested in investigating whether hypothesized relations appear significant in our model, rather than trying to identify all factors that may codetermine choice quality.

Table 3: List of variables entering the Structural Equation Model

Knowledge at the outset of the trip	# Known Alternatives	The number of alternatives that is known at the outset of the trip, i.e. the number of alternatives in S_i^{known}
	Uncertainty	The level of uncertainty at the outset of the trip with respect to travel times and costs (taking the values 1 (low), 2 (medium) and 3 (high uncertainty))
Information Unreliability	Information Unreliability	The standard deviation of travel time information (taking the values 0 (fully reliable), 5 and 10)
Trip purpose	Business	Dummy variable: 1 IF the trip's purpose is business
Socioeconomic	Education[72]	Education level of participant, ranging from 1 (primary school only) to 5 (university degree)
Experimental	Trip Nr[73]	Dummy variable: 1 IF trip umber is between 8 and 15
Information Acquisition[74]	Early Warning	Dummy variable: 1 IF the early warning function was activated for this trip, 0 otherwise
	Assessment	The total number of attributes that information is acquired about
	Generation	The number of alternatives generated
Travel Choice Quality	Quality (Eq. 3)	$L = \prod_{S_i^{known}} \left[P\left(Y_j \middle\| S^{avail}; \{\bar{x}_{k1}, \bar{x}_{k2}, \ldots\} \forall k \in S^{avail}\right)^{y_j} \middle\| S_i^{known}; f_i(x_{k1}, x_{k2}, \ldots) \forall k \in S_i^{known} \right]$

Turning to the hypotheses, formulated in Section 9.2, the results of the SEM analysis indicate the following. First, the estimation results support hypotheses 1 and 2: the choice quality increases with the number of known alternatives and decreases with the uncertainty attached to the attributes of these alternatives (t-value 2.34 and -4.08 respectively). These effects were theoretically expected given the adopted general notion of choice quality and the fact that they appear to hold empirically provides evidence for the validity of the adopted general notion of choice quality and the measure of choice quality derived from it. We will proceed with testing the hypotheses that describe our intuition concerning the role of travel information in decision making processes and its effect on choice quality. Starting with relation 3, which is central to the study presented in this paper: the more information is acquired, the higher will be travel-choice quality. It appears that for all three information types, the sign of the effect of information acquisition on travel choice is positive.

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[72] It might be expected that education level influences the quality of observed travel choices.

[73] Based on preliminary data-analyses, it was found that there exists a relation between the trip number and the choice quality, that appeared to persist, also when a number of other potential factors were controlled for. More specifically, it was found that the first couple of trips (up to about trip number 8), as well the last couple of trips (up from about trip number 16) had a lower average quality than the trips made in between. This may indicate that participants needed some time in order to understand the experiment, and suffered from fatigue effects after some number of trips. It was therefore decided to include trip number as an independent variable, in order to control for this potentially significant effect.

[74] Note that information costs did not enter the SEM. This variable has been removed from the model after it became clear that its correlation with information acquisition (as operationalized in this study) was mostly insignificant. In other studies (e.g. Chorus et al., 2006e) we distinguished between each of the 40 information acquisition options and treated these separately in estimation, this correlation did appear significant. However, for the present study, such a disaggregation appeared unfeasible due to the large number of additional variables involved.

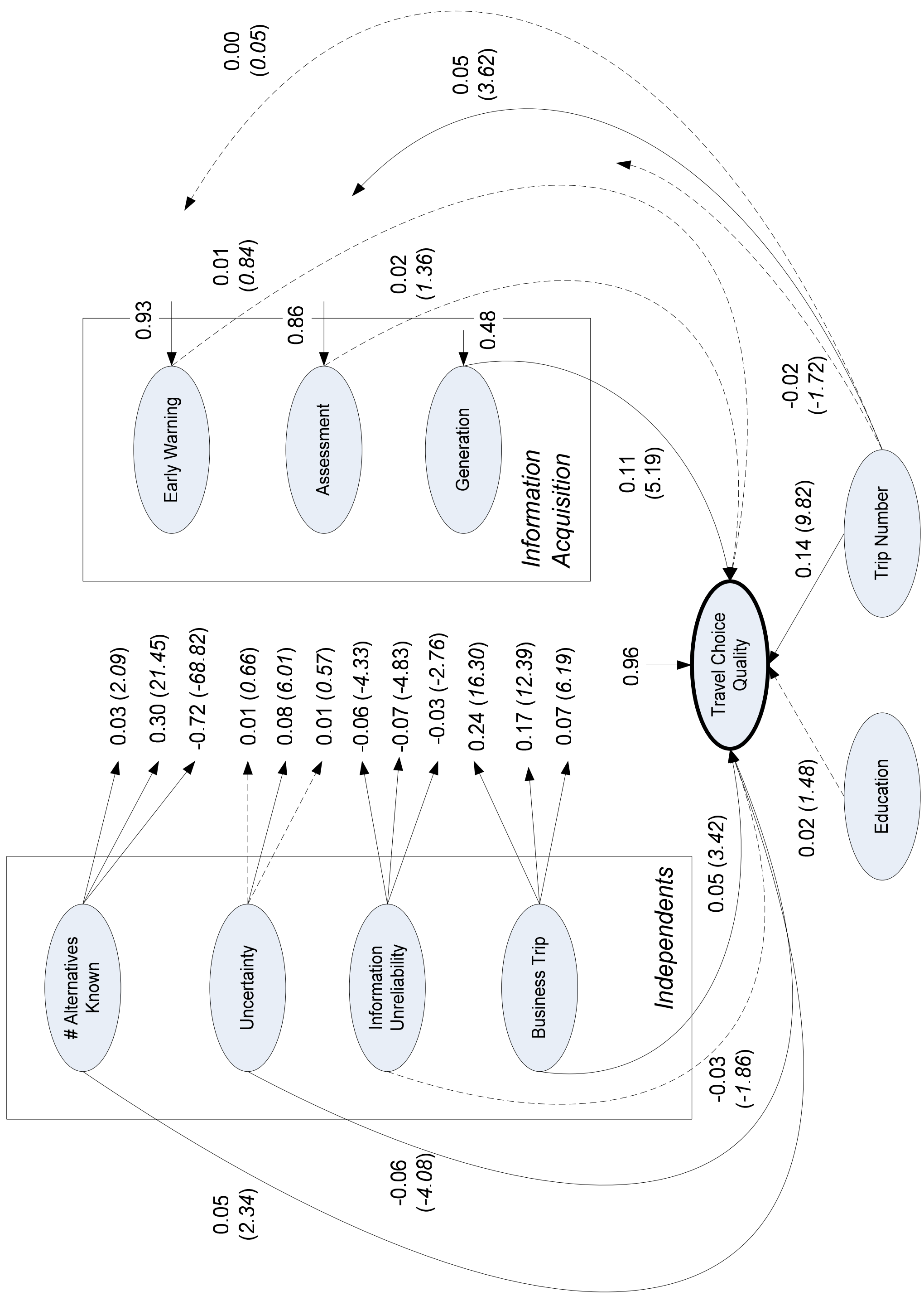

Figure 2: A *SEM* of the impact of information on travel-choice quality

However, concerning the early warning function, the effect is insignificant at any reasonable level (t-value equals 0.84). A closer look at the working of this function explains the absence of a significant effect: the early warning function provides a warning in case travelers are about to embark on a trip on a route that has a substantially higher than expected travel time. Although this type of information may be helpful to travelers as it reduces the costs of thinking (Shugan, 1980) and fits well within so-called satisficing decision-making strategies, the information content of the service is actually quite low. It says nothing about other than travel time-related attributes, and provides no actual messages of predicted travel time, just a warning. In this light, the insignificant effect on choice quality is not so surprising. With respect to the assessment of known alternatives, the effect is only significant at a one-tailed level of 0.10 (t-value equals 1.36), and not quite substantial. Apparently, by investigating the attributes of known alternatives alone, a traveler still remains quite prone to choosing an alternative that may not be optimal given the full set of available alternatives. However, the assessment type of information acquisition may help the traveler in increasing her travel-choice quality somewhat. The effect of generating previously unknown alternatives through the information services does have a highly significant and relatively large effect on choice-quality (t-value equals 5.19). This signals the high information content of this information type: not only is an alternative added to one’s choice set, estimates are provided for its attributes, too. That way, it increases the set of known alternatives and reduces the average level of uncertainty in this set. It is this double impact that apparently leads to an increase in travel-choice quality. Concerning the hypothesized negative relation (nr 4) between knowledge and information acquisition, the following is found: the more alternatives a traveler knows of, the less inclined she will be to have an information service generate additional alternatives, as would be expected (t-value equals -68.82). It can also be seen that an increase in the number of known alternatives leads to an increase in information acquisition concerning the attributes of these alternatives (t-value 21.45) and an increase in the activation of the early warning function (t-value 2.09). This effect makes sense too, as explained in Section 9.2: knowing more alternatives, with uncertainty attached to their attributes, means that there is more uncertainty to be reduced within the set of known alternatives. Finally, increasing levels of uncertainty per known alternative do lead, as hypothesized and found in literature, to more information acquisition concerning these attributes (t-value 6.01). Moving to hypothesized relation 5, concerning business trips, it is found that, as was expected and often suggested in the literature, travelers are more inclined to acquire information on these arrival time sensitive trips (t-values 13.30, 12.39 and 6.19 for early warning, assessment and alternative generation respectively). It appears that especially the early warning function is an attractive option there, as it prevents arriving late, without forcing the traveler to embark on a time-consuming decision-making process for fast and reliable mode-route combinations. Moreover, it appears that when controlling for this increase in information acquisition, the quality of travel choices made for business trips is still higher than that of trips made for other purposes (t-value 3.42). This signals that individuals will put more effort in making a ‘good choice’ when the stakes are high. Indeed, we find that by giving the extra effort, they succeed in making better choices. Relation 6 states that information unreliability has a double negative effect on choice quality, which appears to hold in our sample: firstly, it induces lower levels of information search (t-values equal -4.33, -4.83, -2.76 respectively for activating the early warning function, assessing known alternatives and generating unknown ones). Secondly, information that is acquired has, to the extent that it is unreliable, a lower potential to reduce uncertainty and increase choice-quality (t-value equals -1.86). These results signal the paramount importance of the reliability of information services. A slight positive effect of education level on choice quality is found, though the effect is not significant at high levels (t-value 1.48). Finally, it appears that as was expected, participants made relatively poor choices in the beginning and the end of the experiment (t-value for trips made halfway the experiment equals 9.82). Although we controlled for this factor in model estimation, it might have been wise to limit the duration of the experiment to less than the two and a half hours we took.

9.6 Conclusions and discussion

This paper investigated the impact of travel information on the quality of travel choices. It distinguishes itself from earlier studies on this topic by empirically investigating the impact of a variety of travel information types, including the assessment of known alternatives and the generation of unknown alternatives, on the quality of observed multimodal travel choices, using objective rather than subjective measurements. Furthermore, the potential impact of travel information is considered along multiple attribute-dimensions of alternatives, such as travel times and travel costs of car and transit alternatives, as well as waiting times and seat probabilities in transit. Data needed for empirical analysis is obtained from a choice experiment under conditions of incomplete knowledge and information provision in a multimodal travel simulator, in combination with a web-based mode-choice experiment under conditions of complete knowledge. A Structural Equation Model is estimated that is based on computed values of travel choice quality for each of the 4536 trips that were made under conditions of incomplete knowledge. Estimation results show that theoretical expectations with respect to the workings of the adopted general notion of travel choice quality appear to uphold empirically, providing support for the validity to this general notion and the proposed measure derived from it. Simultaneously with this validation, a number of other hypothesized relations was tested, referring to the role of travel information acquisition in travelers' decision-making processes and its influence on travel choice quality. It is found that the more alternatives a traveler knows, the less she will be inclined to have an information service generate additional alternatives, as would be expected. However, an increase in the number of known alternatives leads to an increase in information acquisition concerning the attributes of these alternatives and an increase in the activation of the early warning function. Increasing levels of uncertainty per known alternative lead, as hypothesized, to more information acquisition. Concerning the effect of acquired information on choice-quality, it is found that the early warning function has a too low level of information content to substantially increase choice-quality. By investigating the attributes of known alternatives alone, a traveler also remains quite prone to choosing an alternative that may not be optimal given the full set of available alternatives. The effect of generating previously unknown alternatives through the information services does have a highly significant and relatively large effect on choice-quality. Furthermore, it appears that on business trips, also when controlling for the increase in information acquisition for these trips, travel choice-quality is higher than on trips made for other purposes, signaling that individuals put more effort in making a 'good choice' when the stakes are high. Information unreliability appears to have a double negative effect on choice quality: it induces lower levels of information search, and information that is acquired has a lower potential to reduce uncertainty and increase choice-quality. The fact that all found relations in the SEM-analysis are either intuitive or well interpretable indicates that the potential issue of confounding between choice quality and the analyst's capability to derive reliable preferences of travelers (see Section 9.4.1) did not play a too substantial role given the present dataset. Given these results, this study provides an indication that claims of a positive impact of travel information on travel-choice quality are, at least, to some extent justified. The size of the impact, however, differs between types of information. A relatively large effect is generated by information services that provide travelers with previously unknown alternatives simultaneously with the provision of estimates of their attributes. Furthermore, as found effects are well explainable and mostly significant, the study provides evidence of the applicability of the proposed measure as a means to study the impact of travel information on travel choice quality. However, it is important to note here again that the sample used for analysis is not a random one: we invited individuals having experience with both travel by transit and private car. The above stated conclusions should therefore be interpreted with caution, and must certainly not be generalized directly towards the full population of travelers. In particular, our findings should not be interpreted to suggest that providing captive car-drivers or transit users with information on other modes would enhance the quality of their choices. Further study efforts, preferably based on revealed travel choice data from actual travel situations involving random samples of travelers, are needed to replicate the findings presented here and test their validity.

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Chapter 10: Conclusions & Reflection

10.1 Introduction

This Chapter draws conclusions from, and reflects on, the research presented in Chapters two to nine of this thesis. Section 10.2 will commence by providing a brief overview of the work presented in this thesis. Section 10.3 relates to the first, and main, research question addressed in this thesis: "*What are the behavioral determinants of the response to travel information among travelers that face incomplete knowledge in multimodal networks, and how can we coherently describe and analyze the mutual relations between these determinants?*" It mainly refers to Chapters two to six. Section 10.4 relates to this thesis' second research question: "*What potential effects might be expected from travel information related transport policies?*" and relates mainly to Chapters seven to nine. Section 10.5 reflects on methodological issues relating to the research presented in Chapters two to nine.

For reasons of readability, this Chapter's findings will not be presented as bullet-wise answers to the research questions raised in the Introduction. Instead, the most interesting research findings will be highlighted relating to these questions, in combination with the author's personal opinion on the matter at hand. Within each paragraph, the essential points to be made are underlined. Note that this Chapter does not reflect on possible directions for future research into travel behavior under conditions of knowledge limitations and information availability. Epilogue II discusses such avenues for further research.

10.2 Overview of research presented in this thesis

This thesis has studied traveler response to information, and information's potential as a transport policy instrument. On each of these topics, theoretical and empirical literature has been reviewed. Building on these reviews, a theoretical model of traveler response to information has been developed, validated using numerical examples, and subsequently applied to study - through simulations - the potential of travel information provision in a mode-choice adaptation context. Complementing these numerical simulations, this thesis is built around the analysis of two datasets: firstly, a web survey, probing into i) the determinants of travelers' knowledge limitations and ii) how these result in the need for (particular types of) travel information. Data collected through this survey was statistically analyzed, without assuming specific behavioral model structures. Secondly, a multimodal travel simulator was built, which enabled the observation of sequences of hypothetical choices per trip made by travelers that are confronted with choice situations that are characterized by i) a variety of knowledge limitations and ii) the availability of a variety of information types. After having established the validity of the simulator environment, the collected data was used for the estimation of a discrete choice-based behavioral model of traveler response to knowledge limitations and information provision. Furthermore, the dataset was used to test conceptualizations concerning (the influence of information on) travel choice quality. Finally, as can be seen in Epilogue I, the dataset was used to empirically test a discrete-choice based operationalization of Regret-Theory. Epilogue II presents promising directions for further research, whereas this Chapter provides conclusions and reflections relating to the two research questions raised in the introduction.

10.3 Behavioral determinants of traveler response to information and how to describe their mutual relationships

10.3.1 Behavioral determinants of traveler response to information

This thesis showed how <u>a traveler's response to information is largely determined by i) her decision style at the observed moment of choice, ii) her valuation of attributes of travel alternatives, iii) her perceived knowledge regarding the travel situation and iv) her knowledge concerning the information available to her.</u> Examples of these four determinants will be briefly presented here.

For the purpose of this research, decision style may be conceptualized in terms of, for example, whether the traveler is about to evaluate alternatives extensively by some form of multiattribute valuation and weighing procedure, or may opt for a more fast-and-frugal procedure, potentially involving statisficing behavior or heuristics. A travel alternative's attribute, e.g. a route's travel time, may be either ignored, or regarded as being more or less important. A traveler's perceived knowledge regarding the travel situation may be characterized along two dimensions: firstly, a traveler perceives herself as being more of less *resourceful* in a given choice situation, in the sense that she perceives herself to be aware of many travel alternatives. Secondly, she may perceive her estimates of relevant attributes of travel alternatives as being more or less *reliable*. Knowledge of available information relates to the traveler's awareness of available information (and the costs to be incurred to acquire the information) and her perception of information relevance and reliability. At first sight, how these determinants may affect a traveler's response to information may appear intuitive. For example, it may sound intuitive to assume that i) a decision style involving extensive evaluation procedures will induce much information acquisition, ii) the more important an attribute, the more information is acquired about it, iii) the less knowledge a traveler has, the more likely she is to acquire information, etc. However, it can be seen that many of these intuitions do not always hold, due to the complex and nuanced interplay between determinants.

Let me give just one brief example of a 'counterintuitive' mechanism: take the intuition that less knowledge leads to more information acquisition. However, as can be argued theoretically, and as is also found empirically in this thesis (see Chapter 9), travelers are more likely to assess mode-route combinations when they are aware of more combinations: knowing more alternatives leads to more uncertainty in terms of which alternative is the best one. This uncertainty induces a need for information about the known alternatives' attributes. Note that this reasoning does not hold for a satisficer, who will simply pick the first alternative that is good enough, without considering the possibility that others may be better. This example suggests that in order to truly understand traveler response to information, more is needed than a list of determinants.

10.3.2 Theoretical descriptions of traveler response to information

As seen above, the fact that many of the determinants of traveler response to information do not impact this response in straightforward, intuitive ways implies the need for a more integrative behavioral perspective. This thesis attempts to provide such a perspective: it has shown how traveler response to knowledge limitations and information availability can be adequately conceptualized in *theoretical frameworks* with a high level of face validity.

Four ingredients (sets of assumptions) are found to be necessary for the construction of such conceptualizations: firstly, a behavioral model of choice under limited knowledge is needed. Such a choice-model may be based on notions of (expected) utility maximization, (expected) regret minimization, satisficing, or other internally consistent decision mechanisms. Secondly, assumptions must be made concerning what messages the traveler believes she may receive when acquiring information. Note that it has been argued in this thesis (Chapter 3) as well as more elaborately in other publications (e.g. Chorus et al., 2005) why the assumption of 'knowing what messages may be received' is not as strong as it may appear at first sight. A third set of assumptions is needed with respect to a traveler's anticipation of how a particular message received will affect her perception of the attribute or alternative the message relates to. Although here the notion of Bayesian updating is put forward as an appropriate way to acknowledge the potential unreliability of information, other updating mechanisms may also prove reasonable for this aim. Fourthly, based on these three sets of assumptions, the value of information should be conceptualized in terms of the difference between the current choice situation and the anticipated situation after having acquired the information. This difference depends on each of the three earlier mentioned sets of assumptions, and may be conceptualized in terms of (expected) utility, regret, etc, depending on what choice model is used. In combination, these four assumptions provide useful structures – with a high face validity - for developing coherent behavioral models of traveler response to knowledge limitations and information availability.

10.3.3 Empirical analysis of traveler response to information

Another question is now, whether the microeconometrical versions of these individual-level theoretical notions give accurate descriptions of *actual traveler behavior*. Based on the research presented in this thesis, specifically Chapter 6, the answer to this question would be "yes, they probably do; at least in the case of fully reliable information". That is, estimation - in the travel simulator dataset - of an expected utility-based model of traveler response to a variety of knowledge limitations and a variety of provided fully reliable information types, resulted in a very substantial increase in sample Log-Likelihood, while using only a very limited number of parameters. This signals that the behavioral model, fueled with an appropriate set of error components and parameters, is capable of predicting to a reasonable extent the choice behavior observed in the sample. Of course, this internal goodness-of-fit regarding estimation on observed hypothetical choices by no means presents the conclusive evidence for a definite “yes” to the question raised above – further research efforts, preferably based on revealed choice data are needed in order to back up the results obtained here. Nevertheless, in the author’s opinion, the estimation results do provide a strong signal that traveler response to knowledge limitations and information provision can generally be well described using the descriptions offered by the theoretical ideas presented in this thesis - such as the notion that information value is a function of the anticipated difference between the current situation and the situation after having acquired the information.

This argumentation can be taken two steps further, while repeating the remark that further studies are needed in order to provide more definite evidence: firstly, the fact that observed behavior fitted the developed theoretical ideas about traveler behavior well provides some indication that participants in the experiment showed considerable understanding of the value of travel information for their trip making under conditions of limited knowledge. In turn, the empirical analyses presented in this thesis thus provide an *indication* that travelers in the real world might well be able to deal in an intelligent way with very complex and nuanced travel situations, involving a variety of knowledge limitations and information types. Rephrased into somewhat more cautious wording, the empirical analyses presented in this thesis certainly do not underpin the suggestion, often heard in the travel behavior community, that travelers have no idea how to cope with uncertainty and other knowledge limitations in a clever way, and that they do not know how to use the available travel information to their advantage.

10.3.4 The role of non-monetary costs in traveler behavior and response to information

Research presented in this thesis strongly underlines the notion that, next to monetary costs, non-monetary costs - e.g. effort, time, attention - are a crucial determinant of traveler behavior. Firstly, Chapter 7’s literature review shows how these costs play a paramount role in travelers’ decisions whether or not to divert to other than their current (or planned) travel alternative in terms of mode, route and/or departure time adaptations. Secondly, this literature review as well as the empirical analysis of the travel simulator data show how the non-monetary costs of information tend to be perceived among travelers as being very substantial, and often prohibitive to the actual acquisition of available information. In combination, these two observations clearly show how the development of habitual behavior may easily arise from repeatedly avoiding the cognitive burden of exploring new travel alternatives. Thirdly, results from the web survey provide an indication that travelers actually need information that makes traveling easier (such as route guidance or early warning systems) more than information that may help them make ‘better’ travel choices in terms of, for example, travel time and costs reductions (such as multimodal information). Furthermore, participants to the web survey indicated a stronger need for ‘basic’ travel time estimates than for many more advanced – but presumably also more ‘difficult’ - types of information, such as personalized information.

The success of travel information services is therefore likely to be strongly determined by its user friendliness, in combination with its potential for reducing the cognitive burden of the traveler. That is, travelers appear to be unwilling to take on a cognitive burden in order to receive moderate gains in terms of travel time reduction or decreases in uncertainty.

10.3.5 Car-drivers versus transit-users

Although from a conceptual point of view it makes sense to conceive travelers as being a homogeneous group, irrespective of their preferred travel mode, analysis of the web survey data strongly suggests that car traffic and transit induce different patterns of knowledge limitations and response to information. For example, it appears that car-drivers' perception of the reliability of their travel time estimates is less heavily affected by incidental disturbances (such as accidents) than transit–users' perceptions. However, in the case of recurrent disturbances (such as bad weather), the opposite is found. Furthermore, it is found that, for the case of trips towards familiar destinations, car-drivers consider themselves more resourceful (i.e. knowing many alternative routes) than do transit-users. The opposite is found for trips towards destinations never visited before. Moreover, observed transit-users perceived themselves as quite knowledgeable in case they had to travel by car. Car-drivers however, considered themselves to be not so knowledgeable when confronted with a transit context (both car-drivers and transit-users on average had sufficient experience in using the 'non-usual' mode[75]).It also appears that car-drivers display a higher need for most types of travel information than do transit-users, especially for trips towards familiar destinations. Although these results should not be simply extrapolated based on one empirical study, it does seem to be the case that in order to provide (multimodal) information services that fit travelers' needs, a distinction between car-drivers and transit-users seems well worth making.

10.4 The potential effects of travel information related transport policies

10.4.1 Travel information as a means to induce behavioral adaptation

Starting with the most debated issue surrounding travel information-related transport policy: will the provision of travel information ever induce a substantial shift from car use towards transit use? In congruence with available literature on the topic, this thesis provides a mixed picture: on the one hand, it appears that car-drivers do exhibit a need for multimodal information, especially in relation to trips towards destinations never visited before. On the other hand, the majority of evidence accumulated here as well as in the literature suggests that one might be mildly optimistic at best with respect to actual mode-choice adaptations: firstly, literature tells us that those car-drivers that drive their car out of habit are very difficult to reach with public transport information in the first place, let alone reconsidering their mode-choice based on the acquired information. Secondly, as a detailed theoretical analysis in this thesis shows (Chapter 8), there are many barriers for the available information to lead to shifts in mode-choice among *non-habitual* car-drivers as well – defined as those that have a preference for their car as opposed to transit, but do consider transit as a feasible modal option. Simulations show how this finding even holds when travel information (e.g. travel time estimates) suggests that for the given choice situation, transit performs very well. Although the combinations of many factors causes this limited effect of transit information provision on car-drivers' mode-choices, one will be listed here, which the author believes is crucial (Chapter 7).

For many car-drivers, transit is perceived as a low-quality alternative, based on a mix of 'hard' (travel times and costs) and 'soft' (image, convenience) factors. It is known that the perceptions of 'hard' factors among car-drivers may be negatively biased towards transit, and

[75] Note that the distinction between car-drivers and transit-users was made based on travelers' indication of their usual travel mode concerning their most important out-of-home activity.

positively towards the car, which might create a role for travel information services to correct these misperceptions and induce greater use of transit. However, as travelers are unlikely to seek for, or pay attention to, information concerning alternatives they perceive as low-quality, such transit information is not likely to be acquired by car-drivers in the first place. Furthermore, as travel information predominantly concerns the 'hard' characteristics of car and transit - travel information services are hardly the ideal tool to convey image-related messages - the effect of transit-information, when it is acquired by car-drivers, on their mode choices is intrinsically limited.

Changes in route and departure time-choices (leading to a more efficient use of available network capacity) are generally found to be more easily obtained, since i) there are no difficult to overcome, image-related, factors that determine traveler behavior and ii) the adaptation costs towards other than the current route or departure time are generally far less than those in a mode-choice adaptation decision.

From a short-term perspective, this thesis provides evidence that expectations concerning the effect of information provision on travel-choice adaptation may be mildly optimistic with respect to car-drivers' route- and departure-time choices, and mildly optimistic *at best* with respect to their mode-choices. Taking a longer term perspective, a somewhat more optimistic picture may arise due to learning effects, although it appears that we have just started to study travelers' responses to information (e.g. Sun et al., 2005) and their choice adaptations (e.g. Thøgersen, 2006) in the longer run. Although this thesis has not been directly concerned with longer term learning effects, it is fair to say here that it appears to be worthwhile to repeatedly confront travelers with easy to use, high quality information concerning their currently chosen option as well as concerning other attractive options. Such information is likely to be able to slowly redress travelers' misperceptions and every once and a while induce a (temporary) behavioral change. In sum, such information may in the longer run slow down the formation of habits and sometimes even help breaking them.

10.4.2 Investing in information accuracy under incident conditions

Providing accurate information under incident conditions is very difficult – and unfortunately, travelers are of course aware of this: they perceive information as being particularly unreliable at those moments they need it most (see Chapter 4). Although the costs associated with improving the performance of an information service (particularly in terms of their reliability) under incident conditions is bound to be high, this is likely to be a cost-effective policy from a longer term behavioral adaptation point of view. Travelers, including the ones that chose their current alternative out of habit, perceive their own knowledge levels as particularly insufficient during such conditions, which increases their need for information, to update their perceptions with received information and adapt their choices when the information gives them reason to. Such a diversion may be a first step in breaking a traveler's habit. Note that a traveler's willingness to pay for information about the performance of their currently chosen option and about the availability and performance of alternative options will be relatively high under incident conditions. This provides an opportunity for earning back some of the investments needed to provide high-quality information.

10.4.3 A special case: providing travelers with advice

Although from a theoretical and empirical point of view, this thesis has focused on information about travel alternatives' availability and their attribute values, one conclusion will be drawn here concerning another type of information: the provision of advice. Many studies have pointed at the relatively high impact (in terms of behavioral adaptation) of providing travelers with advice about which alternative to choose, instead of providing information about available alternatives and their performance. This high impact may be due to the fact that travelers incur little 'cost of thinking' when processing advice, since advice reduces a complex spatial environment into a binary choice (follow the advice or not): advice is therefore more likely to be incorporated into a decision making process than are other types of information. However, in the author's opinion there are severe disadvantages to relying on the provision of advice solely, in terms of the longer term impact on traveler behavior.

Firstly, confronting travelers with advice is likely to be of limited value in the long run, notwithstanding the relatively high diversion rates that may be established in the short run. This is a result of the fact that advice reduces the complex spatial environment into a binary choice environment - it limits a traveler's learning experience: travelers who have a poorly developed knowledge of their spatial environment are known to be more likely to develop habits, and to ignore information about other than their currently chosen option (Chapter 7). When giving advice, the argument behind the advice should be presented as well, in order to help avoid a complete lack of learning among travelers. For example, should a traveler, while driving on a highway, be advised to take route A instead of route B, it is important to tell her if route B is congested due to peak hour traffic (and hence is likely to be congested the next time, at the same time of day, as well), or due to an accident (in which case route B might be an attractive option the next time). Naturally, there is a trade-off to be made here between the amount of information a traveler can easily process and the level of detail that is needed to correctly describe the choice situation at hand and induce some level of learning.

Secondly, it is well known that diverting travelers to alternatives that turn out to be unattractive is a bad idea: this will severely diminish their inclination to acquire information, or divert, in the future. The probability of diverting travelers to alternatives that they will subsequently perceive as ill-performing is relatively high when providing them with advice, purely because of reducing a complex, multifaceted spatial choice to a simple, binary one. Since the authority providing the advice does not know every traveler's valuations of travel times and costs for the current trip, let alone their valuation of such attributes as convenience or their intrinsic preferences for certain alternatives, it simply does not know what alternative the traveler would in fact prefer. As a result, advice is generally based on travel time forecasts only. By foregoing all other potentially relevant attributes of travel alternatives, authorities may tell a traveler to divert to a route which she would not choose, would she have the same information the advising authority has. Obviously, the probability of triggering a diversion towards an alternative that the traveler is likely to regret can be decreased by simply i) providing the traveler with the travel time estimates and ii) let her make the decision whether or not to divert, based on her knowledge and attribute valuations.

10.4.4 The crucial role of information reliability

This thesis underpins the often stated proposition that if anything is crucial to the potential of travel information as a transport policy instrument, it is its reliability. Firstly, Chapters 3 and 8 show theoretically how information unreliability severely limits its value to travelers. Then, the Structural Equation Model in Chapter 9 provides empirical evidence for this notion. Furthermore, once acquired, unreliable information is likely to have less influence on travelers' perceptions (see Chapter 3 and 8 for a Bayesian perspective on this idea) than does fully reliable information – the former is likely to be taken less seriously by travelers, who are of course correct in doing so. Finally, consistent with intuition, and also indicated by the empirical analyses of Chapter 9, the provision of unreliable information will lead to a deterioration in choice quality, relative to the provision of fully reliable information. Together, this signals the paramount importance of information reliability. In fact, acknowledging travelers' stated needs for 'basic' travel time information rather than some forms of highly advanced information (Chapter 4), it appears worthwhile investing in the accuracy of available information sources, rather than in developing more sophisticated forms of information.

10.5 Methodological reflections

10.5.1 The need for rigorous definitions

Practitioners, policy makers, and also researchers, interested in traveler response to information and the role of travel information in a transport policy context, often express expectations such as "information will help travelers make better choices", "information will help travelers reduce the impact of uncertainty", "the value of travel information depends on its reliability", etc. Although one may or may not agree with these expectations, one thing should be noted: they are inherently vague as long as the applied terminology ("better choices", "impact of uncertainty", "value of information") is not properly defined. In the author's view, one of the most important roles of transportation researchers is to eliminate this potential misunderstanding by providing clear, formal definitions of the topics being discussed. This thesis has provided definitions for the notions "information value" (e.g. Chapters 3 and 6) and "travel choice quality" (Chapter 9). In short, information value is defined as the anticipated difference between the anticipated choice situation after having acquired the information, and the current choice situation. Travel choice quality is conceptualized as the correspondence between an alternative that is chosen under conditions of limited knowledge and the alternative that would have been chosen under conditions of complete knowledge. Although establishing such definitions generally leads to relatively complex and subtle reasoning (there is definitely a good reason for being vague!), they will reduce the risk of misunderstanding and the creation of expectations that will never be met. Furthermore, they open up the door to mathematical formulations, computer simulations and the statistical testing of empirical data. Since traveler behavior research is bound to become more complex in the coming years, as we probe ever deeper into the mechanisms that determine traveler behavior, the need for careful definitions will become bigger and bigger.

10.5.2 Studying travelers' perceptions instead of assuming them

It is generally acknowledged that the accuracy of our assumptions concerning travelers' perceptions of the choice situation they face, and of the availability and performance of travel alternatives, is crucial to our understanding of traveler behavior as a whole. Firstly, it is well known that misspecification of these perceptions will generally lead to biases in estimated behavioral parameters (e.g. Williams & Ortuzar, 1982; Manski, 2004). Secondly, even when perceptions are fully controlled for in a Stated Preference context, the question remains whether travelers perceive their environment in ways compatible with the hypothetical environment in which their choices are being observed. Given the well established importance of perceptions, it is somewhat surprising to see that little empirical research has been aimed at directly studying their formation and updating over time. Notwithstanding notable contributions by Hoogendoorn-Lanser & van Nes (2004, concerning choice set composition) and Zhao & Harata (2001, concerning the updating of travel time perceptions), a great deal of work remains to be done. Although this thesis has provided some theoretical ideas along these lines, it relied on many assumptions for its empirical analyses. The travel behavior community would greatly benefit from empirical studies concerning travelers' perception of the choice situation they face. Until we can rely on results from such studies, our models should be based on carefully deduced, and rigorously discussed, assumptions about how our subjects of research perceive their choice situation.

10.5.3 Expected Utility (EU) versus non-Expected Utility models

Although Epilogues I and II will discuss the pros and cons of non-Expected Utility models for risky choice (choice under uncertainty) in more detail, this Sub-section will briefly pay attention to this methodological topic as well. As already noted in the Introduction, there has been a great deal of debate among economic theorists about the usefulness of the Expected Utility maximization paradigm as a representation of how individuals choose under conditions of uncertainty. This debate has reached the travel behavior community, which 'borrows' many of its methodological concepts from the economic sciences. Critics of the EU-perspective state that i) it is an incorrect representation of traveler behavior and that ii) it therefore is bound to lead to flawed conclusions with respect to traveler behavior and hence to suboptimal policy-making / travel demand measure development. In the author's view, it is definitely true that individuals do not maximize Expected Utility when choosing under conditions of uncertainty. However, on average, the author does feel that the EU-maximization perspective is sensitive to a range of stimuli (such as the provision of information) in a way that reflects traveler response to these stimuli. Furthermore, the fact that there has been, until now, very little evidence that actual traveler behavior (as observed in day-to-day travel choices in real life) is better explained by non-EU models should be another reason for skepticism with respect to criticism of the EU-paradigm. This is notwithstanding the fact that much empirical evidence exists of non-EU behavior in carefully constructed binary monetary lotteries. To the author's opinion, EU-theory remains a very intuitive choice paradigm that is extremely compatible with many powerful statistical methods, and therefore of great use to researchers and practitioners alike. Chapter 6 of this thesis has applied an EU-model to traveler response to information.

Having said that, it is definitely true that traveler behavior is in fact a very complicated black box for us analysts. This warrants the development of more than one paradigm for the analysis of choice under uncertainty. Based on this reasoning, this thesis has adopted the notion of regret in Chapters 3 and 8[76], and has developed an operational discrete-choice based formulation of Regret-Theory in Epilogue I. However, these efforts have not been positioned as a critique to EU-theory, perhaps more as homage to the complexity and subtlety of human behavior.

10.5.4 The case for complex empirical models of traveler response to information

Traveler response to information (and particularly their decision whether or not to acquire information) has in past empirical research efforts been predominantly modeled using 'simple' additive linear utility functions. For example, travelers' inclination to search for information has generally been conceptualized as a linear function of information costs and its reliability, the trip's purpose, etc. Notwithstanding the fact that, ceteris paribus, simpler

[76] It can be seen that, mathematically, the regret formulation of Chapter 8 reduces to an Expected Utility decision rule. This fact, only noted by the first author after the Chapter was published as a journal article, does in the author's opinion by no means imply that the regret-based conceptualizations and simulations performed in that Chapter are not a useful complement to the often used EU-paradigm of choice under uncertainty.

models should be preferred over complex ones, there are compelling reasons to adopt more complicated model forms for the study of traveler response to information. Firstly, as pointed out in the introduction, behaviorally realistic models of traveler response to information are, more than linear additive formulations, able to derive from the data generic insights – insights that may not only apply to the current situation, but also to future situations involving (in this case) information sources with unforeseen functionalities. Secondly, there appears to be a trade-off between model complexity and model parsimony: when a model is much simpler than the behavior it aims to describe, many parameters are needed in order to explain sufficient parts of the variation in choice behavior in the sample. Models with a sufficient level of complexity (realism) on the other hand, need only a limited number of parameters to reach the same level of fit. As an example, the model presented in Chapter 6 is based on quite tedious structural assumptions concerning travelers' decisions to acquire information. As a result of this, only a small number of parameters appeared to be needed to describe travel choices from choice sets containing up to more than 30 information acquisition options and travel alternatives. Furthermore, the model enabled the use of observed information acquisition behavior for the estimation of travel related parameters (e.g. value-of-time estimates). In summary, it is felt that complicated behavior deserves to be described by sufficiently complex models.

10.5.5 A note about the validity of travel simulator environments

As put forward in the introduction, one would prefer to use, for model estimation (or in fact for any statistical analysis), data concerning actual choices, made in real life choice environments. Obviously, there are many reasons why such data might be impossible to attain (e.g. with respect to information services not yet available at present), unaffordable in terms of time and money, or even impractical in terms of model estimation (e.g. due to collinearity issues). Over the years, the travel behavior research community has been using travel simulator environments for the observation of hypothetical travel choices. This development has been backed by extensive studies concerning the validity of such data-collection approaches (e.g. Bonsall et al., 1997; Mahmassani & Jou, 2000). Notwithstanding the theoretical arguments that can be made against the use of simulators, they do appear to provide valid, useful data for the estimation of demand models. This thesis has adopted a slightly different perspective on travel simulators, by providing travelers with a completely abstract, multimodal travel environment, and by providing them with a highly sophisticated travel information service. A careful validation effort of the observed choices, and subsequent empirical model estimations, suggest that even in the simulator environment, people are prone to make choices that are compatible with our intuitions.

However, in the author's opinion, results from simulator studies should always be presented with care, and with detailed reference to the conditions under which the choices have been observed. Furthermore, it is felt that, notwithstanding the usefulness of simulators for data-collection concerning travel demand measures that are not yet observable in the real word (such as some advanced information services or certain road pricing schemes), their validity is intrinsically limited. This intrinsic limitation perhaps holds particularly for the most complicated forms of behavior, such as traveler decision making under conditions of limited knowledge, or longer term learning mechanisms. And it is exactly this type of complicated behavior that is being studied using simulators, in the absence of sufficiently rich revealed preference data. In the author's opinion, simulator studies may provide us with *indications* of how such behavioral mechanisms work, as well as with fruitful avenues for further research. But, in the end, researchers as well as practitioners are not likely to be convinced about any premise of traveler behavior until it has been tested against actual behavior, observed in the real world. The case for revealed preference data, for example with prototypes of not yet fully available products or services, remains very strong indeed.

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Chapter 11: Epilogue I

Chorus, C.G., Arentze, T.A., Timmermans, H.J.P., 2007. A regret-based model of risky travel choice: conceptualizations and an empirical estimation. *Submitted for publication*. [77]

Abstract

This paper presents an operational non-Expected Utility model of risky travel choice, rooted in Regret-Theory. The model contributes to the literature on risky travel modeling in adding a plausible and operational alternative to the well established Expected Utility-framework. Furthermore, with respect to the general field of risky choice modeling, this paper extends the operational scope of Regret-Theory-based models towards choice situations including general choice sets and multiattribute decision making. The developed model is then estimated on data from a multimodal travel simulator, where participants could choose between travel alternatives with risky travel times and costs. Estimation results support the validity of the proposed Regret-Theory-based model specification.

[77] This Chapter forms a revised and extended version of: Chorus, C.G., Arentze, T.A., Timmermans, H.J.P., 2007. Validating a regret-based model of traveler response to information and uncertainty using data from a multimodal travel simulator. Paper accepted for presentation at the *11th WCTR Conference*, Berkeley, United States

11.1 Introduction

Traveling is about dealing with risk. When planning a trip, travelers by definition do not know the exact travel time they are about to experience should they choose a particular combination of mode, route and departure time combination. In addition to travel time, the exact values of a variety of other relevant attributes may be unknown in the eyes of the traveler at the moment of choice, such as travel costs, comfort levels, etc. One of the keys to understanding travel behavior is therefore understanding how travelers deal with the risk associated with the travel alternatives they may choose from. This observation is widely acknowledged throughout the travel behavior research community, especially since the development and introduction of Advanced Traveler Information Services in the late 1980s. This substantial and growing interest is reflected in an abundant body of literature concerned with modeling travel choices under risk. Besides a number of theoretical contributions (e.g. Noland & Small, 1995; Bonsall, 2001; Arentze & Timmermans, 2005a, b; Sun et al., 2005; Ettema et al., 2005; Chorus et al., 2006a; Batley, forthcoming), the field has recently witnessed a substantial increase in empirical studies (e.g. Bates et al., 2001; Lam & Small, 2001; Rietveld et al., 2001; Katsikopoulos et al., 2002; Denant-Boèmont & Petiot, 2003; Brownstone & Small, 2005; Avineri & Prashker, 2003, 2006; Chorus et al., 2006b) [78].

Notwithstanding this substantial body of literature on risky travel choice, travel behavior researchers feel that there is still much scope for further work. A key issue that has recently been put on the research agenda in the travel behavior research community is the need for the development of operational[79] alternatives to the standard Expected Utility (EU) framework of risky choice (e.g. Avineri & Prashker, 2003, de Palma & Picard, 2005; Michea & Polak, 2006). This is not to say that the EU-framework has not contributed greatly to our understanding of risky choice in a normative as well as descriptive sense. However, it is felt for some years now that the development of operational alternatives to the EU-modeling approach will help increase our understanding of traveler decision making under risk – perhaps especially of those observed behaviors that appear to violate the rationality principles underlying EU-theory, such as preference-intransitivity, anchoring effects, loss aversion etc.

This paper presents and empirically estimates such an operational non-EU model of risky (travel) choice. The model is rooted in Regret-Theory (RT), developed in the early 1980s (Bell, 1982; Fishburn, 1982; Loomes & Sugden, 1982), which is one of the non-EU theories of risky choice most extensively studied in economics (e.g. Loomes & Sugden, 1983, 1987; Machina, 1987; Quiggin, 1994; Starmer, 2000; Hart, 2005). RT asserts that an individual facing a choice under risk is aware that she may end up having chosen an alternative which turns out to be less attractive than a non-chosen alternative, causing regret. Individuals are assumed to anticipate this possibility of regret and aim to minimize expected regret when choosing from available alternatives.

Generally, RT is put forward as one of the few non-EU models that are able to systematically describe a variety of behavioral patterns that contradict EU-theory while maintaining a relatively simple model form. However, it should be noted here that the research presented in

[78] Note that most of these contributions use the terms ‘uncertainty’ or ‘unreliability’ instead of ‘risk’ to describe the situation where a traveler does not know the exact values of relevant attributes of alternative travel options at the moment of choice. Since in the remainder of this paper we will apply the notion of well described probability distributions in order to model the traveler’s lack of knowledge, economic literature starting with Knight (1921) suggests that the term risk should be applied rather than as uncertainty or unreliability. We will follow this convention here.

[79] The term operational refers to a model that can be directly applied to estimate behavioral parameters based on observed choices.

this paper is not motivated by the aim of describing specific deviations from EU-theory. Rather, it is driven by the notion that travel behavior in general, and risky travel choice in particular, are very complex and multifaceted phenomena, which deserve to be studied from multiple theoretical perspectives. Furthermore, it is felt that RT may provide a particularly attractive perspective on risky *travel* choice by capturing the intuition that traveling may often be about avoiding negative emotions (e.g. being late, missing a bus, getting stuck in traffic), perhaps more than about deriving some maximum level of payoff. Either way, we do wish to stress here that we do not present our operational model of RT as being in any way superior to the EU-approach: rather, this paper aims at contributing to the literature concerning risky travel choice modeling by providing a plausible and operational alternative to the well-established EU-approach. A second contribution of the work presented here is with regard to the general literature on risky choice: to date, to the authors' knowledge, the only available *operational* example of RT (and the bulk of theoretical examples as well) refers to binary choices between monetary prospects (Hey & Orme, 1994). This paper extends the operational scope of RT-based models towards general choice sets and multiattribute decision making. Such a contribution is in line with a general movement in microeconomics towards bringing risky choice research to practice (e.g. Starmer, 2000).

The remainder of this paper is structured as follows: Section 11.2 provides a very brief history of the development of non-EU models of risky choice and provides a more detailed formal account of one of them, RT. Note that a more extensive review of relevant decision theoretic literature would not only be outside the scope of this paper, but would also be unnecessary, given the large number of excellent reviews on this topic. See, for example, Starmer (2000) for an exhaustive overview. Section 11.3 presents an operational, RT-based model of multiattribute risky choice for general choice sets. Section 11.4 describes the data-collection effort. Section 11.5 discusses the results of the RT-based model estimation on the dataset. Section 11.6 draws conclusions and discusses avenues for further research.

11.2 (Non-)Expected Utility models and Regret-Theory

11.2.1 (Non-)Expected Utility models

First proposed as a model of risky choice by Bernoulli (1738, reprinted in 1954), the popularity of *Expected Utility Theory* as a model of risky choice took a flight after Von Neumann and Morgenstern's (1944) axiomatic formalization. EU-theory states that an individual, faced with a choice between two risky alternatives (that is: the exact utility of one or more of the prospects is not known at the moment of choice and depends on a future state of the world), evaluates the utility of each prospect for a given state of the world. Then, the individual multiplies this utility with the probability of occurrence of the particular state of the world. Subsequently, the individual sums these products over all possible states of the world, giving the expected utility of the alternatives. Finally, the alternative with the highest expected utility is chosen. Formally, EU can be written as:

$$EU_i = \sum_{s \in S} \left[p(s) \cdot U_i(s) \right] \tag{1}$$

where i stands for an alternative, s represents a particular state of the world, S gives all possible states of the world, $p(s)$ gives the probability of occurrence of state s and $U_i(s)$ gives the utility of alternative i given state s. EU-theory, for a brief while, became *the* building block for modeling risky choice. However, starting with Allais (1953) and Ellsberg (1961) in the 1950s and early 1960s, and culminating in the 1970s (e.g. Tversky & Kahneman, 1974; Kahneman & Tversky, 1979) and beyond, an abundance of empirical evidence accumulated which showed that in real life, individuals often behaved in systematic contradiction with the premises and predictions of EU-theory. For example, individuals appeared to have great difficulty interpreting probabilities and outcomes 'correctly', and their choices turned out to be easily influenced by the formulation of the choice task at hand, leading to intransitive preferences and a wide variety of other well documented 'anomalies of choice'. McFadden (1999) provides an extensive overview of observed deviations from EU-premises and predictions. This empirical evidence did not affect EU-theory's appeal as a normative theory of risky choice, but it did cast doubt to EU-theory as a descriptive framework, describing actual behavior. Although the concept of EU-theory continued to be a widely used framework for the analysis of risky choice, the empirical evidence of deviations from EU-theory did spur the development of a number of so-called non-EU theories of risky choice (see Starmer (2000) for a well documented overview of the most widely used of these theories).

These non-EU theories aimed at providing coherent and empirically consistent descriptions of observed risky choice behavior (including 'anomalies of choice'). Of these non-EU frameworks, it appears that *Prospect Theory* (PT), (Kahneman & Tversky, 1979, 1992) is the most widely acknowledged alternative to EU. Recently, PT has been finding its way to a number of fields related to that of microeconomics and behavioral decision theory - including that of travel behavior research (e.g. Katsikopoulos et al., 2002; Avineri & Prashker, 2003; Arentze & Timmermans, 2005b). As summarized by Starmer (2000), Prospect Theory hypothesizes that "choice is modeled as a two-stage process. In the first phase, prospects are 'edited' using a variety of decision heuristics; in the second, choices among edited prospects are determined by a preference function …". This preference function is concave for gains, and convex for losses, and kinked at the status quo. Besides PT, a number of other decision theories have been developed with similar aims as the ones motivating Kahneman and Tversky. Some of the most well known of these non-EU theories are *Generalized Expected Utility Analysis* (Machina, 1982), *Weighted Utility Theory* (Chew, 1983), *Rank Dependent Expected Utility Theory* (Quiggin, 1982) and *Regret-Theory* (Bell, 1982; Fishburn, 1982; Loomes & Sugden, 1982). In the following of this paper, we will focus on the latter of these non-EU theories and present an operational version of RT that can be applied for the analysis of multiattribute risky choice from general choice sets. First, we will briefly discuss the basic notions and mechanisms underlying RT.

11.2.2 Regret-Theory

RT is developed, independently, by Bell (1982), Fishburn (1982) and Loomes & Sugden (1982) as a model of pairwise choice between lotteries (Machina, 1987). That is, the situation is considered where individuals face a choice between two alternatives. These alternatives are characterized by a probability distribution and a (monetary) outcome for each probability. The crucial difference now, between EU-theory and RT, is that the latter is based on the notion that individuals base their preference structure for some state of the world not only on the anticipated 'performance' of a considered alternative for that state of the world, *but also on that of the other alternative*. More specifically, the individual is hypothesized to anticipate and take into account the possibility that the non-chosen (foregone) alternative turns out to be more attractive than the chosen one. In other words, instead of evaluating the utility of each alternative for each state of the world, RT postulates that individuals anticipate, for each state of the world, the possible regret (the chosen alternative performs worse than the non-chosen one) or rejoice (vice versa) associated with an alternative, and subsequently aggregate this regret/rejoice over all possible states of the world. Formally, RT states that an alternative i is chosen from the choice set containing i and j if and only if:

$$\sum_{s \in S} \left[p(s) \cdot R_{ij}(s) \right] > 0 \tag{2}$$

where s represents a particular state of the world, S gives all possible states of the world. $p(s)$ gives the probability of occurrence of state s, $R_{ij}(s)$ gives the regret (a negative number - in case j is more attractive than i) or the rejoice (vice versa) of alternative i compared to alternative j, given state s. This regret is a function of the monetary outcomes x_i and x_j of the two alternative lotteries for a given state of the world s: $R_{ij}(s) \equiv \varphi(x_i(s), x_j(s))$. It is assumed that $R_{ij}(s) = -R_{ji}(s)$. Note, that if $R_{ij}(s) \equiv U_i(s) - U_j(s)$, RT reduces to the expected utility model. It has been well established that particular functional forms of the regret/rejoice function $R_{ij}(s)$ give rise to models that are able to systematically describe a variety of behavioral patterns which contradict EU-theory, including preference reversals[80] (e.g. Loomes & Sugden, 1983) and some forms of preference-intransitivity (e.g. Loomes & Sugden, 1982). This consistency with real behavior in combination with its relatively simple formal structure have made RT a relatively popular candidate for risky choice analysis in such areas as psychology (e.g. Zeelenberg, 1999; Crawford et al., 2002), marketing (e.g. Simonson, 1992; Taylor, 1997; Inman et al., 1997) and finance (e.g. Stoltz & Lugosi, 2005). Its application in the travel behavior domain is to the authors' knowledge virtually non-existing (but see a theoretical study by Chorus et al. (2006a)). It should be noted here that many of the applications of RT in other fields than decision theory are based on the general notion of regret as a determinant of choices, rather than being based on the full formalism of the regret/rejoice structure presented above.

11.3 An operational RT-based model of multiattribute risky choice from general choice sets

11.3.1 An RT-based formalization of risky choice

Although the analysis of observed pairwise choices between monetary lotteries may provide useful building blocks for theories of risky choice such as RT, the analysis of risky *travel* choice needs a more general perspective: first, the average travel choice set contains considerably more than two alternatives and second, the average travel alternative is characterized by considerably more than one attribute. This is evident for example in the situation where a traveler may consider a variety of mode-route-departure time alternatives, each determined by travel times, costs and comfort levels which may or may not be exactly known by the traveler at the moment of choice. Therefore, in order to successfully apply RT in a travel behavior context, two forms of generalizations need to be made: one towards general choice sets, another towards multiattribute decision making.

To start with the first of these, we may build on work done by Quiggin (1994) who derived a functional form of RT for general choice sets, based on the requirement of *Irrelevance of*

[80] The notion of preference reversal is defined as the situation where an individual prefers lottery (or alternative) i over j , but places a higher certainty equivalent value (the amount of money she wishes to receive in order to forego executing a lottery) on lottery j than the one placed on i.

Statewise Dominated Alternatives (ISDA). This requirement states that a choice from a given choice set should not be affected by adding to or removing from this set an alternative that is dominated by the other alternatives for every state of the world. This requirement turns out to imply that "the regret associated with a given action *i*, assuming state *s* to occur, depends only on the actual outcome $x_i(s)$ and the *best possible outcome* that could have been attained in state *s* " (Italics added and notation adapted). There are two fundamental consequences to this generalization: firstly, it states that regret associated with an alternative does not depend on other alternatives that are (for some state of the world) better, but not the best one available. Secondly, by only considering regret with respect to the best available alternative, Quiggin's general form removes from RT the notion of rejoice, and with that its symmetrical or compensatory nature. As Quiggin puts it, the first consequence is not unreasonable from the viewpoint of psychology of choice (regret may be assumed to particularly felt with respect to the best of the foregone alternatives)[81]. The second consequence, he argues, is consistent not only with the ISDA-requirement, but also with the notion that RT has always been more about regret, than it has been about rejoice. For the remainder of this paper, we adopt Quiggin's notion of *regret with respect to the best alternative for a given state of the world* as a generalization of RT towards general choice sets. Note that, also in the general form, RT reduces to EU-theory when regret is defined as the difference, for a state of the world, *in terms of utility* between a considered alternative and the best alternative available.

The second generalization that is needed to obtain an operational RT-based model of travel choice is one towards the case where the (anticipated) performance of an alternative is based on more than one attribute. A literature search provided no building blocks for this generalization, which led the authors to develop a notion of multiattribute regret that can be put as follows: regret associated with alternative *i*, when compared to alternative *j* is the sum of the regret that is associated with alternative *i*'s first attribute, when compared to alternative *j*'s first attribute, and the regret associated with alternative *i*'s second attribute, when compared to alternative *j*'s second attribute, etc. That is, we assume that individuals evaluate the alternatives in terms of the *associated regret on an attribute by attribute basis*. Consistent with Quiggin's (1994) suggestion to apply a regret-function, rather than a regret/rejoice function, we hypothesize that the regret associated with alternative *i*, due to a comparison with alternative *j* based on a particular attribute equals zero in case alternative *i* scores equal or better than *j* on the particular attribute. Otherwise, the regret associated with the attribute comparison is a non-decreasing function of the difference in attribute-values. It may be noted here that our conceptualization of multi-attribute regret for general choice sets is compatible with the idea of discordance-indices applied in multi-criteria analyses that are based on the concept of outranking (Roy, 1991).

Formally, consider a traveler *n* that faces a choice between alternatives *i*, *j* and *k*. The alternatives are fully defined in terms of risky attributes x_i, x_j, x_k and y_i, y_j, y_k, and intrinsic preferences z_i, z_j, z_k (one may, for example, envisage *x* and *y* representing travel times, respectively travel costs of a car-, bus- and train-option, and *z* representing the individual's intrinsic preferences for different travel modes). The individual is assumed to believe that both the *x* and *y* attributes will depend on the state of the world *s,* and that *x* and *y* are independent from one another. This latter assumption is not critical for the model developed here, and may be replaced by more complex assumptions including covariances between beliefs for different attributes within and between alternatives. She has some ideas about the

[81] However, as Bell (1982) suggests, it is also not unreasonable to hypothesize that regret with respect to second best alternatives may play a role in decision making - see Chorus et al. (2006a) for a model of travel choice where this idea is formalized.

probability that x and y will take on particular values. Let us assume that these beliefs may be represented by a multi-dimensional probability density function:

$$f(s) = f(x_i, x_j, x_k, y_i, y_j, y_k) = f(x_i)\cdot f(x_j)\cdot f(x_k)\cdot f(y_i)\cdot f(y_j)\cdot f(y_k) \tag{3}$$

Now consider the occurrence of a particular state of the world s, reflected through a draw from the density function given by Equation (3). Given this draw, the individual faces three alternatives, characterized as follows: $i^s = \{x_i^s, y_i^s, z_i\}$, $j^s = \{x_j^s, y_j^s, z_j\}$ and $k^s = \{x_k^s, y_k^s, z_k\}$. In this particular state of the world s, she associates regret with each of the three alternatives *i, k* and *j*. Following Quiggin, this regret equals the regret associated with the comparison of the alternative with the *best* of the other two alternatives:

$$R_i^s = \max\{R_{ij}^s, R_{ik}^s\}, R_j^s = \max\{R_{ji}^s, R_{jk}^s\}, R_k^s = \max\{R_{ki}^s, R_{kj}^s\} \tag{4}$$

Note that this specification implies that, where for one state of the world the regret associated with, say, alternative i equals the regret associated with the comparison of i with j, it is well possible that for another state, i's regret stems from a comparison with k.

Each of the binary regrets entering Equation (4) is a sum of the regrets associated with comparing the alternatives on an attribute by attribute base, take for example the binary regret between alternative i and j for state s, R_{ij}^s:

$$R_{ij}^s = \varphi_x(x_i^s, x_j^s) + \varphi_y(y_i^s, y_j^s) + \varphi_z(z_i, z_j) \tag{5}$$

Although many, more complex than the linear, specifications may be appropriate for the attribute-regret functions φ_x, φ_y and φ_z, we will for now define them as follows:

$$\begin{cases} \varphi_x(x_i^s, x_j^s) = \max\{0, \beta_x\cdot(x_j^s - x_i^s)\} \\ \varphi_y(y_i^s, y_j^s) = \max\{0, \beta_y\cdot(y_j^s - y_i^s)\} \\ \varphi_z(z_i, z_j) = \max\{0, \beta_z\cdot(z_i - z_i)\} \end{cases} \tag{6}$$

That is, either alternative i performs better than j in terms of an attribute, in case there is no attribute-regret, or alternative i performs worse than j, in case the regret associated with this attribute comparison is a linear function of the difference in attribute values. The non-symmetrical nature (based on the behavioral assumption that only regret with respect to the best alternative, not rejoice with respect to other alternatives, plays a role in decision making) implies that non-fully compensatory decision making is assumed at the attribute level: bad performance of an alternative with respect to one attribute is not compensated by a good performance with respect to another attribute. Parameters β are now to be estimated from observed choices, the sign of the estimate signaling whether an increase in a particular attribute adds to or does not add to the formation of regret. Also note that, since we only allow for positive or zero attribute-regret, the regret associated with a particular alternative (as specified in Equation (4)) is by definition non-negative.

Now that the regret associated with each alternative for a given state of the world is derived, we proceed by defining expected regret as the sum of the regret associated with every possible state of the world, weighed by their probability of occurring. For the case of alternative *i*, we thus write:

$$ER_i = \int_S R_i^s \cdot f(s)\, ds \tag{7}$$

The individual is subsequently assumed to choose the alternative with the lowest expected regret.

11.3.2 Econometrical aspects

Together, Equations (3) to (7) in augmentation with a minimum regret decision rule, define risky choice behavior at the individual level. In order for the model to become operational, in the sense described in Footnote 79, we now take the perspective of an analyst that is facing a sample of individuals *n*. Let us start by assuming that the analyst is unable to exactly assess an individual's intrinsic preferences β_z for some alternatives over others, assuming these are not constant within the sample[82]. Capturing this intrinsic preference-heterogeneity implies that an error vector is added to the vector of constants *Z*. Let us denote this vector as $\eta_n \sim N(0, \sigma_{\eta_n})$. Subsequently, we add an i.i.d. error component ε to *ER*, in order to reflect the analyst's measurement errors in combination with his failure to capture all attributes that are relevant to the decision maker, as well as the 'mistakes' and idiosyncrasies that travelers may display when choosing. Adding the error components produces a random expected regret: *RER* = *ER* + ε. Now, the minimization of this random expected regret is mathematically equivalent to maximizing –*RER*. Therefore, the probability that individual *n* chooses alternative *i*, conditional on a particular value of η_n, may be derived using the well known multinomial logit-model, and the unconditional choice probability may be written as:

$$P_{in} = \int_{\eta_n} \left(\frac{\exp\left(-RER_{in}(\eta_n)\right)}{\sum_{l \in \{i,j,k\}} \exp\left(-RER_{ln}(\eta_n)\right)} \right) \cdot f(\eta_n)\, d\eta_n \tag{8}$$

And, acknowledging that individual *n* makes a number of trips $t = 1,2,...,T_n$, the unconditional sample likelihood for *N* individuals can be written as:

$$L = \prod_{n=1}^{N} \int_{\eta_n} \left[\prod_{t=1}^{T_n} \left(\frac{\exp\left(-RER_{in}^t(\eta_n)\right)}{\sum_{l=i,j,k} \exp\left(-RER_{ln}^t(\eta_n)\right)} \right)^{y_{in}^t} \right] \cdot f(\eta_n)\, d\eta_n \tag{9}$$

where y_{in}^t equals one if alternative *i* is chosen by individual *n* at trip *t*, zero otherwise.

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[82] A logical extension would be to allow also for parameters β_x and β_y to vary randomly. Extension towards such random taste heterogeneity is straightforward.

11.3.3 A note on the differences between the RT-based and the EU-based approach

It can be seen by inspecting Equations (5)-(7) that, in a binary choice set, our formulation of (expected) regret-minimization reduces to (expected) utility-maximization. This is consistent with Loomes & Sugden (1982) findings: a more complex specification of the regret function (7), involving non-linearity, will prohibit this reduction to utility maximization in a binary choice situation. As an Epilogue to this Section on an operational RT-based model of risky choice, we will briefly illustrate how an individual, choosing from a choice set containing more than two alternatives characterized by more than one attribute, that applies regret-minimization may arrive at different choices than an individual that maximizes utility. Assume the situation where, for a given state of the world, three travel alternatives are characterized by their travel times (*TT*, minutes) and travel costs (*TC*, euros) only: $car1 = \{TT = 75, TC = 1\}$, $car2 = \{TT = 41, TC = 3\}$ and $car3 = \{TT = 61, TC = 1.5\}$. The traveler now values travel time (differences) as -0.01/minute, and travel cost (differences) as -0.5/euro. Should the traveler maximize utility, she arrives at her choice as follows: $V(car1) = -0.01 \cdot 75 - 0.5 \cdot 1 = -1.25$, and by similar calculation she finds that $V(car2) = -1.91$ and that $V(car3) = -1.36$. Her preference over the choice set is easily seen to be $car1 \succ car3 \succ car2$; $car1$ is chosen as a result. Another traveler minimizes regret, instead of maximizing utility. Her choice is determined as follows. First, all binary regrets are calculated, giving (note the positive parameter signs: higher times and costs add to regret): $R_{12} = 0.01 \cdot (\max\{75 - 41, 0\}) + 0.5 \cdot (\max\{1 - 3, 0\}) = 0.34$. In words, the traveler experiences regret in terms of travel time, but not in terms of travel costs. Similarly it can be seen that $R_{13} = 0.14$ (also due to a regret in terms of travel time only), and that $R_{21} = 1$, $R_{23} = 0.75$, $R_{31} = 0.25$ and $R_{32} = 0.20$. For each alternative, the highest regret is relevant only (following the notion that no regret is experienced with respect to second-best options). This gives: $R_1 = 0.34$, $R_2 = 1$ and $R_3 = 0.25$. Minimizing regret leads to the following preferences of the traveler: $car3 \succ car1 \succ car2$; $car3$ is chosen as a result.

Intuitively, this difference in choice behavior between the two decision strategies can be explained as follows: in a utility-maximization framework, *car*1's bad performance in terms of travel time can be fully compensated by its strong performance in terms of costs. This is not the case in the above formulated regret-minimization framework, which rather rewards the absence of substantial regret for all attributes. The provided example illustrates this by showing how *car*2, a mediocre performer on each attribute, ends up being preferred over an alternative (*car*1) with a more extreme performance at the attribute level. Note that the above illustration deals with utility and regret for a given state of the world, not with *expected* utility and *expected* regret. The authors performed a monte-carlo simulation to evaluate the differences at the EU-ER level. The simulation results (which are not provided here) indicate that differences between the utility maximizing and regret minimizing rule are still present at the EU-ER level, in the cases considered, though less profound due to averaging effects.

Another feature of the RT-based model is worth mentioning here: the interpretation of ratio's of estimated taste parameters is not equivalent to their interpretation in an EU-framework: take for example estimated time- and cost-parameters, whose ratio is often used in EU-based models as a measure of value-of-time. However, the fact that our RT-based model does not assume fully compensatory decision-making implies that a positive time difference does not necessarily make up for a negative cost difference, and that the whole concept of parameter ratio's has a different interpretation than within an EU-based model. Here, a parameter ratio should be regarded a measure of the contribution of one parameter to an alternative's regret, relative to another parameter's contribution. Another consequence of foregoing the assumption of fully compensatory decision making at the attribute level, is that the assumption of a linear, one parameter per attribute formulation of the regret-function does not imply the assumption of risk neutrality with respect to the attribute (as would be the case in an EU-based model, which would reduce to an Expected Value model in that case). Rather, the linear form in Equation (6) implies that in the domain of relative gains (i.e. a considered alternative performs better than another one in terms of the attribute), the individual is risk-neutral with respect to the relative performance of the considered alternative. Also note that the fact that our model is based on the notion of an attribute-by-attribute comparison implies that the less attributes alternatives have in common, the less elaborate the comparison is assumed to be. In contrast, the EU-approach is based on the notion that every alternative should always be evaluated in terms of all its relevant attributes.

Finally note the following proposition (prop. 1): it can be shown (see Appendix 1) that for general choice sets, regret minimization as specified by Equations (4) to (6) reduces to utility maximization if there exists an alternative which performs as good as or better than every other alternative, in terms of every single attribute. This implies that our specification of ER-minimization reduces to EU-maximization if for all states of the world there is such an alternative (this does not need to be the same one for every state).

11.4 Data-collection

11.4.1 A multimodal travel simulator with information provision

The constructed simulator is geared towards the study of decision making under incomplete knowledge in multimodal networks, in the presence of highly functional travel information services. A dynamic stated preference travel and information simulator is used in order to study in a controlled environment hypothetical ATIS-technology without requiring expensive field trials, and without being limited by more basic stated preference surveys. It stands in a long tradition of computer-based travel simulator tools of varying levels of sophistication (See Koutsopoulos et al. (1995) and Bonsall (2004) for useful overviews). See Chorus et al. (2006c) for an extensive introduction and validation of the simulator as a data-collection tool. Figure 1 shows the screen plot of an arbitrary travel situation that a participant may be confronted with. The workings of the simulator will be discussed based on this example. The screen consists of 4 parts: lower left presents the trip context, upper-left shows the transport network, upper right presents the information service and lower right shows a visual aid.

Trip purpose
The trip purpose consists of a story line describing trip purpose (business, commute, social visit and leisure) and possibly preferred arrival times, generated at random for each trip from a set of predefined options. These story lines were presented at the beginning of each new trip through pop-up windows, after which they were located at the lower left of the screen during the completion of the trip. Next to the story line, the trip context displays a clock, presenting accelerated time. It ticks away one minute waiting time or in-vehicle time per actual second, after a travel alternative is executed. Finally, beneath the clock, a money counter registers the amount of money spent so far on a given trip, including both travel costs and costs of information acquisition.

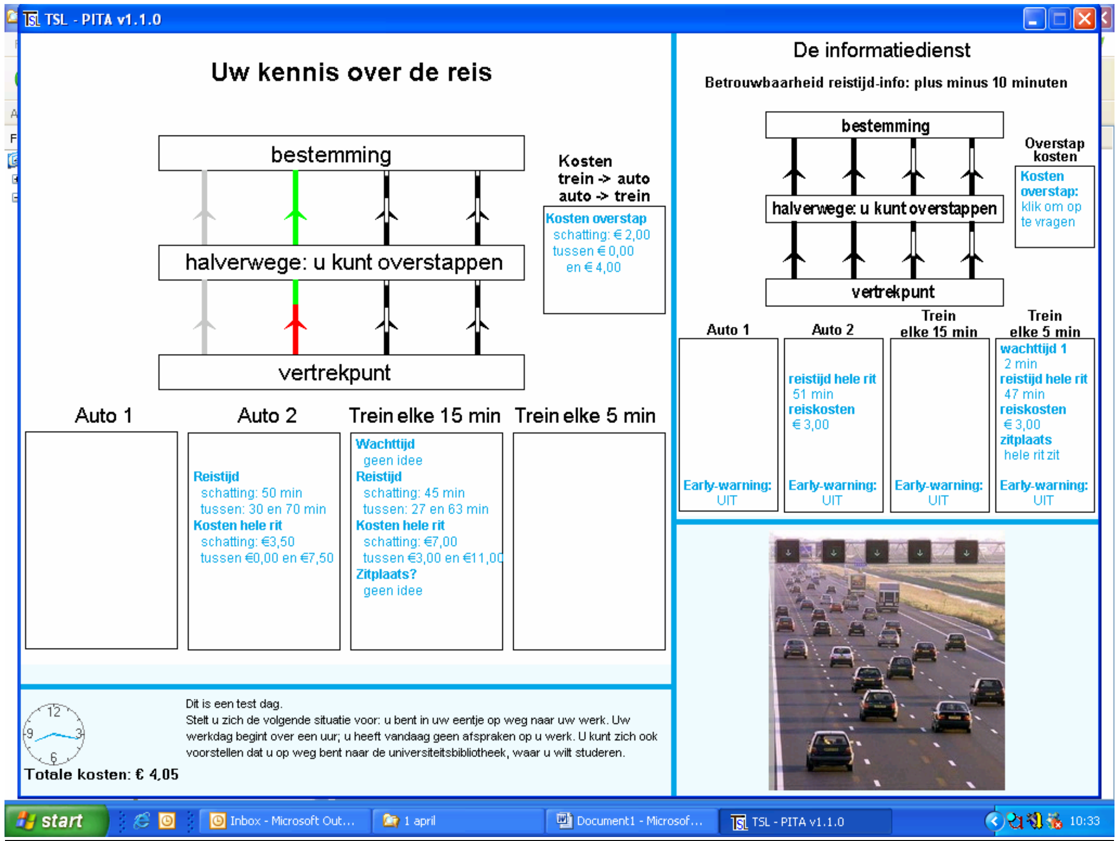

Figure 1: screen plot of the simulator *(in Dutch)*

The transport network

A purely fictive O-D pair was created, connected by four paths displayed as arrows and an interchange facility halfway. As our current analyses do not deal with in-trip choice adaptation, we will not discuss here the interchange possibilities. The two left arrows symbolize two car-options, i.e. highway routes. The two routes are equivalent except that they may differ in terms of travel times and costs. Next to these two car-options, two intercity train options exist which are also equivalent, except that they may also differ in travel time and cost, as well as seat availability. Furthermore, the left one of the two trains departs once every 15 minutes, the right one once every 5 minutes, thus inducing a lower expected and maximum waiting time. The number of a priori alternatives 'known' to the traveler varies per trip. 'Unknown' alternatives are marked grey instead of black, and the traveler initially has no knowledge concerning their characteristics. These alternatives are inactive, and cannot be executed by the traveler. For the trip displayed in Figure 1, one car-option and the 15 minute train option are known a priori. The other train alternative is activated by the information service. The participant's initial knowledge of the alternatives (i.e., before acquiring any information) is presented in the boxes below the black arrows. The following a priori knowledge is provided to the traveler for the known alternatives: for both car and train options, i) *best guesses* for travel times and travel costs[83] are provided, as well as ii) *certainty*

[83] Travel times were framed as door to door for car-trips, and door-to-door minus waiting times for train-trips. All 'best guess' travel times were randomly varied beforehand and could take the values of 50 and 60 minutes for the car-option and 45 and 55 minutes for the train option (since to the latter also waiting times had to be added to get the total travel time). Travel costs were framed as fuel expenditures + parking costs for car-trips, and ticket tariffs for train-trips. Travel costs were randomly assigned beforehand the values of 3.5 euro or either 7 euro.

intervals, i.e. ranges of times and costs within which the participants are told (correctly) that actual values will fall almost certainly. A priori, train travelers do not know the exact departure times (although they do know the service's frequency), neither do they know whether or not a seat is available for them. A participant may start his journey by clicking one of the arrows, and subsequently confirming his choice in the appearing pop-up window. By confirming his or her choice, there is no possibility of adaptation until the interchange point is reached. Directly after confirmation, the traveler is confronted with the actual costs of the alternative, and train travelers were also informed whether or not they had a seat. As the trip commences (Figure 1 shows the situation where a car option is chosen), the clock starts ticking and the arrow that represents the chosen alternative incrementally turns red, indicating the amount of distance traveled so far. These actual travel costs were drawn from a normal distribution, having the best guess as mean, and a quarter of the length of the 'confidence' interval as standard deviation, so that 95% of the drawn actual values would indeed fall within the 'certainty' interval. The same applies to the generation of actual travel times. On the other hand, seat availability was randomly drawn from a discrete distribution (50% chance of having a seat), waiting times from a uniform distribution between 0 and the headway (either 5 or 15 minutes).

The information service

Instead of choosing to execute one of the known alternatives, based on its uncertain characteristics, the traveler may choose to postpone choice and acquire information first, before eventually executing a travel alternative. As can be seen in Figure 1, the information service's layout is an exact copy of the transport network. In the sample used for our current analyses all provided information was fully reliable, meaning that every received message corresponds to the actual value of that particular attribute. Participants were told about this complete reliability.

The service presents three ways of acquiring information. Firstly, a traveler may acquire information concerning one or more particular attributes of a known alternative, be it travel times and/or costs for a car or train option, and/or waiting times and seat availability for train options. This is done by first clicking on the arrow of a 'known' alternative and subsequently checking the boxes for those attributes for which information is needed (the information price is listed at every box, and varies between .15, .30, .45 eurocents). After the boxes are checked, the service displays the information in the information box. Figure 1 presents the situation where for one of the car-options, both travel time and costs are informed about by the information service. Secondly, a traveler can ask the service to generate or activate one or more alternatives that are currently 'unknown' to him or her. This is done by clicking on an arrow within the information service screen that corresponds to an unknown alternative in the transport network. After this is done, a pop-up window appears that states the price of the information acquisition (being varied between .45, .60 and .75 eurocents) and asks for a confirmation. After confirmation, the alternative is made active, that is, its color turns black in the transport network, and the alternative can be executed from then on. Furthermore, the information service provides estimates for all the alternative's characteristics. These estimates are displayed in the box below the activated alternative in the information service screen part. Figure 1 presents such an information acquisition for the 5 minute train option. Thirdly, a traveler may activate the so-called early-warning function. This function notifies a traveler when an alternative that is about to be chosen has an actual travel time that is substantially larger than the traveler's best guess (no strict level of travel time differences that triggers these messages is mentioned to the travelers). This type of information is acquired by clicking on a known alternative and checking the early warning box. Note that all these types of information can be acquired either pre-trip, as well during the trip, which makes the information service 'mobile'.

11.4.2 The experiment

Participants were recruited through placement of advertisements in a campus newspaper and another free newspaper. Also a mail was sent out to ± 500 students. A 20 euro reward was offered for participation. All participants were required to have had some experience with both car and train travel. In total, 264 individuals were recruited this way, of which 31 were randomly assigned to the experimental conditions on which we focus here (i.e. fully reliable information conditions). Table 1 presents response group characteristics, and shows a rather heterogeneous group in terms of socio-economic characteristics.

Table 1: response group characteristics (N=31)

Variable	Frequency
Gender	
female	14
male	17
Age	
< 25	16
< 40	10
< 65	5
Completed education	
lower education	0
secondary school	21
higher education	10
Main out-of-home activity	
paid work	9
education	18
other	4
Car availability	
always	6
usually	5
sometimes	14
less than sometimes	6
Public Transport (PT) season ticket	
some form of	24
none	7

Before commencing with the simulator experiment, an extensive web survey was filled out by the participants concerning among other things their actual travel behavior. Following this, participants performed a brief binary mode-choice experiment. Subsequently, they were given a rather extensive introduction in the simulator. Participants were asked very explicitly to not regard the experiment as some form of a game (e.g. by trying to travel as fast as possible, or spending as much or as little money as possible), but rather to try to identify with the travel situations presented and make choices that they would make, would they be confronted with such a situation in real life. It is known that in simulated travel situations like the ones presented in this experiment, the issue of motivation is a difficult one (see Carson et al. (2000)

and Bonsall (2002) for overviews of possible incentive-caveats). In order to increase the motivation of participants to put effort in identifying themselves with the simulated travel environment, the following approach was chosen: participants were told during the introduction that they could win a 7,5 euro bonus, to be awarded to about half of the respondents, based on the success of their identification effort. It was mentioned that the correspondence of their choice-behavior as observed in the simulator experiment with the choice-behavior observed in the stated mode choice experiment and the answers to web-survey questions concerning revealed behavior would be used to measure the degree of identification. It was made clear to the participants that they would probably be most likely to obtain the bonus by simply making a real effort to identify with each of the travel situations presented. After the introduction, about 50 minutes were left. In these 50 minutes, participants made two test-rides, during which they were encouraged to try out all possible types of traveling and information acquisition. These trips were not saved in the database, as was told to the participants.

The first two trips after the trials were performed without information being available. Subsequently, a number of trips (maximum 25) were to be made in the presence of information services. In total, the 31 participants made 559 trips (excluding the test-trips and the trips without information service available), on average equaling about 18 trips per participant. Some 30% of trips made fell under trip purpose of an important business trip. Although most observed trips consisted of a sequence of decision stages (consisting of one or more information acquisitions followed by one travel choice), we are currently only interested in the choice the individual makes directly at the outset: either she chooses to acquire some form of information, or else she decides to execute one of the available travel alternatives. For this paper's analyses, the information acquisition alternatives are aggregated into one alternative. This alternative may be described as postponement of choice, and serves as a base-alternative in the analysis. See Table 2 for the observed choice frequencies at the outset of each trip.

Table 2: Choice frequencies for information acquisition and travel choices

Choice alternative	Availability at the outset (# trips)	Freq. (N=559)	Rel. Freq. (100%)
Choice postponement	559	413	74 %
Execute car 1	367	31	5 %
Execute car 2	390	29	5 %
Execute train 1	355	64	11 %
Execute train 2	213	22	4 %

11.5 Model estimation

It should be emphasized here, that the model is estimated here primarily to demonstrate and illustrate the workings and feasibility/plausibility of the developed RT-based risky choice model.

11.5.1 Model operationalization and parameters to be estimated

Table 2 shows the dataset available for analysis: 559 choices made by 31 individuals at the outset of trips where either a choice is made for choice-postponement (information acquisition) or for one of the available travel alternatives, the latter being risky in terms of their attributes. We adopt the following overall model structure to combine the notion of choice postponement with a regret-minimalization decision-rule: an individual is assumed to first consider all available travel alternatives to derive a measure of expected regret for each of them. The travel alternative with lowest expected regret is assumed to be the preferred one. However, it is possible that the preferred travel alternative's expected regret is still too high for the individual to be acceptable. In that case, where the expected regret of the most attractive alternative is above the individual's regret-threshold, (s)he chooses to postpone choice and acquire information first – with the aim of reducing the uncertainty (resulting in expected regret) of the choice situation. When we assume that an individual's regret-threshold consists of a deterministic part, an individual-specific random component $\delta_n \sim N\left(0,\sigma_{\delta_n}\right)$ and an i.i.d. random component, the above presented choice structure can be written as a multinomial logit-model. Consider travel alternatives *i, j, k* and a regret-threshold π. Equation (8) can then be extended into the following choice probabilities for travel alternative *i* and for choice postponement:

$$P_{in} = \int_{\eta_n,\delta_n} \left(\frac{\exp\left(-RER_{in}\left(\eta_n\right)\right)}{\sum_{l\in\{i,j,k\}} \exp\left(-RER_{ln}\left(\eta_n\right)\right) + \exp\left(-\pi\left(\delta_n\right)\right)} \right) \cdot f\left(\eta_n,\delta_n\right) d\left(\eta_n,\delta_n\right) \qquad (10)$$

$$P_n^{\text{postpone}} = \int_{\eta_n,\delta_n} \left(\frac{\exp\left(-\pi\left(\delta_n\right)\right)}{\sum_{l\in\{i,j,k\}} \exp\left(-RER_{ln}\left(\eta_n\right)\right) + \exp\left(-\pi\left(\delta_n\right)\right)} \right) \cdot f\left(\eta_n,\delta_n\right) d\left(\eta_n,\delta_n\right) \qquad (11)$$

That is, a higher regret-threshold, or a lower expected regret of a travel alternative, results in a lower probability that choice is postponed, and in a higher probability that the travel alternative is executed.

We estimate the average regret-threshold. Also, the standard deviation of the individual-specific threshold-component σ_{δ_n} is estimated, allowing for different individuals to have different regret thresholds - and associated inclinations to acquire information before executing a travel alternative. We estimate a constant for traveling by car, and the standard deviation of the random component reflecting the individual-specific intrinsic preference for traveling by car. A travel time parameter is estimated, as well as an additional travel time valuation for business trips, and a travel cost parameter. Since there was no variation in seat availability for train options at the outset of the trip, no parameter is estimated for this attribute.

Before moving to the estimation results, note that the model of risky choice presented in Section 11.3 assumes that individuals perceive risky attributes of alternatives in terms of a multidimensional probability density function (pdf). Since the alternatives were presented in terms of best guesses and certainty intervals, additional assumptions are needed with respect to their translation towards a multi-dimensional pdf that may be used for our analyses. i) We assume mutual independence of attributes within and between alternatives. Given the set up of the experiment (where independency was assured) and the provided meaning of the attributes, see Footnote 83, this is a reasonable assumption. ii) The following assumptions were made to arrive at an operational multidimensional pdf. Travel times and costs, presented to the participant through a best guess and a certainty-interval, are assumed to be perceived in the form of a normal distribution around this 'best guess' with a standard deviation that equals one-quarter of the length of the certainty interval, implying that 95% of draws from this density function are within the certainty-interval. Perceptions of waiting time for trains, presented to participants through a headway ("a train departs every *x* minutes"), are assumed to consist of a uniform distribution between 0 and *x*. Note that these distributions match those that are used to generate actual travel times, waiting times and costs – that is, we assume that participants' beliefs concerning risky attributes contain no structural bias.

Given these assumptions, Equations (3) to (7) are used to calculate regret for each travel alternative: for each observed choice. The regret associated with each alternative is calculated by comparing it, for a given parameter setting, to all other travel alternatives in terms of travel times, travel costs, and intrinsic preferences for traveling by car, rather than train. Subsequently, the expected regret of the travel alternative with lowest expected regret is compared to the individual's threshold, leading to choice probabilities as given by Equations (10) and (11) for each travel alternative and choice-postponement. Equation (9) gives the sample likelihood.

11.5.2 Model estimation and results

The model was coded in GAUSS 7.0. Note that, from the analyst's point of view, the computation of the sample likelihood function as given in Equation (9) involves evaluating two multidimensional integrals: one two-dimensional integral captures the intrinsic individual-specific preference for traveling by car as well as the individual-specific component of the regret-threshold. A second multidimensional integral reflects that travelers do not know beforehand what state of the world they will encounter when executing one of the available travel alternatives. Since the four travel alternatives have been characterized in terms of risky travel times (consisting of a waiting-time draw added to a travel-time draw for train options) and costs, this latter integral has 2+2+3+3=10 dimensions. Note the crucial difference in terms of interpretation between the two sets of integrals: where the error component integral reflects the *lack of knowledge from the side of the analyst* with respect to the traveler's intrinsic preference and her regret threshold, the state-of-the-world integral reflects the *traveler's lack of knowledge* with respect to what travel time and cost she will encounter when choosing a particular travel alternative. Both multidimensional integrals were evaluated through simulation, using 400 Halton draws per individual per dimension for the individual-specific car-preference and regret-threshold component, and 1000 Halton draws per dimension for the 10-dimensional state-of-the-world integral. That is, for each individual-specific two-dimensional draw for the error components, 1000 draws are made to simulate states of the world. Sensitivity analysis with a varying number of draws showed that the numbers used where sufficiently large. Table 3 shows the estimation results.

Concerning the performance of the model as a whole, it appears that the parameters are generally highly significant and all have the expected sign. Furthermore, the large increase in Log-Likelihood signals that a substantial part of the variation in travelers' choices is captured with our seven-parameter regret-based model. Together, the model fit in combination with the significance and expected sign of the parameters suggest validity of the proposed methodology in terms of the regret-based model specification, the assumptions made to operationalize the model, and the data gathered through the simulator-experiment.

Table 3: Estimation results

Variable	Parameter	t-Statistic
Car constant	-1.123	-3.917
Sigma (car constant)	0.934	1.624
Travel time (minutes)	-0.175	-6.305
Business * Travel time (to be added to Travel time)	-0.414	-6.561
Travel costs (euros)	-0.485	-5.117
Regret threshold	1.723	3.411
Sigma (regret threshold)	1.677	5.109
Model statistics		
0-Log-Likelihood	-652	
Log-Likelihood at convergence	-332	
Number of cases	559	

Looking at the parameter estimates in more detail, it appears that there is an intrinsic preference for traveling by train, rather than by car. Heterogeneity concerning modal preferences (*Sigma(car constant)*) remains insignificant. On average, individuals maintain a substantial and significant regret-threshold, and a substantial level of heterogeneity exists concerning its magnitude (*Sigma (regret threshold)*). The latter signals that individuals may differ widely concerning the level of expected regret they are willing to incur from a given travel choice situation. Travel time- and cost-parameters are of the expected sign, but note that, as mentioned in Section 11.3, their interpretation is not equivalent to time- and cost-parameters in a random utility model. The estimated values imply that a cost-difference between alternatives of one euro adds, for the average traveler, almost three times as much regret to the considered alternative as does a time-difference of one minute. The fact that our model does not assume fully compensatory decision-making implies that a positive three minute time difference does not necessarily make up for a negative one euro cost difference. Finally, for business trips, high travel times appear to cause a very substantial extra amount of regret (*Business * travel time*).

11.6 Conclusions

This paper presents an operational non-Expected Utility model of risky travel choice. The model is rooted in Regret-Theory (RT), one of the leading alternatives for the EU framework. RT asserts that an individual making a choice under risk is aware that she may end up having chosen an alternative which turns out to be less attractive than a non-chosen alternative, causing regret. It is subsequently asserted that the individual anticipates this possibility of regret and aims to minimize expected regret when choosing from available alternatives. The RT-based model presented in this paper contributes to the literature on risky travel modeling by adding a plausible and operational alternative to the well established EU-framework. Furthermore, with respect to the general field of risky choice modeling, this paper extends the operational scope of regret-based models towards general choice sets and multiattribute decision making. The RT-based model of risky travel choice is estimated on data from a multimodal travel simulator, where participants could choose between travel alternatives with risky travel times and costs. Estimation results, i.e. a good model fit in combination with significance and expected sign of the parameters, suggest the validity of the proposed RT-based model specification.

Notwithstanding this, some reflections are in place here: firstly, it should be noted here that the RT-based model is vulnerable to combinatorial explosion: the number of evaluations that need to be performed in order to arrive at a measure of expected regret per alternative increases exponentially with the number of alternatives available in the choice set. This vulnerability will cause computational problems for large choice sets (note that in our case, involving 5 alternatives and 2 risky attributes per alternative, these problems were certainly not persuasive). Secondly, due to the fact that the RT-based model does not assume fully compensatory decision-making, the meaning of ratio's of parameter values have a less intuitive meaning than those derived from a random utility model. Parameter ratio's in random-utility models are often applied to derive supplementary behavioral insights such as value-of-time estimates. The lack of such an interpretation in the RT-framework can be seen as a disadvantage. However, it is important to note here that this result is not due to a specific operationalization of RT-premises. In fact, the non-compensatory, or asymmetric, nature of RT for general choice sets is a basic model premise (Quiggin, 1994) which suggests that individuals experience regret only with respect to the best option available, rather than experiencing regret or rejoice with respect to other alternatives available (better or worse than the considered one). In other words, individuals are assumed to consider regret, not rejoice, when making choices. From the RT-based approach, at least the one designed for general choice sets, there is no such thing as an individual's value of time, since it assumes that there is not a fully compensatory trade-off between the two attributes, for all different alternatives in the choice set. We feel that this non-compensatory structure may be particularly useful in a travel behavior context, e.g. for describing the situation where high travel times are unacceptable for the individual for certain trips.

As a final remark we note that an interesting avenue for further research would be to create a choice experiment where choice tasks are constructed in such a way that (expected) regret-minimization implies different choice outcomes than (expected) utility maximization. This would increase our insight into the determinants of (risky) choice behavior. However, it should again be stressed that we do not propose the RT-model presented here as superior in any way to EU-theory. Rather, we feel that EU-theory incorporates the rare combination of an intuitive and simple model structure, highly suitable for empirical analyses as well. But, it is felt that operational non-EU models of risky choice should, more than is done nowadays, be considered for the analysis of risky travel choice. Looking at travel behavior from different angles and perspectives is likely to deepen our understanding of its underlying choice dynamics and subtleties. The RT-based model presented here is an attempt to provide such a different perspective. Nothing less, nothing more.

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Appendix

We here prove proposition 1, which states that for general choice sets, regret minimization as specified through Equations (4) to (6) reduces to utility maximization if there exists an alternative which performs as good as or better than every other alternative, in terms of every single attribute.

We assume a three alternative (i, j, k), two attributes per alternative (x, y) choice situation. Generalization towards larger choice sets and more than two attributes per alternative is straightforward. We adopt the following notation: $i = \{x_i, y_i\}$, $j = \{x_j, y_j\}$, $k = \{x_k, y_k\}$. The higher the value of x or y, the more attractive the alternative, i.e. β_x and β_y, reflecting the individual's taste with respect to the attributes, are strictly positive. Assume now that alternative i is at least as good as j and k in each of the attributes: $(x_i \geq x_j) \wedge (x_i \geq x_k) \wedge (y_i \geq y_j) \wedge (y_i \geq y_k)$. Now we apply Section 11.3's Equations (4) to (6) in order to obtain measures of regret for each of the alternatives (for example, R_{ij}^x representing the regret associated with alternative i, compared to alternative j with respect to attribute x). First, it is easily seen that there is by definition no regret associated with alternative i:

$$\left.\begin{array}{l} \left.\begin{array}{l} R_{ij}^x = 0 \\ R_{ij}^y = 0 \end{array}\right\} R_{ij} = R_{ij}^x + R_{ij}^y = 0 \\ \left.\begin{array}{l} R_{ik}^x = 0 \\ R_{ik}^y = 0 \end{array}\right\} R_{ik} = R_{ik}^x + R_{ik}^y = 0 \end{array}\right\} R_i = \max\{R_{ij}, R_{ik}\} = 0 \tag{A.1}$$

Now, it can be seen (see (A.2) and (A.3)) that any regret that might be associated with alternative j due to a comparison with alternative k is by definition either zero or non-zero but smaller than or equal to the regret that is due to the comparison of j with i (since for each attribute, i performs at least as good as k, by definition). Therefore, the comparison of j with k becomes irrelevant for the determination of choice. The same reasoning holds for the derivation of alternative k's regret due to comparison with i and j. Only the comparisons of j and k with i remain relevant for the choice process:

$$\left.\begin{array}{l} \left.\begin{array}{l} R_{ji}^x = \beta_x (x_i - x_j) \\ R_{ji}^y = \beta_y (y_i - y_j) \end{array}\right\} R_{ji} = \beta_x (x_i - x_j) + \beta_y (y_i - y_j) \\ \left.\begin{array}{l} R_{jk}^x = \Theta \leq R_{ji}^x \\ R_{jk}^y = \Psi \leq R_{ji}^y \end{array}\right\} R_{jk} = \Theta + \Psi \leq R_{ji} \end{array}\right\} R_j = \beta_x (x_i - x_j) + \beta_y (y_i - y_j) \tag{A.2}$$

And

$$\left.\begin{array}{l}\left.\begin{array}{l}R_{ki}^x = \beta_x(x_i - x_k)\\ R_{ki}^y = \beta_y(y_i - y_k)\end{array}\right\} R_{ki} = \beta_x(x_i - x_k) + \beta_y(y_i - y_k)\\ \left.\begin{array}{l}R_{kj}^x = \Xi \leq R_{ki}^x\\ R_{kj}^y = \Omega \leq R_{ki}^y\end{array}\right\} R_{kj} = \Xi + \Omega \leq R_{ki}\end{array}\right\} R_k = \beta_x(x_i - x_k) + \beta_y(y_i - y_k) \tag{A.3}$$

Note that, should there not be an alternative that is at least as good as all the others with respect to all attributes, all mutual comparisons are potentially relevant to the choice process, which prohibits reduction of regret-minimization to utility maximization.

If we now normalize the attribute-values by setting $x_i = y_i = 0$, we can rewrite the outcome of (A.1)-(A.3) as follows (note that $x_j \leq 0, y_j \leq 0, x_k \leq 0, y_k \leq 0$, so that R_j and R_k are non-negative, and V_j and V_k non-positive, for strictly positive β's):

$$\begin{array}{l}R_i = 0\\ R_j = -\beta_x \cdot x_j - \beta_y \cdot y_j\\ R_k = -\beta_x \cdot x_k - \beta_y \cdot y_k\end{array} \tag{A.4}$$

A utility maximizer would arrive at the following utilities:

$$\begin{array}{l}V_i = 0\\ V_j = \beta_x \cdot x_j + \beta_y \cdot y_j\\ V_k = \beta_x \cdot x_k + \beta_y \cdot y_k\end{array} \tag{A.5}$$

Now it is directly seen that not only is alternative *i* the chosen alternative under both strategies, but also that differences in regret between alternatives exactly equal the opposite of the differences in utility: $R_i - R_j = -(V_i - V_j)$, $R_i - R_k = -(V_i - V_k)$ and $R_j - R_k = -(V_j - V_k)$. This implies that minimization of regret reduces to maximization of utility. Note that this finding is not a result of our linear specification of the attribute-regret function. **QED**

Chapter 12: Epilogue II

Chorus, C., G., Timmermans, H.J.P., van Wee, G.P., 2006. Traveler decision making under knowledge limitations and information provision: Possible research avenues for trailblazers. In van Zuylen (eds.): Selected Papers of the 9^{th} *TRAIL Conference: TRAIL in MOTION*, Rotterdam, The Netherlands.

Abstract

This paper presents promising avenues for future research into the topic of traveler decision making under conditions of knowledge limitations and information provision: new research questions are identified and research methodologies that may be applied to address these questions are also presented. Research questions concern i) an exploration of travelers' knowledge limitations and learning mechanisms in their full dimensionality, ii) an exploration of the full variety of travel information types, iii) a study of how the behavior of one traveler is influenced by the behavior of others, iv) the identification of the potential role of travel information during area evacuations, v) understanding the actual process behind information use and effect and vi) understanding the geographical and cultural generalizability of travel behavior insights. Research perspectives that are presented and discussed here as potentially useful for the study of the above mentioned research questions are i) behavioral economics, ii) evolutionary biology, iii) artificial intelligence and iv) decision-neuroscience.

12.1 Introduction

The introduction of travel information services in the late 1980s has brought about substantial changes in the subjects and methods covered in travel behavior research. First, the development and deployment of ever more sophisticated information services has led to the birth of a new research stream concerning the acquisition of information among travelers and the effect of received information on their subsequent travel choices (e.g. van Berkum & van der Mede, 1993; Emmerink et al., 1996; Kenyon & Lyons, 2003). Secondly, in an indirect way, the introduction of travel information services has led to a fundamental change in research paradigm among travel behavior researchers: no longer did it appear reasonable to assume that travelers had complete knowledge of the transport network and the attributes of available travel alternatives when making travel choices. Gradually instead, the dominant perspective in the travel behavior community became that of travelers being decision makers that face i) all sorts of knowledge limitations and ii) the possibility to reduce those limitations by acquiring information before making a travel choice. This paradigm shift has led to the development and testing of more complex, but presumably more realistic models of traveler behavior (e.g. Avineri & Prashker, 2003; Arentze & Timmermans, 2005a; Chorus et al., 2006a). Altogether, a large and rapidly growing body of literature is convincing evidence of the major changes that have occurred in travel behavior research over the last 15 years, as a result of the introduction of ever more advanced travel information services.

Notwithstanding the numerous contributions this literature has provided to our knowledge of the ways in which travelers (and individuals in general) cope with knowledge limitations and information provision when making choices (see Chorus et al., 2006b for a review of this body of research), much remains unknown. In fact, one of the main lessons that may be learnt from recent research efforts on the topic is that travel decision making, especially under conditions of knowledge limitations and information provision, is a very complex and perhaps even wicked area of research – an area we have only just begun to explore. This paper aims to point out potentially interesting avenues for future trailblazers into the remaining unknown area. It commences by formulating what subjects of research may have not yet been adequately covered in literature concerning traveler decision making under conditions of limited knowledge and information provision (Section 12.2), and proceeds by pointing out what perspectives of research (Section 12.3) may be useful to address the subjects of research identified.

This paper does not present a review of the state of the art of traveler decision making under conditions of limited knowledge and information provision: we will provide a limited number of key-references, instead of making reference to the full body of potentially relevant literature. Also note that this paper focuses on the behavioral aspects of travel choices; we do not consider how growing insights into traveler behavior might lead to new research questions in the transport policy arena, and what methods may be used to address these questions. We will however give some attention to the transport policy perspective in the discussion part of this paper (Section 12.4). Furthermore, note that by identifying new research avenues, we do not mean to say that these avenues have been completely ignored in past research efforts, and hence are completely 'new'. Also note that we do not consider the important issue of data-collection methods here. Finally, note that we are not under any illusion of being complete. Rather, we aim to identify and briefly discuss, within the allowed space, future research avenues that are, in our view, particularly interesting.

12.2 Avenues into the unknown: subjects of research

Before exploring potential avenues into the unknown, let us briefly touch upon what subjects of research have dominated the field of traveler decision making under conditions of limited knowledge and information provision in the past years. In a very broad sense, it may be said that until now, research efforts have predominantly focused on i) exploring the determinants of travelers' decisions to acquire information, and on ii) exploring the effect of acquired information on travelers' travel choices. Early efforts were mainly concerned with the effect of manifest factors (such as trip purpose, socioeconomic characteristics of travelers, etc) on information acquisition and effect. Recently, a shift towards a behavioral perspective has taken place, focusing on the behavioral determinants (such as knowledge, decision styles) of information acquisition and effect in general. The following avenues of research might provide fruitful opportunities to build upon these research efforts.

12.2.1 Exploring knowledge limitations and learning mechanisms in their full dimensionality

The large majority of travel behavior research that concerned itself with knowledge limitations and learning has focused on uncertainty with respect to travel times associated with travel alternatives (e.g. Horowitz, 1984; Ben-Akiva et al., 1991; Jha et al., 1998). However, there are many more knowledge limitations that a traveler may face and that hence should be considered in travel behavior research. Not only is it reasonable to assume that travelers face uncertainty with respect to other attributes of travel alternatives than travel time alone, they may also be unaware of existing and feasible travel alternatives in the first place. Also, when considering information provision as a means to redress such knowledge limitations, it should be acknowledged that travelers may face severe knowledge limitations concerning these travel information services themselves: it may not be known to them what information services exist that may help them make travel choices (e.g. Goulias, 2004), and how these services perform in terms of reliability (e.g. Sun et al., 2005), costs and usability. The more complex the transport network, the more diverse will be the knowledge limitations a traveler might face and the learning mechanisms she might apply. For example, besides learning from all sorts of provided travel information, travelers may learn about transport networks by communicating with others (word-of-mouth learning (e.g. Banerjee & Fudenberg, 2004)), by reasoning (e.g. Aragones et al., 2005) or by observing others (e.g. Merlo & Schotter, 2003). In general, a traveler's knowledge of a potentially multimodal and highly complex transport network (i.e. her knowledge concerning the availability and performance of i) alternative mode-/route-/departure time-options for getting from origin to destination and ii) information services) can be regarded as a mental or cognitive map (Arentze & Timmermans, 2005b). This map is potentially adjusted each time she moves through the network or uses some form of information. The formation and updating of mental maps over time and the role that gaps in such a mental map play in traveler decision making, are not yet sufficiently understood among travel behavior researchers. Further work, theoretically and empirically, thus needs to be done on this topic.

12.2.2 Exploring the full variety of travel information types

Several of the following information types may be available to travelers before or during their trip: information on specific attributes for specific alternatives (e.g. travel time information for car-options), information services that generate complete travel alternatives for a given trip, services that give advice to travelers concerning what mode/route/departure time to choose, and services that offer full trip guidance from origin to destination. All these types of information are becoming more and more dynamic (i.e. based on the actual and projected state of the transport network), intermodal (i.e. taking into account multiple travel modes and their linkages) and personalized (i.e. based on a traveler's personal preferences and her location in the transport network). Notwithstanding the variation in information types available to travelers, past research efforts have mainly focused on the use and effects of travel time information (e.g. Jha et al., 1998), often in combination with advice (e.g. Abdel-Aty & Abdalla, 2004). This focus is consistent with the above-mentioned research interest in the role of travel time uncertainty in traveler decision making. It seems fruitful however, to explore in greater depth how travelers may use other types of information in future theoretical and empirical research. Potentially interesting topics include: how do travelers learn from potentially unreliable, multiattribute information (e.g. combined information on travel times, costs, frequency and number of interchanges for transit alternatives)? How do they respond to having previously unknown travel alternatives added to their choice set?[84] How does the provision of guidance affect travelers' learning efficacy in the long term? How do travelers react to advice or guidance that may be partly perceived as counterintuitive or unreliable?

12.2.3 Towards acknowledging that travelers do not make choices in isolation of others

Throughout the social sciences (e.g. in microeconomics and social psychology), there is a large and growing tendency to acknowledge that individuals rarely make decisions in complete isolation of others and the decisions they make. Recently, this notion has become more and more common in travel behavior research. For example, researchers have studied how travelers may exhibit strategic behavior by anticipating the possible choices made by others (Han et al., 2005), how households may reach activity-travel decisions based on aggregation of the preferences of their individual members (Zhang et al., 2005) and vice versa, how social networks may serve as generators of activities and travel as well as facilitators of information exchange (Arentze & Timmermans, 2006), and how the fact that others choose some travel mode may increase the utility attached to the same mode (Dugundji & Walker, 2005). Notwithstanding this growing body of literature, it is still poorly understood how the fact that travelers make decisions partly as group members affects the way in which information is used among those travelers, and how it affects their behavior. For example, it appears worthwhile studying the possible occurrence of so-called information cascades (Anderson & Holt, 1997) within groups of travelers: these cascades hypothesize the possibility that provision of information to a small group of individuals might lead to changes in behavior among larger groups of individuals, due to their copying (Banerjee, 1992) of decisions made by members of the informed group. Another example of the nuanced ways in which travel information may influence the behavior of individuals in groups is that when travelers observe collectively provided information, they may anticipate the behavior of others in their vicinity and use this anticipation when making their own decisions. Taking into account strategic behavior, copying or herding behavior and other individual-group interactions is likely to improve our understanding of when and to whom information should be provided to have maximum impact.

12.2.4 Identifying the potential role of travel information during area evacuations

[84] Possible theoretical descriptions of these situations are provided and tested using travel simulator data in Chorus et al. (2006a, c).

Recent years have seen quite a few situations where large numbers of people needed to be evacuated from cities or regions. This has led to an increasing interest in the behavioral and network dynamics in the event of evacuation (e.g. Jha et al., 2004; Murray-Tuite & Mahmassani, 2004). During these evacuation moments, the availability and performance of travel alternatives (e.g. the underground, particular highway routes, etc.) may differ immensely from the normal situation. In other words, a traveler's mental map, formed and updated over time, may become an inadequate instrument to base travel decisions on. The accurate provision of travel information during such situations is likely to be of paramount importance. However, very little is known about how travelers deal with information during calamities. The frameworks of traveler learning and decision making used under normal circumstances may not be applicable to calamity situations, due to phenomena such as panic (see Sime, 1995 for a study of crowd psychology), although this has not been proven. Furthermore, it might be so that during area evacuations, group level dynamics such as herding behavior and information cascades might play a particularly important role. Trying to better understand the role of travel information provision during such evacuations is not only of scientific, but also of societal importance. A better understanding might start by observing the progress being made in research concerning the evacuation of pedestrians from large buildings (e.g. Schreckenberg & Sharma, 2001).

12.2.5 Towards understanding the actual process behind information use and effect

Although a substantial body of research exists regarding the modeling of the process of information acquisition and decision making in the travel behavior community, it cannot be said that there is abundant understanding of the actual processes that are being modeled[85]. For example, researchers use the concept of Bayesian perception updating to model how information might be combined with earlier perceptions into updated perceptions. However, it remains largely unknown to these researchers how the brain of a traveler actually stores knowledge, and combines this knowledge with new information. This is not to say that models of such processes are wrong or useless, if they do not correctly describe the actual process; however, their realism might be improved by enriching them with insights into the actual workings of our brains. Recently, as is further elaborated below, advances in neuroscience have led to the point where it may be possible that the insights gained in this field may actually provide such enrichment (e.g. Shiv et al., 2005). These insights may particularly enhance our understanding of decision making under uncertainty, short and longer term learning and memory decay, and the different ways in which visual, auditive and spoken information is processed by travelers.

12.2.6 Understanding the geographical and cultural generalizability of insights

Although some studies into travel information use and effects have addressed the question of whether findings for one region may be generalized towards other regions (e.g. Jou & Mahmassani, 1996; Petrella & Lappin, 2004), little is known about how differences in cultures, transport network lay-out etc codetermine variation in behavioral responses to travel information provision. Such knowledge is necessary in order to prevent travel behavior researchers from repeatedly reinventing the wheel .

[85] This in contrast to an abundance of literature on the process of decision making in psychology (e.g. Anderson et al., 2004).

12.3 Avenues into the unknown: perspectives of research

Traveler behavior researchers have been known to borrow many of their crucial methodological perspectives from across the full spectrum of sciences, especially the social sciences. This diversity has led to heated debates about the validity of behavioral assumptions underlying different model frameworks. We wish to note here, that in our opinion, the complex nature of traveler behavior benefits from being studied from a variety of perspectives, and especially from cross-disciplinary approaches. Energy that is lost on vigorous positioning of one approach with respect to another (as has for example recently been done in the case of psychology-based approaches versus utility-maximization approaches) might be better used to enhance these approaches or combine their most useful ingredients into a new interdisciplinary perspective. This Section builds on this notion and presents some promising examples of how apparently different branches from the tree of social science have met and formed new branches, of varying maturity[86], bearing fruit of their own.

12.3.1 Decision making perspectives: behavioral economics

Combining insights regarding decision making from both neoclassical economics (NE) and psychology, this research approach has been gaining in popularity and maturity over the last decades (e.g. Simon, 1982; Kahneman, 2003). The axioms of behavioral economics (BE) assert that individuals are prone to make mistakes or use simple heuristics when making choices, rather than faultlessly performing complex trade-offs and optimization procedures. Furthermore, they assert that economic models should reflect these limits to rationality in order to give accurate accounts of economic phenomena such as the working of markets and the formation of equilibria[87]. This applies especially when choices are made under conditions of uncertainty and other types of knowledge limitations. It appears reasonable to suggest that, given the enormous uncertainty and complexity of modern transport networks, in combination with the existence of time pressure, most traveler decision making might be better described by a BE perspective than by adopting a purely NE perspective. The BE-viewpoint is illustrated in a growing stream of BE-based research (e.g. Foerster, 1978; Mahmassani & Chang, 1987; Avineri & Prashker, 2003; Han et al., 2005; Arentze & Timmermans, 2005a). Note that there are compelling reasons why the NE ('utility maximization') perspective is still dominant in travel behavior research. Firstly, NE provides a modeling framework that is more solidly based on a transparent and elegant fundament of axioms. Secondly, NE is highly compatible with a range of statistical/econometrical methods for data-analysis (as is most convincingly illustrated by the discrete choice framework, see Ben-Akiva & Lerman (1985)). Thirdly, although intuitively the BE approach might seem more behaviorally valid than the NE perspective, the empirical evidence of this intuition, especially concerning external (or predictive) validity, is less overwhelming. Notwithstanding these issues, it seems worthwhile to proceed with the development of BE-based traveler behavior models, especially when their underlying behavioral assumptions are transparent and coherent, and statistical analysis can be performed in a meaningful and tractable way.

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[86] And of varying aggregation level.

[87] A field that is very much related to behavioural economics is behavioural decision theory (e.g. Edwards, 1961; Tversky & Kahneman, 1974; Payne et al., 1993). Although it is impossible (and if it were possible, certainly outside the scope of this paper) to draw a strict line between these two streams of literature, it might be said here that behavioural economics is rooted in behavioural decision theory, and has expanded its scope by also considering the impact of not fully rational decision makers on the workings of the economy.

12.3.2 The group perspective: evolutionary biology

Microeconomics (e.g. Fudenberg & Tirole, 1991; Brock & Durlauf, 2002) and social psychology (e.g. Ajzen & Fishbein, 1980) have developed a stream of useful ideas concerning how individuals make decisions which are partially dependent on the expected behavior of others, many ideas of which have been and are still successfully applied in travel behavior research. A perspective on group decision making that has been an inspiration to economics for decades (leading to the birth of evolutionary economics), but which has been largely ignored in the traveler behavior research arena is provided by the field of evolutionary biology (EB, e.g. Maynard Smith & Price, 1973; Maynard Smith, 1982; Hagen & Hammerstein, 2006). EB uses concepts like 'evolutionarily stable strategies (ESS)' and 'selection' in order to describe the behavioral dynamics observed within and between species. Loosely put, the first of these concepts refers to strategies that, once adopted by all members of a large group, cannot be beaten by a new group member’s strategy . An example of such an ESS is driving on the right side of the road in continental Europe. Although driving on the left side may be a good strategy too (as is shown in the UK), when a traveler decides to drive on the left side in continental Europe this is a bad idea, and his strategy will never beat the ESS of driving on the right side of the road. Selection, again loosely put, refers to the way in which advantageous strategies or behavior of group members may become dominant in the group over time due to competition (e.g. aggressive versus non-aggressive driving behavior). It appears that these concepts, although rooted in the animal world, may be quite useful for explaining how humans base their decisions on the observed or expected behavior of others. Acknowledging that travelers often behave as herd-animals (in the sense of following one another or anticipating each other's behavior), this biological perspective - and particularly its merger with economics into the field of evolutionary economics - might turn out to be a useful approach for traveler behavior research. It seems particularly promising to see whether the EB-perspective is a suitable approach for describing the behavioral dynamics of area evacuations.

12.3.3 A learning perspective: artificial intelligence

Classical learning models such as variants of weighted average learning (e.g. Horowitz, 1984; Ben-Akiva et al., 1991) and Bayesian perception updating (e.g. Jha et al., 1998; Chorus et al., 2006a) have been the dominant approaches for describing travel time learning mechanisms in traveler behavior research. When attempting to understand more complex learning mechanisms that travelers may apply when moving through transport networks and using information services (see Section 12.2), the above learning models are likely to be too simplistic to cover the wide range of dynamics that may underlie traveler behavior. A research field that has built a body of knowledge that is both deep and wide regarding complex learning mechanisms, is that of Artificial Intelligence (AI, see Gardner (1985) for a history of AI as one of the new cognitive sciences developed in the 20th century). AI is often said to have a double aim: firstly, it aims to build machines that have the cognitive capabilities of humans. A stream of research has, over the last 5 decades, been concerned with the formulation of new notions of learning and the design of so-called machine learning algorithms to reach this aim. Secondly, AI aims to increase our understanding of human learning mechanisms by applying the notions and algorithms developed for the first aim. It is research stemming from this latter aim that appears to be a promising source for modeling travelers' learning behavior. Prominent examples of learning notions that were developed or brought to maturity by the AI-community are reinforcement learning (e.g. Kaelbling et al., 1996) and Bayesian Belief Networks (e.g. Pearl, 1988). The former is based on the notion that individuals are rewarded by good behavior (e.g. by receiving a high utility for their action), which means that they are relatively prone to perform this behavior again in the future, in comparable circumstances. The latter is based on the notion that individuals may perceive their environment as a set of variables with explicit causality assumptions and probability distributions attached to those variables. Recently, such AI-rooted learning models have been successfully introduced in traveler behavior research (e.g. Arentze & Timmermans, 2003 – Reinforcement Learning; Ibid, 2005a, b – Bayesian Belief Networks), and it seems that their full potential to model complex learning mechanisms which may be assumed to guide travelers through transport networks may be realized in coming years. This may apply for example to travelers' learning of the structure of transport networks, the interlinkages between different modal layers of the network and the causal relations that govern the working of transport networks.

12.3.4 A process perspective: (decision-) neuroscience

As mentioned in Section 12.2, it may be envisaged that deeper knowledge regarding the actual process of traveler decision making and learning under conditions of limited knowledge may enhance the behavioral validity of our models of those processes. A term coined by Shiv et al. (2005), decision-neuroscience, might be considered a fruitful candidate for gaining such deeper process knowledge[88]. Decision neuroscience is positioned as an integration of neuroscience and behavioral decision making. Let us give some concrete examples of how this new perspective may be applied in traveler behavior research: firstly, it is often wondered whether travel choices are based on emotions or on rational deliberations. Neuroscience is increasingly capable of identifying whether the ‘emotion’ or ‘deliberation’ parts of a brain are active or not at some moment in time. Thus, the part of the brain which is most active during travel choice making can be measured, providing a possible answer to the question raised. The same procedure may apply for research concerning the habitual versus deliberative nature of travel choices. Furthermore, decision neuroscience may shed light on the validity of the utility-concept in travel choice making versus other candidates of preference-measures such as regret (e.g. Loomes & Sugden, 1982), by observing the activity of ‘pleasure’ and ‘pain’-related parts of our brain. Although these ideas are still speculative, it seems that decision-neuroscience may be a quite promising candidate for the study of the process of traveler decision making. However, it should be mentioned here that many practical barriers do exist with regard to actual application of this perspective, as for example experimental costs are very high, leading to severe research scope limitations. Notwithstanding this, a study concerning how mental representations of the environment are learned (route versus map learning) shows the potential of the approach (Mellet et al., 2000).

12.4 Discussion

This paper presented promising avenues for future research into the topic of traveler decision making under conditions of knowledge limitations and information provision: new research questions have been identified and research methodologies that may be applied to address these questions have also been presented. Research questions concern i) the exploration of knowledge limitations and learning mechanisms in their full dimensionality, ii) an exploration

[88] Note that another, less elaborate and more indirect way of gaining insight in the decision making and learning process is to simply ask travelers about their mental processing when facing a choice situation or some information. However, seminal work by Nisbett & Wilson (1977) showed that this is a bad idea: verbal reports on complex mental processes such as choosing and learning appear to be far from reliable.

of the full variety of travel information types, iii) the study of how traveler behavior is influenced by the behavior of others iv) identification of the potential role of travel information during area evacuations, v) understanding the actual process behind information use and effect and vi) understanding the generalizability of travel behavior insights. Methodological approaches mentioned and discussed are i) behavioral economics, ii) evolutionary biology, iii) artificial intelligence and iv) decision-neuroscience.

Notwithstanding the exciting outlook these and many other research questions and methodological perspectives provide for future travel behavior research, and notwithstanding their potentially high scientific relevance (as it appears that much concerning traveler decision making still remains unknown), the societal relevance of future research in this area is not self-evident. Although it is generally acknowledged that the move from aggregate to dis-aggregate demand models in the 1970s (and thus the birth of travel behavior research) has greatly improved the predictive ability of these models and has enabled more informed transport policy making, the ongoing progress since then in dis-aggregate demand modeling is likely to have suffered from decreasing marginal returns. There may come a time when further added behavioral realism to travel demand models, or increased computational power used for ever more advanced econometrical analyses, might still make a difference in terms of model fit and internal model validity, but stops leading to noticeably better predictions of travel behavior and, more importantly, more informed transport policy making. The societal (not the scientific) relevance of advances in travel behavior research, say by using advanced method B instead of old method A, ends when policy makers and other actors in the transportation community, consistently reach the same solutions for policy problems (say, whether or not and how and where to introduce road pricing schemes) whether applying method A or B. Future progress in travel behavior modeling should be accompanied by attempts to establish its societal relevance using concrete case studies. Another issue is that policy-makers might want to use method A instead of B, if they perceive the potential costs of method B in terms of usability (e.g. due to increased computational complexity) as higher than the benefits that may be derived from its increased behavioral realism.

Notwithstanding this, it is to be expected that the near future will show progress in terms of realism and tractability of travel behavior models that is relevant to society. The societal relevance of such research progress may be further increased by technology-driven changes in the transportation system, as happened in the late 1980s surrounding the impact of the introduction of travel information services.

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Summary: Traveler Response to Information

Background

Until the late 1980s, information services available to travelers could be described as being rather low-tech systems that predominantly served to help people find their way as they moved through transport networks. Take for example travel information in the form of road maps and transit time tables. From that moment on, technological advances started to trigger the development of so-called Advanced Traveler Information Services (ATIS) that displayed increasingly sophisticated functionalities, e.g. by informing travelers about expected travel times for given routes, based on the current state of traffic. By the end of the 1990s, ATIS delivered information through various media (e.g. radio, variable message signs, telephone and text-message services, the internet) and became widely used among travelers before as well as during the execution of trips. By then, a second wave of technological developments, in particular the increasing deployment of Geographic Information Systems (GIS) in combination with the rapid market penetration of mobile phones, triggered visions of even more advanced functionalities: information services are gradually becoming Personal Intelligent Travel Assistants (PITA). Although full-fledged PITA-services are not yet available, it is hoped that in the near future they will be able to at any time provide a traveler with all the travel information relevant to her, given her time and place in the transport network and her personal characteristics, whether asked for or not.

Parallel to the fast-paced growth in technological opportunities, awareness regarding the negative effects of passenger transport, for example in terms of congestion, safety issues, utilization of fossil resources, has grown rapidly over the past decades amongst the public and all levels of government.

Combining these two trends, it is hoped by many that travel information provision may serve as a means to change traveler behavior in ways that are beneficial to the transport system, and to society as a whole. Such hoped for behavioral changes mainly concern shifts in mode-, route- and departure time-choices amongst car-drivers. To give just two examples, it is hoped that i) the provision of reliable public transport information may stimulate current car-drivers to travel by train instead and that ii) the provision of information in the case of an accident may reduce subsequent congestion by diverting people to different routes and (for those that have not yet left home) departure times. In order to be able to design information services that will actually encourage the desired behavioral, and in order to be able to make effective decisions about investments and subsidies for travel information-related transport projects, a thorough insight is needed into the behavioral aspects of travel information services. These behavioral aspects mainly relate to two types of questions: i) what makes travelers acquire (search for or pay attention to) information that is available to them? And ii) how does travel information, once acquired, impact subsequent travel choices? As a reaction to this need, an abundant body of academic research has been established that is concerned with the two questions stated above.

Notwithstanding the fact that past studies have provided many valuable insights into how travelers respond to provided information, the current state of knowledge suffers from two major drawbacks: firstly, research efforts have generally been very specific, failing to provide generic, *integrative* knowledge concerning the (potential) response to information amongst travelers. Secondly, a great majority of the research efforts lacks a rigorous *behavioral* perspective. It is the author's opinion that only an approach that combines an integrative perspective with a behavioral one will enable a durable capability among transportation researchers, practitioners and policy-makers to reap the benefits of the ongoing technological advances described above. In short, this thesis' most important research goal is therefore to *develop an integrative, behavioral perspective on traveler response to information*. Furthermore, this thesis puts into practice this perspective, as it aims to *provide realistic expectations concerning the potential of travel information provision as a transport policy-instrument*.

This thesis' contents

In order to reach the research goals formulated directly above, this thesis applies a variety of research methods. First, more than 150 theoretical and empirical studies are reviewed that are concerned with how individuals in general, and travelers in specific, deal with knowledge limitations and information when making choices. Building on these reviews, theoretical models of traveler response to information are developed, validated using numerical examples, and subsequently applied in order to study - through simulations - the potential of travel information provision in a mode-choice adaptation context. Complementing these numerical simulations, this thesis is built around the analyses of two datasets: firstly, a web survey is held, probing into i) the determinants of travelers' knowledge limitations and ii) how these result in the need for (particular types of) travel information. Data collected through this survey is statistically analyzed, without assuming specific behavioral model structures. Secondly, a multimodal travel simulator is built, which enables the observation of sequences of hypothetical choices per trip, made by travelers that are confronted with choice situations that are i) characterized by a variety of knowledge limitations and ii) the availability of a variety of information types. After having established the validity of the simulator environment, the collected data is used for the estimation of a discrete choice-based behavioral model of traveler response to knowledge limitations and information provision. Furthermore, the dataset is used to test conceptualizations concerning (the impact of acquired information on) travel choice quality. Also, the dataset is used to empirically test a newly developed discrete-choice based operationalization of Regret-Theory (an alternative to the Expected Utility-paradigm often used by economists). Finally, this thesis presents promising directions for further research into the topic of traveler response to knowledge limitations and information provision, based on a study of literature from research fields adjacent to that of transportation.

Conclusions

This Section presents the main conclusions for each of the Chapters 2-9, as well as for the two Epilogues. Subsequently, this thesis' two main conclusions are presented, referring to the two research goals presented above.

Chapter 2 provides a literature review of past research efforts concerning the determinants of traveler response to information. The Chapter's main focus is on providing coherent, *behavioral* frameworks. However, several empirical findings concerning the *manifest* determinants of response to information (particularly concerning the determinants of information acquisition) are also identified: for example, there appears to be a consensus that male, highly educated, high income, professional travelers that frequently use internet and mobile phones are particularly likely to engage in information acquisition. Furthermore, consistent with intuition, business trips and commuter trips, and arrival-time sensitive trips in general, are found to induce high usage levels of information acquisition. Variability in the performance of travel alternatives, due to for example peak traffic, bad weather or long trip duration also positively affects a traveler's inclination to use information. Literature is also in agreement concerning the suggestion that travelers use information predominantly in order to be informed about their favored mode of transport. There appears to exist a clear need for multimodal, personalized travel information-services. However, willingness to pay for travel information is generally found to be very low. Our own analyses show that all these empirical findings are fully consistent with the developed behavioral frameworks: the manifest determinants are in fact nothing more than proxies for the true, behavioral determinants of information acquisition.

Chapter 3 proceeds by formulating a formal mathematical model concerning traveler response to information, built around the concept of regret (rather than utility) as the main determinant of choice behavior. The model assumes that i) a traveler may be aware of the fact that, due to her limited knowledge, she may end up having chosen a travel alternative that turns out to be less attractive than a non-chosen alternative; ii) this induces the potential of regret; iii) the traveler anticipates this possibility of regret and aims to minimize expected regret when choosing from available modes. By incorporating in the regret-based framework notions of search-theory and Bayesian updating of perception, the models are able to describe both satisficing and maximizing decision-strategies. The formulations explicitly take into account both the availability of information that aims at generating new alternatives, as well as information aimed at assessing alternatives that are already known to the traveler. In order to clarify some important mechanisms behind these formulations, and at the same time provide some initial face validity to the approach, numerical examples are presented that simulate traveler response to information for different knowledge levels of the individual, and for different levels of reliability of the information service. The examples indeed provide preliminary confidence, as occurring trends are consistent with intuition and empirical literature.

Chapter 4 presents the statistical analysis of data obtained through a web-survey and provides many empirical insights into the formation of travelers' (perceived) knowledge levels and information needs: for example, it was found that the level of experience of a given mode is of far less importance for the development of traveler knowledge than the traveler's familiarity with the trip destination. It was also found that a perceived lack of knowledge does trigger a need for information in general, although actual relations are not particularly strong, signaling that many other factors co-determine information needs. Furthermore, concerning travelers' needs for specific types of information, it was found that there appears to be a genuine need for 'basic' time-related information, especially for trips towards unfamiliar destinations. As far as the more advanced types of information are concerned, it appears that especially those types of information that promise to make traveling 'easier' are needed, rather than information types that facilitate advanced search possibilities. Finally, there appear to be substantial differences between car-drivers and transit-users in terms of knowledge formation and information needs. For example, it was shown that car-drivers appeared less knowledgeable concerning transit than the other way around, signaling a potential role of transit information provision to car-drivers in order to 'educate' them. Also, it appears that car-drivers display a higher need for most types of travel information (including multimodal information) than do transit-users, especially for trips towards familiar destinations.

Chapter 5 presents a multimodal travel simulator with information provision. The simulator is designed to empirically study traveler decision making under conditions of limited knowledge and information provision, and has several novel features, including a fully abstract multimodal travel network and a highly sophisticated information service. An extensive validation of the observed behavior in the simulator strongly suggests the validity of the data: firstly, participants in the experiment enjoyed participation and indicated that they found the simulator easy to interpret. Secondly, a comparison of observed behavior with revealed choice data shows significant relations of expected signs. Thirdly, it appears that the choices made in the simulator are determined by a variety of determinants in ways that are perfectly in line with intuition. That is, choices for travel modes, choices whether or not to acquire information, as well as reactions to received messages appear to be made in an explicable and reasonable manner. Overall, it can be said that, notwithstanding the high level of abstraction and the provision of not-yet existing sophistication-levels of information, participants' motivation and capability to exhibit consistent and real-life like behavior remained strong. The simulator thus appears to offer a means to generate valid data concerning multimodal travel behavior under conditions of knowledge limitations, in the presence of several types of advanced travel information.

Chapter 6 presents an expect-utility, discrete-choice based model of traveler response to information, which is geared towards understanding the full dimensionality and iterative nature of traveler behavior in uncertain multimodal travel situations, where a variety of travel information types is available before embarking on a trip. The model is subsequently estimated on the travel simulator data. Estimation results show that the proposed model specification captures a substantial part of the variation in i) travelers' choices for a wide range of information acquisition options, as well as ii) the effect of acquired information on multimodal travel choices. It is found that for most trip purposes, travel time itself and not its variability is negatively valued. However, for business trips, travel time variability is valued almost as negatively as travel time itself. The non-monetary costs of information acquisition appear to play a very substantial role in the decision whether or not to acquire available information. Furthermore, it appears that travelers generally have intrinsic preferences for having unknown alternatives generated over other types of information acquisition.

Preferences for acquiring (specific types of) information appear to differ widely within the population, signaling the need for adequate segmentation studies.

Chapter 7 identifies, based on a review of literature, the potential role of travel information as a transport-policy tool and studies in particular how the provision of information may alter car-drivers' behavior in ways that are beneficial to the efficiency of transport network use. Based on the performed review, a number of generic, integrative insights is derived, including the following: i) our expectations with respect to the effects of information provision on car-drivers' travel choices in general may be mildly optimistic, particularly for behavioral adaptation not involving changes in mode choice; ii) information provision on the performance of the currently chosen mode-route combination, also under normal circumstances, may help change car-drivers' choices in the long run; iii) in situations where a high variability of conditions exists in parts of the network the traveler is familiar with, information acquisition and choice adaptation is likely to be relatively high; iv) making information services work well under incident conditions is likely to be a cost-effective transport-policy; v) providing travelers with information as early as possible is likely to increase its effectiveness in terms of behavioral adaptation; vi) the effect of information provision on other than the currently chosen or intended option is conditional on the extent to which the information takes into account information acquisition costs and the costs of adaptation to the alternative options.

Chapter 8 applies one of the formal models developed in Chapter 3, in order to study the potential effect of transit travel time provision on the mode-choices of travelers that have an intrinsic preference to use their private car. The performed calculations show that, even among car-drivers that do consider transit as a potential alternative to their car, the inclination to acquire transit information may be severely affected by a lack of perceived information reliability and relevance, and also by the existence of a base preference for traveling by car. Furthermore it is identified that even in those situations where i) travel information is acquired by these car-drivers and the ii) message is highly favorable to the transit option (e.g. in terms of travel times), then the same factors as mentioned above will severely limit the impact of the received information on mode choice adaptation to transit. Given these results, it is suggested that for car-drivers in general, including therefore the substantial share of habitual drivers, conservative estimates regarding the impact of transit information on the modal shift to transit appear to be realistic.

Chapter 9 statistically tests the validity of the often held expectation that the acquisition of travel information actually helps travelers make better choices. In order to do so, a measure of travel choice quality is proposed around the notion that a traveler's choice for an alternative (e.g. a mode-route combination), made under incomplete knowledge, is of high quality if the traveler, given complete knowledge, would choose the same alternative. Estimation results from a Structural Equation Model based on the above conceptualization provide an indication that claims of a positive impact of travel information on travel-choice quality are, at least to some extent, justified. The size of the impact, however, appears to differ between types of information. A relatively large effect is generated by information services that provide travelers with previously unknown alternatives simultaneously with the provision of estimates of their attributes. On the other hand, early warning functions (notifying a traveler about strongly deviating travel times) have a level of information content that is too low to substantially increase choice-quality. By investigating the attributes of the already known alternatives, a traveler also remains quite prone to choosing an alternative that is suboptimal given the full set of available alternatives. Furthermore, it appears that business trips, also when controlling for the increase in information acquisition for these trips, trigger a higher travel choice-quality than trips made for other purposes; this indicates that individuals put more effort into (and succeed in) making a 'good choice' when the stakes are high. Information unreliability appears to have a double negative effect on choice quality: it induces lower levels of information acquisition, and information that is acquired has a lower potential to reduce uncertainty and increase choice-quality.

Epilogue I builds on the theoretical, individual level regret-based models of Chapters 3 and 8 by showing how Regret-Theory, a widely used alternative to Expected Utility Theory for the analysis of risky choices, may be translated into a discrete choice model geared towards econometrical analysis of multiattribute risky decision making within general choice sets. The developed model is subsequently estimated on the data collected in the travel simulator experiment. The fit of the estimated model, in combination with the significance and expected sign of the estimated parameters, suggests validity of the proposed model formulation. Furthermore it is found that when the expected regret associated with a choice situation is higher than some threshold, the individual postpones choice and acquires information first. This regret-threshold varies substantially across the population.

Epilogue II provides an account of promising research avenues in the field of traveler decision making under conditions of knowledge limitations and information provision. First, a number of promising substantive research avenues is identified, including the following: i) future research might consider broadening its scope from response to travel time uncertainty and travel time information to examining the response to the full variety of knowledge limitations a traveler may face, and to all types of information potentially available to her; ii) there is more scope for acknowledging that travelers, when making decisions, anticipate the behavior of other travelers by displaying for example strategic or herding behavior in combination with other individual-group interactions; Furthermore, an argument is put forward for why more attention might be given to iii) the potential role of information provision during area evacuations; iv) the actual physiological process behind traveler response to information and vi) understanding the geographical and cultural generalizability of travel behavior insights at large. Following the identification of these promising substantive research avenues, a number of research paradigms are highlighted which may help to provide answers to the substantive issues presented. In particular, the following paradigms are considered fruitful: i) behavioral economics, which forms a bridge between mainstream microeconomics and psychology; ii) evolutionary biology, which enriches microeconomics with insights from biology (e.g. the role of herding behavior); iii) artificial intelligence, a research field geared to modeling the processes of learning and behavioral adaptation over time; iv) decision-neuroscience, a fairly new research paradigm which studies decision making by observing the actual working of the human brain at the moment choices are made.

In conclusion: an integrative, behavior perspective on traveler response to information

This thesis shows by means of theoretical argumentation how a traveler's response to information results from a complex and nuanced interplay between many determinants; it is then shown how the interplay can be, in theory, adequately and coherently described from an integrative behavioral perspective. Another question is, whether such theoretical models give an accurate description of actual traveler behavior. Based on the empirical research presented in this thesis, the answer to this question would be "yes, they probably do". Furthermore, the presented empirical analyses provide an indication that travelers appear to be able to deal in an intelligent way with very complex and nuanced travel situations, involving a variety of knowledge limitations and information types.

In conclusion: travel information as a transport-policy instrument

The most debated issue surrounding travel information-related transport policy relates to travel information's potential to induce a substantial shift from car-use towards transit use. This thesis provides a mixed picture in this regard: on the one hand, it appears that car-drivers do exhibit a need for multimodal information. On the other hand, the majority of evidence accumulated here suggests that one might be mildly optimistic at best with respect to travel information-induced mode-choice adaptations amongst car-drivers towards transit. Changes in route- and departure time-choices (leading to a more efficient use of available network capacity) are found to be more easily obtained through the provision of travel information. Taking a longer term perspective, a somewhat more optimistic picture may arise due to learning effects, although it appears that much work remains to done before this expectation can be substantiated.

Three main contributions of this thesis

This thesis aims to contribute to our understanding of traveler response to information. In the author's opinion, the research done has provided a contribution in particular to the following three dimensions:

Firstly, this thesis has contributed to the theoretical literature on (travel) choice behavior by *developing and testing theoretical models* concerning decision making under conditions of limited knowledge and information provision. These models, displaying high levels of face validity, are founded in frameworks established in the fields of microeconomics, mathematical psychology and decision theory. They are applicable to coherently describe a wide range of decision problems, including but not limited to, the travel choice situations that were the particular topic of this thesis.

Secondly, this thesis has contributed to the empirical literature on (travel) choice behavior in two ways: firstly, a *rich dataset has been created* on the topic, containing data obtained by a web survey, a Stated Choice experiment and a travel simulator experiment. The mentioned travel simulator is unique in facilitating active acquisition of a wide variety of travel information types. Secondly, *econometrical formulations of the developed theoretical models have been designed and empirically tested*. They appear to be able to systematically describe and predict a wide variety of behavioral responses to knowledge limitations and information availability.

Thirdly, this thesis has contributed to the academic as well as practitioner-oriented traveler behavior literature by *providing substantive insights*, concerning traveler response to information and the potential role of travel information as a transport-policy instrument. These insights have been supported by either i) literature reviews, ii) theoretical argumentation and simulation or iii) empirical analysis. They range from very specific to generic ones, and cover a wide spectrum of facets of traveler behavior.

Caspar Chorus
Eindhoven, January 2007

Samenvatting: Hoe Reizigers Omgaan met Informatie

Achtergrond

Tot aan de late jaren 1980 waren reisinformatiesystemen geen technologische hoogstandjes. De kaarten van (spoor)wegen en tabellen van vertrektijden van treinen waren vooral bedoeld om mensen te helpen hun weg te vinden in transportnetwerken. Vanaf dat moment namen de technologische ontwikkelingen een vlucht, en begon de snelle ontwikkeling van meer geavanceerde reisinformatiesystemen. Deze systemen gebruikten diverse media zoals autoradio, routepanelen, (mobiele) telefoons en later ook het internet, om reizigers bij voorbeeld te informeren over verwachte reistijden van routes gegeven de huidige stand van zaken in het transportnetwerk. De populariteit van deze systemen en de explosieve ontwikkelingen op het gebied van Geografische Informatie Systemen en mobiele telecommunicatie zorgden al snel voor een tweede golf van ideeën en ontwikkelingen: reisinformatiesystemen gaan meer en meer lijken op 'persoonlijke intelligente reisassistenten'. Dergelijke 'assistenten' moeten in de nabije toekomst een reiziger te allen tijde –gevraagd en ongevraagd – alle reisinformatie kunnen bieden die relevant is voor haar, gegeven haar plaats in het transportnetwerk, de huidige en verwachte situatie in het verkeer en Openbaar Vervoer (OV) en haar persoonlijke kenmerken en voorkeuren.

Parallel met de snelle groei in technologische mogelijkheden tijdens de laatste twee decennia seeg ook de publieke en politieke aandacht voor de negatieve effecten van personenmobiliteit, zoals congestie, verkeersonveiligheid, het verbruik van fossiele brandstoffen.

De combinatie van de twee hierboven geschetste trends leidt ertoe dat velen hun hoop hebben gevestigd op reisinformatiesystemen als instrument om het keuzegedrag van reizigers te beïnvloeden in het voordeel van het transportsysteem, en de maatschappij als geheel. Zo wordt bij voorbeeld gehoopt, en door sommigen verwacht, dat i) betrouwbare OV-reisinformatie, bij voorbeeld in combinatie met mobiliteitsheffingen, automobilisten kan verleiden meer gebruik te maken van het OV, of ii) het aanbieden van geavanceerde reisinformatie in geval van ongelukken de daarop volgende files kan verminderen door mensen om te leiden naar andere routes. Het is duidelijk dat inzicht in de gedragsaspecten van reisinformatie noodzakelijk is om te beoordelen of dergelijke verwachtingen reëel zijn of niet. Het gaat hier vooral om twee typen vragen: i) wat maakt dat reizigers informatie die tot hun beschikking is, ook daadwerkelijk gebruiken? En ii) wat is het effect van gebruikte informatie op de daarop volgende keuzes van reizigers? De noodzaak erkennend van een dieper inzicht in de gedragsaspecten van reisinformatiesystemen, hebben wetenschappers een aanzienlijke hoeveelheid onderzoek verricht met als doel deze vragen te beantwoorden.

Niettegenstaande het feit dat dergelijk onderzoek veel waardevolle inzichten heeft verschaft met betrekking tot de wijze waarop reizigers omgaan met informatie, kan het gesteld worden dat de huidige kennis op dit vlak twee belangrijke gaten vertoont. Ten eerste: bestaand onderzoek spitst zich voornamelijk toe op zeer specifieke typen informatie, en zeer specifieke reissituaties (bij voorbeeld: de impact van reistijdinformatie via routepanelen, op de routekeuzes van automobilisten). Het nadeel hiervan is dat er weinig *generieke* kennis wordt vergaard. Ten tweede blijkt dat de overgrote meerderheid van studies niet werkt vanuit een samenhangend gedragsperspectief. Naar de mening van de auteur zal juist de combinatie van een generieke, gedragsmatige aanpak tot die kennis leiden die wetenschappers, mensen uit het veld en beleidsmakers helpt om de huidige en toekomstige technologische mogelijkheden met succes in te zetten. In het kort: deze dissertatie heeft als doel om een *generiek, gedragsmatig perspectief te ontwikkelen met betrekking tot de wijze waarop reizigers met informatie omgaan*. Een tweede doel is het *vertalen van dit perspectief in realistische verwachtingen met betrekking tot de rol van informatiesystemen als transportbeleidsinstrument*.

Inhoud van deze dissertatie

Om de hierboven aangegeven doelen te bereiken worden diverse onderzoeksmethoden aangewend. Allereerst worden de voornaamste resultaten besproken uit meer dan 150 bestaande theoretische en empirische studies over hoe individuen in het algemeen, en reizigers in het bijzonder, met kennisgebrek en informatie omgaan bij het maken van keuzes. Voortbouwend op deze bespreking van literatuur worden theoretische modellen ontwikkeld van de wijze waarop reizigers met informatie omgaan. Na te zijn gevalideerd, worden deze modellen toegepast om door middel van computersimulaties te onderzoeken wat de potentie is van reisinformatie in een vervoerswijzekeuze-context. Complementair aan deze numerieke simulaties, is deze dissertatie gebouwd rondom de analyse van twee datasets: om te beginnen, is er via het internet een enquête gehouden met als focus i) de determinanten van kennisgebrek onder reizigers en ii) de relatie tussen deze kennisgebreken en de behoefte aan reisinformatie. De gegevens verzameld middels deze enquête zijn statistisch geanalyseerd zonder specifieke gedragsmatige modelstructuren te veronderstellen. Vervolgens is een multimodale reissimulator gebouwd die het mogelijk maakt om reeksen van gemaakte keuzes (bij voorbeeld keuzes voor vervoerswijzen, routes of informatieacquisitie) per hypothetische reis te observeren. In deze simulator zijn kennisgebreken en informatiemogelijkheden experimenteel gevarieerd. Na de validiteit van de simulator te hebben aangetoond, zijn de verzamelde gegevens gebruikt om een gedragsmodel te schatten aangaande de wijze waarop reizigers met kennisgebrek en aanwezige informatie omgaan. Ook is de dataset gebruikt om te achterhalen of het aanbieden van reisinformatie daadwerkelijk leidt tot betere keuzes. Vervolgens zijn de geobserveerde keuzes gebruikt om een nieuw ontwikkelde operationalisatie van Spijttheorie (Regret-Theory, een tegenhanger van de door economen vaak gebruikte nutstheorie) te testen. Tenslotte presenteert deze dissertatie veelbelovende richtingen voor toekomstig onderzoek naar reizigersgedrag, gebaseerd op een bespreking van literatuur uit vakgebieden grenzend aan dat van de transportwetenschappen.

Conclusies

Deze sectie presenteert eerst de belangrijkste conclusies per hoofdstuk afzonderlijk. Vervolgens worden, in relatie tot de twee eerder aangegeven onderzoeksdoelen, twee overkoepelende conclusies getrokken.

Hoofdstuk 2 bevat een literatuurbespreking van gedaan onderzoek naar de wijze waarop reizigers met informatie omgaan. De voornaamste bijdrage van het hoofdstuk is dat samenhangende, *gedragsgeoriënteerde* raamwerken worden afgeleid. Echter, ook een reeks aan empirische bevindingen uit de literatuur van de afgelopen twintig jaar wordt op een rij gezet. Deze bevindingen betreffen voornamelijk de rol van *manifeste* variabelen. Zo blijkt bij voorbeeld dat er consensus is over de stelling dat mannelijke, hoog opgeleide, goed verdienende, professionele reizigers, die vaak internet en hun mobiele telefoon gebruiken, meer dan andere groepen gebruik maken van aanwezige reisinformatie. Er is ook overeenstemming over de bevinding dat zakelijke reizen en woon-werk verkeer meer dan andere ritten gebruik van reisinformatie uitlokken. De mate van gebruik van reisinformatie wordt ook positief beïnvloed door variabiliteit in de prestaties van routes en vervoerswijzen, bij voorbeeld door spitsuur of slechte weersomstandigheden. De meeste onderzoeken suggereren ook dat reizigers met name informatie zoeken met betrekking tot de vervoerswijze die ze meestal gebruiken (dus in tegenstelling tot het zoeken naar informatie over andere vervoerswijzen). Toch blijkt er een behoefte te zijn aan multimodale reisinformatie. Echter, de betalingsbereidheid voor de meeste informatiediensten blijkt zeer laag te zijn. Uit onze analyses blijkt dat al deze empirische bevindingen volledig consistent zijn de ontwikkelde gedragsgeoriënteerde raamwerken: de manifeste variabelen zijn in feite niks meer dan *proxies* voor de werkelijke gedragsmatige determinanten van omgang met reisinformatie.

Hoofdstuk 3 formuleert een formeel wiskundig model van de wijze waarop reizigers met informatie omgaan. Het is gebaseerd rondom het concept ‘spijt’ (in tegenstelling tot het vaak gebruikte nutsidee) als determinant van keuzegedrag: het model is gebaseerd op de aanname dat i) de reiziger zich bewust is van het feit dat, door gebrek aan kennis, ze kans maakt een keuze te maken die achteraf niet de beste keuze blijkt te zijn; ii) dit potentiële spijt achteraf veroorzaakt; iii) de reiziger de mogelijkheid van spijt achteraf anticipeert en zich richt op het minimaliseren van verwachte spijt bij het kiezen tussen alternatieven. Deze modellen combineren zoektheoretische concepten met Bayesiaanse perceptie-updating, en zijn in staat om zowel ‘maximizing’ als ‘satisficing’ gedrag te representeren. De modellen zijn geschikt voor de analyse van gebruik van informatiediensten die nieuwe reisalternatieven generen, als van diensten die informatie verschaffen over reeds bekende alternatieven. Om de werking van de modellen te illustreren worden vervolgens numerieke voorbeelden gepresenteerd waarin de wijze van omgang met informatie wordt gesimuleerd voor verschillende kennisniveaus van het individu en verschillende betrouwbaarheidsniveaus van de informatiedienst. De voorbeelden verschaffen tevens validiteit aan de modellen, aangezien de resultaten van de simulaties overeenkomen met intuïtie en resultaten uit eerdere empirische onderzoeken.

Hoofdstuk 4 presenteert de statistische analyse van gegevens die zijn verzameld door een webenquête, en bevat een groot aantal empirische inzichten in de formatie van (gepercipieerde) kennisniveaus bij reizigers en hun informatiebehoeften. Eén van de conclusies is dat de gepercipieerde kennis van reizigers veel minder wordt beïnvloed door de mate van ervaring met een bepaalde vervoerswijze dan door de mate van bekendheid met de bestemming van een rit. Ook wordt aangetoond dat kennisgebrek wel een behoefte aan informatie induceert, maar dat ook een veelheid van andere factoren een rol speelt in dit proces. Het blijkt ook dat er, naast geavanceerde informatietypen, een sterke behoefte bestaat aan 'basale' reistijdinformatie, zeker voor ritten naar nooit eerder bezochte bestemmingen. Van de meer geavanceerde reisinformatietypen zijn de typen die reizen makkelijker maken (bij voorbeeld begeleiding tijdens de reis) meer in trek dan informatie die geavanceerde zoekmogelijkheden biedt. Ten slotte blijken er forse verschillen te bestaan tussen automobilisten en treinreizigers ten aanzien van de formatie van kennis en de omgang met reisinformatie. Het wordt bijvoorbeeld aangetoond dat automobilisten minder kennis hebben over reizen per trein dan omgekeerd het geval is. Ook blijkt dat automobilisten in het algemeen een wat sterkere behoefte hebben aan informatie (inclusief multimodale informatie) dan treinreizigers, in het bijzonder aangaande ritten naar vaak bezochte bestemmingen.

Hoofdstuk 5 presenteert een multimodale reissimulator met informatievoorziening. De simulator is ontworpen om empirische studie van keuzegedrag van reizigers onder condities van kennisgebrek en informatievoorziening mogelijk te maken. Ze bevat verschillende nieuwe kenmerken, zoals een volledig geabstraheerde multimodale transportnetwerkrepresentatie en een zeer geavanceerde informatiedienst. Een uitgebreide validatie van de simulator suggereert haar geschiktheid als dataverzamelingsinstrument: ten eerste blijkt dat deelnemers aan het simulator-experiment plezier beleefden aan hun deelname en de simulator eenvoudig te begrijpen vonden. Ten tweede blijkt uit een vergelijking tussen in de simulator gemaakte keuzes en gerapporteerde keuzes door de deelnemers in vergelijkbare omstandigheden in het dagelijkse leven, dat deze goed overeenkomen. Ten derde blijkt dat de in de simulator gemaakte keuzes (bij voorbeeld voor vervoerswijzen, routes, of informatieacquisitie) bepaald worden door een reeks aan gedragsmatige mechanismen op een manier die volledig in lijn ligt met intuïtie. In het algemeen kan gesteld worden dat, niettegenstaande de hoge mate van netwerkabstractie en de aanwezigheid van nog niet in de markt verkrijgbare informatiediensten, deelnemers zeer goed in staat bleken om met behulp van de simulator consistente en realistische keuzes te maken. De simulator blijkt dus een valide onderzoeksinstrument te zijn om gegevens te verzamelen over de wijze waarop reizigers met kennisgebreken en geavanceerde vormen van reisinformatie omgaan.

Hoofdstuk 6 presenteert een verwacht-nut gebaseerd discrete-keuzemodel van de wijze waarop reizigers met informatie omgaan. Het model is ontworpen om een veelheid aan facetten, en de iteratieve aard, van reizigergedrag in onzekere multimodale reissituaties in de aanwezigheid van een variëteit aan informatiebronnen te bestuderen. Het model is vervolgens geschat met behulp van de hierboven besproken simulator-dataset. Schattingsresultaten geven aan dat de gekozen modelspecificatie in staat is een substantieel deel van de variatie te verklaren in i) de keuze van reizigers tussen informatieacquisitie opties en ii) het effect van geäcquireerde informatie. Het blijkt dat voor de meeste reisdoelen reistijd zelf en niet reistijdvariabiliteit negatief wordt gewaardeerd. Voor ritten met een zakelijk reisdoel wordt reistijdvariabiliteit echter even sterk negatief gewaardeerd als reistijd zelf. Niet-monetaire kosten van informatieacquisitie blijken een grote rol te spelen bij de beslissing van reizigers om aanwezige informatie te acquireren. Verder wordt aangetoond dat reizigers gemiddeld genomen een intrinsieke voorkeur hebben voor het genereren van nieuwe route- en vervoerswijze-opties boven andere soorten van informatieacquisitie. Preferenties voor verschillende informatietypen variëren sterk binnen de populatie, wat suggereert dat er behoefte is aan diepgaandere segmentatiestudies.

Hoofdstuk 7 identificeert, gebaseerd op een literatuurbespreking, de potentiële rol die reisinformatie kan spelen als transportbeleidsinstrument. In het bijzonder wordt bestudeerd hoe de provisie van informatie de keuzes van automobilisten kan beïnvloeden op manieren die in leiden tot een efficiënter gebruik van transportnetwerken. Gebaseerd op de literatuurstudie is een aantal generieke inzichten afgeleid, waaronder de volgende: i) onze verwachtingen met betrekking tot de effecten van informatievoorziening op de keuzes van automobilisten in het algemeen mogen enigszins optimistisch zijn, zeker aangaande de overstap naar andere routes en vertrektijdstippen; ii) het aanbieden van informatie over de prestaties van de al gekozen vervoerswijze-route-vertrektijdstipcombinatie (bij voorbeeld in termen van verwachte reistijd), ook onder normale omstandigheden, kan helpen om op lange termijn gedragsveranderingen teweeg te brengen; iii) in situaties waar een grote mate van reistijdvariabiliteit bestaat op delen van het netwerk waar de reiziger bekend mee is, is de acquisitie van informatie en het aanpassen van eerder gemaakte keuzes relatief waarschijnlijk; iv) het loont de moeite (en het geld) om er voor te zorgen dat informatiediensten betrouwbaar blijven in geval van ernstige verstoringen; v) om zo effectief mogelijk te zijn in termen van gedragsaanpassingen, is het aan te raden informatie op een zo vroeg mogelijk moment voor of tijdens de rit aan te bieden; vi) het effect van het aanbieden van informatie over een andere dan de gekozen vervoerswijze-route-vertrektijdstipcombinatie is sterk afhankelijk van de mate waarin deze informatie rekening houdt met de (niet-monetaire) kosten van informatieacquisitie zelf en de eventuele gedragsaanpassing.

Hoofdstuk 8 past één van de in hoofdstuk 3 ontwikkelde modellen toe om het potentiële effect van OV-reisinformatie op de vervoerswijzekeuze te onderzoeken van reizigers die een intrinsieke voorkeur hebben voor de auto. De berekeningen die op basis van dit model zijn uitgevoerd tonen aan dat, zelfs bij automobilisten die het OV als een mogelijk alternatief zien voor de auto, de neiging om OV-reisinformatie te gebruiken sterk nadelig beïnvloed wordt door potentiële onbetrouwbaarheid en irrelevantie van de informatie, en door de intrinsieke voorkeur voor de auto. Ook wordt duidelijk dat, zelfs wanneer i) OV-informatie dadwerkelijk wordt geäcquireerd door de automobilist en ii) de boodschap sterk in het voordeel is van de OV-optie (bij voorbeeld in termen van reistijd), dezelfde factoren als hierboven aangegeven er voor zorgen dat de impact van de ontvangen informatie op de kans dat het OV uiteindelijk gekozen wordt, klein blijft. Gegeven deze resultaten lijkt het verstandig om voor de groep van automobilisten in het algemeen (dus inclusief de grote groep die het OV niet als een serieuze optie beschouwt) conservatieve schattingen op hun plaats zijn aangaande de effecten van OV-reisinformatie.

Hoofdstuk 9 test op statistische wijze de validiteit van de vaak geuite verwachting dat reisinformatie reizigers helpt om betere keuzes te maken. Eerst is de notie van keuzekwaliteit gedefinieerd in termen van de notie dat een keuze die een reiziger maakt onder condities van gebrekkige kennis van hoge kwaliteit is wanneer de reiziger, gegeven volledige kennis, dezelfde keuze zou hebben gemaakt. Schattingsresultaten van een zogenaamd Structural Equation Model op de simulator-dataset, geven een indicatie dat er inderdaad een positieve impact is van informatie op keuzekwaliteit. De mate van impact hangt af van het type informatie. Alleen informatie die nieuwe alternatieven genereert leidt tot zeer significante kwaliteitstijgingen. De zogenaamde Early Warning functie die waarschuwt wanneer zich verstoringen voordoen in het netwerk leidt tot marginale stijgingen in kwaliteit, net als informatie over reeds bekende alternatieven, alhoewel het effect van deze informatie iets groter is. Verder blijkt dat het reizen met een zakelijk doel leidt tot betere keuzes dan reizen met een recreatief doel, ook wanneer gecontroleerd wordt voor het feit dat er voor de laatste reizen minder informatie geäcquireerd wordt: dit suggereert dat mensen meer moeite doen (en er ook in slagen) om goede keuzes te maken wanneer de belangen groter zijn. Betrouwbaarheid van informatie blijkt een dubbele rol te spelen met betrekking tot keuzekwaliteit: onbetrouwbare informatie leidt tot minder informatieacquisitie, en geacquireerde onbetrouwbare informatie heeft een relatief lagere potentie om keuzekwaliteit te verhogen.

Epiloog I bouwt voort op de theoretische spijt-minimalizatiemodellen van hoofdstukken 3 en 8 door aan te geven hoe de zogenaamde Regret-Theory, een vaak gebruikt alternatief voor verwachte nutstheorie, vertaald kan worden in een discrete-keuzemodel gericht op econometrische analyse van multiattribuut beslissingen binnen generieke keuzesets. Het ontwikkelde model is vervolgens geschat op de reissimulator data. De schattingsresultaten suggereren de validiteit van de gekozen conceptualisaties en modelspecificatie. Een empirisch resultaat van de schatting is dat, wanneer de verwachte spijt gerelateerd aan de keuzesituatie hoger is dan een bepaalde (tussen individuen verschillende) drempel, het individu de keuze blijkt uit te stellen en meer informatie zoekt vooraleer te kiezen.

Epiloog II bevat een compilatie van veelbelovende onderzoeksrichtingen op het gebied van reizigersgedrag onder condities van gebrekkige kennis en informatievoorziening. Ten eerste wordt een aantal inhoudelijke onderzoeksrichtingen besproken, waaronder de volgende: i) het verdient aanbeveling de huidige onderzoeksfocus te verbreden van reistijdonzekerheid en reistijdinformatie naar andere typen kennisgebrek en andere typen reisinformatie; ii) het verdient aanbeveling om te erkennen dat het gedrag van individuele reizigers sterk beïnvloed kan worden door het feit dat reizigers deel uitmaken van groepen – dit kan leiden tot bij voorbeeld strategisch gedrag, kuddegedrag of zogenaamde informatiewatervallen; iii) meer aandacht is wenselijk voor onderzoek naar de mogelijke rol van informatie tijdens de evacuatie van gebouwen en gebieden; iv) ook is aandacht op zijn plaats voor het daadwerkelijke achterliggende fysiologische proces van informatiegebruik en voor v) de geografische en culturele vertaalbaarheid van inzichten in reizigersgedrag. Vervolgens wordt aangegeven wat de rol kan zijn van de volgende methodische perspectieven, die veelbelovend worden geacht voor toekomstig reizigersgedragsonderzoek: i) zogenaamde behavioral economics, een combinatie van psychologie en traditionele micro-economie; ii) (evolutionaire) biologie, een perspectief dat bij voorbeeld de concepten ‘kuddegedrag’ en ‘selectie’ geïntroduceerd heeft in de economische wetenschappen; iii) kunstmatige intelligentie, een onderzoeksgebied dat vergaande vorderingen heeft gemaakt op het vlak van leren en gedragsadaptatie; iv) zogenaamde decision-neuroscience, een vrij nieuw onderzoeksgebied dat zich bezighoudt met het bestuderen van de processen die zich afspelen in het menselijk brein tijdens het maken van keuzes.

Concluderend: met betrekking tot de gedragsaspecten van reisinformatie

Deze dissertatie toont door middel van theoretische argumenten aan hoe de wijze waarop reizigers omgaan met informatie het resultaat is van een complexe en genuanceerde dynamiek tussen een veelheid aan determinanten; vervolgens is aangetoond hoe deze dynamiek in theorie adequaat en samenhangend beschreven kan worden vanuit een integraal gedragsperspectief. De hierop volgende vraag is dan natuurlijk, of deze theoretische modellen een accurate beschrijving geven van daadwerkelijk reizigersgedrag. Op basis van het empirische onderzoek dat ook in deze dissertatie wordt gepresenteerd, is het antwoord op deze vraag: “ja, waarschijnlijk wel”. Bovendien verschaffen de empirische analyses een indicatie dat reizigers blijken in staat te zijn om op intelligente wijze om te gaan met zeer gecompliceerde en genuanceerde reissituaties, die gekenmerkt worden door aanzienlijke kennisgebreken en de aanwezigheid van een veelheid aan informatietypen.

Concluderend: met betrekking tot reisinformatie als transportbeleidsinstrument
Het meest besproken onderwerp rondom de rol van reisinformatie als transportbeleidsinstrument is de potentie van informatie om substantiële aantallen reizigers uit de auto en in het OV te krijgen. Op dit vlak geeft deze dissertatie een gemengd beeld: aan de ene kant blijkt het zo te zijn dat automobilisten wel degelijk behoefte zeggen te hebben aan informatie die ook het OV in beschouwing neemt. Aan de andere kant suggereert de meerderheid van analyses in dit onderzoek dat niet meer dan licht optimisme gerechtvaardigd is met betrekking tot de rol van reisinformatie in het tot stand brengen van veranderingen in vervoerswijzekeuzes. Veranderingen, door de inzet van reisinformatie, in termen van route- en vertrektijdstip-keuzes worden gemakkelijker bereikt. Op de langere termijn kunnen leereffecten leiden tot een grotere impact van reisinformatie, al is het duidelijk dat op dit vlak nog veel onderzoekswerk gedaan moet worden.

Drie belangrijkste bijdragen van deze dissertatie

Deze dissertatie heeft als doel bij te dragen aan ons begrip van de wijze waarop reizigers met informatie omgaan. Naar de mening van de auteur heeft het onderzoek met name een bijdrage geleverd langs de volgende drie dimensies:

Ten eerste heeft deze dissertatie bijgedragen aan de theoretische literatuur aangaande keuzegedrag (al dan niet van reizigers) door *theoretische modellen* te ontwikkelen en te testen van keuzegedrag onder condities van kennisgebrek en informatievoorziening. Deze modellen zijn geworteld in raamwerken en conceptualisaties uit de micro-economie, wiskundige psychologie en besliskunde. Ze vertonen sterke gezichtsvaliditeit en kunnen worden ingezet om op samenhangende wijze een variëteit aan beslisproblemen te beschrijven, inclusief (maar niet beperkt tot) de reissituaties die het onderwerp van deze dissertatie vormden.

In de tweede plaats heeft deze dissertatie op tweeërlei wijze bijgedragen aan de empirische literatuur aangaande (reizigers)keuzegedrag: ten eerste is er een *rijke dataset* gecreëerd op basis van een webenquête, een zogenaamd Stated Choice experiment en een reissimulator-experiment. The reissimulator is uniek in die zin dat de acquisitie van een variëteit aan reisinformatietypen wordt gefaciliteerd. Ten tweede zijn *econometrische formuleringen van de ontwikkelde theoretische modellen* aangedragen en empirisch getest. Deze blijken in staat om op systematische wijze de keuzes te beschrijven en voorspellen die reizigers maken wanneer ze geconfronteerd worden met kennisgebrek en informatievoorziening.

In de derde plaats heeft deze dissertatie bijgedragen aan de academische alsmede de niet-academische literatuur op het gebied van reizigersgedrag door *inhoudelijke inzichten* te presenteren, aangaande de wijze waarop reizigers met informatie omgaan en aangaande de potentie van reisinformatie als transportbeleidsinstrument. Deze inzichten zijn ondersteund door ofwel i) literatuuroverzichten, ii) (simulaties op basis van) theoretische modellen en iii) empirische analyses. Deze inzichten variëren van zeer specifiek tot generiek, en bestrijken een breed spectrum van facetten van reizigersgedrag.

Caspar Chorus
Eindhoven, January 2007

About the author

Caspar Chorus was born in The Hague, 26 May 1977. He studied *Systems Engineering, Policy Analysis & Management* at Delft University of Technology. In 2002, he graduated on a thesis about the integration of fuzzy mathematics into discrete choice models. In 2000, he also obtained a propedeutics diploma in *Econometrics* at Erasmus University Rotterdam. From 2002 to 2006, he was a PhD-student at Delft University of Technology's Section of Transport Policy & Logistics' Organization. From 2003 on, he was also a part-time visitor at Eindhoven University of Technology's Urban Planning Group. During the Fall semester 2005, he was a visiting doctoral student at Massachusetts Institute of Technology's program of Intelligent Transportation Systems. It is in the Urban Planning Group at Eindhoven University of Technology that, in September 2006, he started to work as an assistant professor.

Caspar is the first author of 8 papers published in peer reviewed journals, and of 10 papers appearing in conference proceedings with full paper review. In 2004, he became an editor for the *European Journal of Transport and Infrastructure Research*. He is a member of TRAIL Research School and a senior staff member of NETHUR Research School. In 2005, he was granted a Fulbright scholarship.

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