The Effects of Information and Communication Technologies on Accessibility

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The Effects of Information and Communication Technologies on Accessibility

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To

My family

Preface

It has been a long journey, which may be, to an extent, longer than I planned for, and it is not without difficulties and regrets. But in all regards, it is definitely most rewarding and exciting – a significant and profound chapter in my life.

The journey started with a talk with one best friend of mine, Chao, from whom I learnt the PhD vacancy for this research project, entitled *Traveler Response and Information Service Technology: Analysis and Modeling of Accessibility Effects*. Inspired already by the title itself and with the all-time desire to pursue a PhD degree, I made an application and later was interviewed by Bert and Caspar. Luckily, the interview went well, and I was given this opportunity to be a PhD candidate after the interview.

This opportunity really started a new chapter in my life. This project differs from what I studied before and was familiar with. Although I followed my bachelor and master degrees in the transport field, the focus was more on engineering-side. This PhD journey really broadened the horizon of my knowledge into a different world. Pursuing the PhD degree was not only just about performing academic research on the research topic itself, but more importantly this journey shaped my perspective towards the world and equipped myself with a set of skills that would surely play an important role in my entire career and life. The every moment in these past years is still so memorable, and every piece of experiences is so valuable. In all, I am so privileged to have been through such a wonderful journey.

Among others, I was so fortunate to have Caspar and Bert as my supervisors along this not-easy journey, which involved many challenges, difficulties, and unexpected issues. At this moment to the finishing point, I would like to express my deepest gratitude to Caspar and Bert. Caspar, you are such an exceptional supervisor in every sense. I am so grateful for your sharp viewpoints for help pinpointing research gaps and directions, your inspirational lessons for teaching me how to conduct research, and your supports in every step along the journey. I deeply appreciate every moment of our meetings, every part of our discussions, and every

piece of advice from you. Bert, I also owe great gratitude to you! Your all-time refreshing ideas, thorough reasoning, useful suggestions, encouragements, and positive attitudes are really essential parts for the successful completion of this journey. Caspar and Bert, thank you very much – without your superb supervision, guidance, and supports, all this would have not happened. Simply, any words cannot sufficiently address my deepest gratitude to you two.

I would also like to acknowledge the support from the Netherlands Organization for Scientific Research (NWO) for funding this research, and also the facilitation of TRAIL, and TBM faculty of TUDelft for this research.

I was also lucky enough to have worked in the Transport and Logistics group – of which a number of nice colleagues I would like to express my gratitude. Chao, being my colleague, my roommate, and one best friend of mine, thank you very much, sincerely! I think that the fact that we have known each other for more than a decade through many ups-and-downs already explains everything. Sander and Niek, my dear office roommates, I appreciate all the conversations we had on research and life, your suggestion and ideas, and your helps and supports. I also miss all your jokes and laughs – I am not sure that I followed all of them, but they certainly made the journey a very delightful one as well. Finally, I am so honored and pleased to have been one member of the Transport and Logistics Group, surrounded by a number of smart, friendly, and supportive colleagues. Without addressing each of your names, I would like to express my thanks to every one of you as well!

Furthermore, I would like to express words of thanks to a number of other people. First of all, I would like to thank all my HUTAC fellows – Brenda, Knut, Ebru, Erdenay, Alicia, Brenden, Yenni, Mitko, Stojan, Egemen, Nilgun, Eszti, Genia, Steffie, Leonardo, Sofia, Karen, Connie, Ankur, Eleni, Cristina, Lucila, Gerbert, Sharon, Mahmut, etc. – who accompanied and encouraged me through the journey. In particular, great thanks to Mitko who is so talented in 3D animation and so kind to help me with the design of the cover page. Secondly, thanks to my TRISTAM fellows – Sergejs, Giselle, and Zahra – for the sharing of your knowledge and experience. Also thanks to Paul and Thomas for helping improving my English. I would like to extend my gratitude to several close friends of mine – Lan J., Andras, Yinyi, Mikhail, Song Y., Jie L., Rui W., Mo Z., and Zheng W. – for your encouragements as well. Same thanks to my current colleagues Yvo, Remmelt, Kim, Sagar, Menno B., etc. Finally, special thanks to Keith for your all-time encouragement, valuable helps and unreserved supports. Same to the friends of Keith and mine – Robin, Mario, Jeroen, Paulo, Karim, Oliver and Rick – especially for your encouragement during the final stage of the journey to the realization of this thesis.

Last but not least, I am blessed to be unconditionally loved and supported all time by my family back in China – my parents, my brother, and my grandparents. Although we are thousands of kilometers distant from each other, I always feel your moral encouragement and support so close, which were always an essential and significant driving force to keep me moving forward. Thank you very much from the bottom of my heart! In particular, I attribute this to my dear grandma, who passed away last year. Grandma, this is for you and I miss you!

Ruihua (Zack) Lu

Den Haag, November, 2014

Contents

1 Introduction

This research is part of the TRISTAM (Traveler Response and Information Service Technology: Analysis and Modeling) sub-program in the SAR program (the Sustainable Accessibility of the Randstad research program) financed by the Dutch Ministry of Infrastructure and the Environment, the Dutch Ministry of Economic Affairs and the Netherlands Organization for Scientific Research (NWO). More information concerning the SAR program can be found at http://dbr.verdus.nl.

1.1 Research background and problem statement

Accessibility[1] is of vital importance to society, and is a key concept in research and the policy making process. It is studied by scholars in a number of disciplines, including transport engineering, geography, economics and sociology. Although the concept of accessibility is defined and operationalized in various ways, the importance of accessibility to human activities and sustainable development is widely recognized. For example, accessibility is often used to measure the level of service provided by transport infrastructure in transport engineering. It is also a critical measure of the benefits that households and firms receive from the use of their local transport infrastructure (see, e.g. Linneker and Spence, 1992; Spiekermann and Neubauer, 2002; Talen and Anselin, 1998). Accessibility is also an

[1] The distinction between *access* and *accessibility* should be clarified. Strictly speaking, *accessibility* should be defined from the perspective of locations/activities, while *access* should be defined from the perspective of people. That is, a location/activity is accessible to people and a person has access to a location/activity (Geurs and van Wee, 2004). However, the terms *accessibility* and *access* are often used indiscriminately in the literature (Van Wee et al., 2013). This thesis uses "accessibility" from the perspective of both location and a person.

important topic in urban planning, such as residential location choice and the urban environment (see, e.g. Graham and Marvin, 1996; Iacono et al., 2010; Moss and Townsend, 2000; Rhee, 2009). Accessibility is often operationalized and interpreted as an important economic indicator that represents the potential for reaching spatially distributed opportunities for employment, consumption, recreation, etc. (see, e.g. Berechman and Paaswell, 2001; Giuliano et al., 2012; Páez et al., 2012). In addition, accessibility is often coupled with the economic, environmental and social dimensions of sustainability (see, e.g. Cass et al., 2005; Church et al., 2000; Farrington and Farrington, 2005; Farrington, 2007). Moreover, accessibility is also used as an indicator in evaluating the quality of people's lives (Dijst and Kwan, 2005; Mieczakowski and Clarkson, 2012; Wachs, 2002).

Given the widely acknowledged importance to human activities and society, a paramount goal of transport policies is to improve accessibility. Taking the Netherlands as an example, improving accessibility is set as a priority for Dutch transport policies. According to the Dutch National Policy Strategy for Infrastructure and Spatial Planning (*Structuurvisie Infrastructuur en Ruimte*) of the Dutch Ministry of Infrastructure and Environment (Ministerie van Infrastructuur en Milieu, 2012), making the Netherlands competitive, accessible, livable and safe is what the central government wants to achieve by 2040. In particular, to improve, preserve, and physically guarantee accessibility, putting users first is one of three main goals designed to keep the Netherlands competitive, accessible, livable and safe in the medium term (2028).

In the past decades, most attempts at increasing accessibility have focused on the development of transport infrastructure (e.g., roads, railways) followed by land use planning policies. However, it is being increasingly recognized that *information and communication technology*[2] *(ICT)* could be utilized as a (potential) measure, *inter alia*, to help achieve the goal of improving accessibility (Van Wee et al., 2013). The potential of utilizing ICT as a measure to improve accessibility stems from two main features.

> First of all, ICT is rapidly penetrating society and people's daily lives. For example, the Netherlands was ranked 6th of the most advanced ICT economies in the world in 2012 (ITU, 2012). The report *ICT, knowledge and the economy* by CBS (Statistics Netherlands) (CBS, 2012) reports that, in 2011, 94% of the households in the Netherlands had an internet connection. Dutch citizens increasingly use laptops and/or mobile telephones to access the internet. The number of individuals shopping online increased to 9.5 million in 2011, while over two-thirds of Dutch employees used computers at work in 2010. 91% of companies in the Netherlands had a fixed broadband connection in 2010. More and more companies are offering their employees the option of teleworking from home. This share increased in 2010, reaching 62%. This high and increasing level of ICT penetration in the Netherlands provides a strong foundation for planning ICT-related policies to improve accessibility.

[2] *ICT*, used as an abbreviation of *information and communication technology*, refers to all the information technologies and the telecommunication technologies that provide access to information or teleactivities. ICT, as a broad term, includes both old ICT, such as radio and television, and new ICT, such as the internet and mobile phones.

Secondly, it is expected that ICT has significant impacts on accessibility. For instance, ICT can help workers gain access to travel information, and help reduce the amount of time they spend commuting and in turn increase travelers' accessibility. The option to telework may also help make people's office very accessible when the roads are heavily congested. In addition, as identified in the literature, ICT also has impacts upon people's travel behavior [3], which is closely associated with accessibility. For example, teleactivities (such as teleworking and teleshopping) may not only substitute location-based activities and travel, but may also generate complementary activities and therefore more travel (see, e.g. Andreev et al., 2010; Mokhtarian, 1990; Mokhtarian, 1998; Salomon, 1986). Teleactivities may also help travelers relax or even avoid constraints, such as time-space constraints, they may face when performing activities and travel (see, e.g. Dijst, 2004; Schwanen and Kwan, 2008). The provision of travel information and the behavioral impacts of ICT also interact: travel information may help travelers to assess known travel alternatives or generate new unknown alternatives or (see, e.g. Chorus et al., 2013). Traffic-related papers show that traffic information (as a subcategory of travel information) can change travel behavior, such as traveler's route choice and departure time choice (see e.g., Bogers, 2009; Ettema and Timmermans, 2006). In summary, travel behavior changes, due to having additional options within access, or due to being able to make a "better" choice among known options. Such changes to travel behavior are expected to in turn result in changes to travelers' accessibility,

However, our understanding of the effects of ICT on accessibility is still limited, despite the intuitive relation between ICT, travel behavior and accessibility and knowledge of ICT's effects on travel behavior. One of the prominent reasons is the lack of generic formal analytical frameworks and methodologies for measuring ICT's effects on accessibility. This limits our capability to measure the changes in accessibility due to ICT-use. The traditional accessibility measures in the literature and the recent models that have been developed to measure ICT's effects on accessibility[4] exhibit several drawbacks.

First, the traditional accessibility measures (e.g., proximity-, space/time-, activity-, and utility-based measures) that have been developed in the physical realm from different perspectives only focus on physical accessibility (Van Wee et al., 2013). As such, they do not consider any ICT-related factors into measure formalizations, and therefore are not suitable to measure ICT's effects on accessibility. For example, according to traditional accessibility measures, a serious peak traffic congestion en-route from an individual's home to the workplace would result in the workplace being considered to be poorly accessible. However, the workplace might be considered very accessible because of an option for the individual to connect to the workplace digitally via ICT (e.g., remote desktop). Traditional physical accessibility measures are insufficient in capturing the actual accessibility of the workplace as perceived by the individual in this case.

[3] Travel behavior refers to both the involved activities and the related travels.

[4] *Chapter 2* provides a literature overview of these traditional accessibility measures, and the models that attempt to measure ICT's effects on accessibility.

Secondly, the few models that have been developed aiming to measure ICT's effects on accessibility, notwithstanding their obvious values, also have limitations. These models can be categorized into three main types:

a) Models that focus on the *extension of space/time-based accessibility measures* via *the introduction of new conceptualization of space-time into classical time-geographic concepts* (see e.g., Dijst, 2004; Janelle, 1995; Kwan, 2007; Miller, 2005a). These models are developed at a conceptual level and their lack of mathematical formalization restricts their practical use. In addition, they only focus on telecommunication and its effects on people's space-time prism, and ignore the travel information-dimension.

b) Models that analyze ICT's effects on accessibility via *Geographic Information System (GIS)-based time-geographic frameworks with the virtual realm included* (see e.g., Couclelis, 2009; Ren and Kwan, 2007; Shaw and Yu, 2009). Recent developments in GISs have increased the applicability of space-time accessibility measures studying ICT's effects. But the limitations of space-time accessibility measures (e.g., difficulties in operationalization and incorporating people's preferences, and heavy data requirements) still remain, and limit the applicability of these GIS-based frameworks.

c) Models that attempt to *include certain ICT-related factors into traditional physical accessibility measures*. These models are practically feasible in operationalization, but their applicability is limited given their focus on certain *specific* ICTs or *specific* categories of accessibility (e.g., job accessibility) (see e.g., Scott, 2000; Shen, 2000).

In summary, each of these categories of models is limited to a certain extent in their capabilities to measure changes of accessibility due to ICT use.

The lack of models to measure the effects of ICT in its different forms on accessibility has also (partly) resulted in a lack of related empirical studies. The few exceptions that exist generally study the impact of ICT on job accessibility (see e.g., Muhammad et al., 2008). This lack of models, along with a lack of related insights, limits our capability to reap the benefits of using ICT to improve accessibility. Based on this argument, the general problem statement that provides the main reason for this thesis is derived as follows:

There is still a lack of generic formal models to measure the effects of ICT on accessibility, thereby restricting our knowledge in this regard and limiting our capabilities to make use of the ongoing advances in ICT to improve accessibility.

In particular, it is the author's opinion that the following aspects seem to have been overlooked in current efforts to develop models to measure ICT's effects on accessibility, while they are essential in better understanding ICT's effects on accessibility.

First, *travel behavior of individuals*[5] is an essential component. Any models that do not consider travel behavior in measuring ICT's effects on accessibility not only may lack theoretical rigor but are also of limited practical relevance. As mentioned, changes of travel behavior due to ICT use may result in changes to accessibility. Models that do not consider travelers' choices and preferences may result in lack of sensitivity in identifying travelers' behavioral changes due to ICT use. This may result in measurement bias with respect to the actual accessibility to people or the accessibility of locations/activities. For example, if a researcher assumes that the employees of a company provided with the option to telework would all automatically adopt teleworking while ignoring individual preferences (e.g., some employees may not prefer teleworking), the actual accessibility benefits of allowing these employees to telework would therefore be over-estimated.

The second essential aspect that seems to be often overlooked is that ICT has *two major functions* – to provide travel information via information-related technologies (the "I" in ICT), and to enable people to engage in teleactivities via telecommunication facilities (the "C" in ICT). Literature concerned with ICT's effects on travel behavior generally only focus on either the effects of teleactivities or the effects of travel information – a point also made by Van Wee et al. (2013). Hardly any literature exists that combines both streams, whereas travelers' preferences for, and use of, travel information and telecommunication facilities may be interrelated. The combination of both effects is relevant and materializes in three ways. First, more ICT devices have both travel information- and telecommunication-related facilities (e.g., tablets can be used to check travel information and also used for teleworking). Secondly, a traveler's use of travel information and telecommunication facilities can be mutually influenced. Take, for example, the situation where an individual chooses to work from home after having received travel information that his or her route to work is severely congested. Or consider the example where a telework-option available makes a traveler more inclined to acquire travel information in the morning (given that he/she knows that depending on the received information, he or she has the option to decide to work from home). Finally, an individual's use of travel information and telecommunication facilities can be (partly) driven by the same set of factors, such as unreliable commuting time due to peak-hour congestion. Commuters may choose to acquire travel information to assess the commuting time or choose to telework from home in order to avoid congestion.

[5] Note that travel behavior should be always considered in the context of related activities. For example, whether or not teleworking substitutes travels is actually determined by travelers' decisions on whether to engage in work at workplaces or to engage in teleworking from home. Multi-tasking behavior during traveling is induced by travelers' engagement of activities while they travel. Hence, strictly speaking, *activity-travel behavior* should be used. However, for ease of communication, travel behavior is used instead throughout in this thesis.

Based on these arguments, two parts of the problem statement are distinguished.

The first part of the problem statement, which is *model-oriented*, is as follows:

> *There is a lack of generic formal integrative behavioral models that measure the effects of different forms of ICT on accessibility.*

The second part of the problem statement, which is *outcome-oriented*, is as follows:

> *There is a lack of insight with regard to the effects of different forms of ICT on accessibility.*

The literature overview (*Chapter 2* of this thesis) further positions the problem statement with respect to the available academic literature.

1.2 Research goals and research relevance

This research predominantly aims to "*increase the understanding of the effects of ICT on accessibility*". Based on the (two dimensions of the) problem statement presented above, two research goals (a model- and an outcome-oriented goal) are formulated.

The primary research goal (*model-oriented*) is as follows:

> *The research aims to develop and test a generic formal integrative behavioral model for measuring the effects of different forms of ICT on accessibility.*

The second research goal (*outcome-oriented*) is as follows:

> *The research also aims to derive and provide substantive insights with regard to the effects of different forms of ICT on accessibility.*

The research is of the following scientific and practical relevance.

Scientific relevance:

> *This research is of scientific relevance with respect to the development of models for measuring ICT's effects on accessibility. It contributes to the scientific community in this regard by providing a formal integrative model that is validated via an empirical study and that can also be used as a foundation for the development of further models. In addition, the substantive findings that originate from this study increase our scholarly understanding of the interrelations between different forms of ICTs, travel behavior, and accessibility.*

Practical relevance:

> *This research is also of practical relevance, as it provides insights into the effects of different forms of ICT on accessibility, and implications for practitioners and policy makers in actual planning and policy-design process. In addition, the model has potential practical value as well, as it may be used to help evaluate the potential benefits associated with ICT-related investments and transport policies.*

1.3 Conceptualization of accessibility and ICT in the research

Before presenting the research methodology, focus and scope, it is important first to define how accessibility and ICT are conceptualized in this research.

Accessibility

In this research, the definition of accessibility as *"the maximum utility that an individual can derive from a set of activity-travel choices*[6]*"* is used. Due to the wide range of definitions of accessibility suggested in the literature, it is essential to define the concept of accessibility before any further research is conducted. It has been stated that accessibility is often a poorly-defined, misunderstood or narrowly-perceived concept (Geurs and Ritsema van Eck, 2001). This is partly because accessibility, as an abstract entity, is difficult to translate into a single universal notion. As a result, many researchers are reluctant to make any kind of tautological definition (Martinez, 1995). Accessibility is often defined differently given specific focus or context. In particular, in this research accessibility is conceptualized as the maximum utility that an individual can derive from a set of activity-travel choices. This is in line with how accessibility is conceptualized in the well-known utility-based LogSum accessibility measures (Ben-Akiva and Lerman, 1979). As will be explained in this thesis, the main reasons for this conceptualization are as follows. First, although there is no universal agreement[7], utility-based LogSum accessibility measures based on such conceptualization are, in general, considered effective measures of accessibility with a high level of theoretical rigor and usability in economic evaluations (Geurs and van Wee, 2004). Secondly, the conceptualization is also based on the research context, where individuals' travel behavior is addressed as an essential component to be taken into consideration. Accessibility is therefore conceptualized at a disaggregate level (i.e., individual). In addition, LogSum measures have the advantages of modeling individuals' behavior, because they can be analyzed via discrete choice models, which have been used in modeling travel behavior and decision-making to a dominant extent (McFadden, 2001).

ICT

As reflected in section 1.1 and section 1.2, the research defines ICT according to *its function* rather than according to other dimensions (e.g., technical specifications). Despite the wide range of ICT types (e.g., desktops, laptops, mobile phones, tablets, etc.) currently available, this research generally distinguishes between ICT's two major functions*: information technologies (the "I" in ICT)* and *communication technologies (the "C" in ICT)*. Information technologies refer to all the technologies that provide access to travel information (e.g., radio or apps on mobile phones that provide traffic information), while communication technologies refer to all the technologies that provide access to teleactivities (e.g., the internet and web shops that provide people with teleshopping opportunities). This thesis therefore focuses on the effects of travel information provided via information-related technologies and

[6] This definition also includes the choices of teleactivities, in which no travel is involved.

[7] The different perspectives towards utility-based accessibility measures are discussed in detail in *Chapter 2*.

teleactivities enabled via telecommunication-related technologies on accessibility[8]. Such an abstract categorization based on ICT's functions ensures that the developed model for measuring ICT's effects on accessibility remains generally applicable in the context of the wide variety of different ICTs currently available. In addition, it ensures that the model can be applied relatively long term, regardless of the rapidly changing nature of ICT.

It is important at this point, to note that the teleworking-dimension of ICT may be a substitute for physical travel, whereas the travel information-dimension is not. Furthermore, travel information acquisition is not a substitute for teleworking. That is, travelers may decide to work from home rather than to travel to the office and work from there, but they may not decide to acquire travel information instead of going to the office or (tele-)working from home. Rather than being a potential substitute for teleworking or physical travel, information acquisition supports both these decision dimensions. In that sense, conceptually speaking, teleworking (the 'C' of ICT) and physical travel are both positioned on a different level in the decision-making hierarchy than is travel information. However, there are two places in this thesis, where the information acquisition-dimension and the teleworking-dimension of ICT are treated seemingly as if they were both on the same level in the decision hierarchy. The first is in *Chapter 3*, where an empirical study into travelers' preferences for ICT is performed. In this study, the aim is to investigate to what extent different factors co-determine the use of ICTs for information acquisition and teleworking purposes, and to explore if there are common factors and inter-actions in this regard. Secondly, in *Chapter 5* a nesting structure is designed to accommodate potential correlation in the unobserved utilities of different dimensions of ICT use (information acquisition versus teleworking). In these two cases, the fact that the information acquisition and the teleworking dimensions of ICT are being treated jointly does not mean to imply that they are considered to be at the same level in the decision-making hierarchy, which they are clearly not, conceptually speaking.

1.4 Research methodology

This section presents a general overview of the methods applied in this research. These methods are detailed in the following chapters. Among many potentially applicable methods, the methods used in this thesis include:

- Literature overview
- Web-survey for data collection and statistical analyses of survey data
- Formal model development
- Travel simulator experiment for data collection and estimation of model based on simulator data

[8] Note that the remainder of this thesis does not explicitly make the following distinction each time when the "I" and the "C" of ICT, or travel information provided by ICT and teleactivities enabled by ICT are described. But it should be clarified that, strictly speaking, travel information itself and teleactivity itself cannot be considered as the forms of ICT. Rather, information-related technologies (the "I" in ICT) that provide access to travel information and telecommunication-related technologies (the "C" in ICT) that provide access to teleactivities are the forms.

Each method is employed with different aims. In combination, they aim to provide an integrated and coherent way to achieve the two main research goals. The remainder of this section provides a general overview of these methods[9]. The focus and the scope of the research are described in the next section.

- The aim of the *literature overview* is to provide a general understanding of the effects of ICT on accessibility as well as to form a theoretical basis for the research conducted in this thesis. It also provides inputs to identify the problem statement, formulate the research goals, choose the appropriate research methods, and define the research focus and scope. The overview focuses on: a) accessibility measures in the literature, including the models that have been developed to measure ICT's effects on accessibility; b) ICT's (potential) effects on accessibility; and c) models and methods for the study of ICT choice and ICT's effects on travel behavior. Although other approaches are also applicable in this study (such as interviews), a literature overview was considered the most effective method to obtain a complete overview of knowledge needed for the research of this thesis, due to the large body of the literature available.
- The aim of the *web-survey for data collection and the statistical analyses of survey data* is to investigate to what extent different factors co-determine the use of ICTs for information acquisition and teleworking purposes, and to explore if there are common factors and interactions in this regard. The web-survey approach to data collection is used because of its capacity to collect data in a low-cost, flexible and efficient way (Chorus, 2007). Another advantage of using a web-survey is that it can collect revealed-preference (RP) data (e.g., travelers' actual usage of ICT in daily life) and stated-preference (SP) data (e.g., travelers' stated behavior in hypothetical situations). This fits with the aim of the study. Structural equation modeling (SEM) is applied in order to analyze the survey data. SEM is particularly useful in testing complex and multiple dependence relationships. It takes measurement errors into account, which results in less bias in estimation (Bollen, 1989; Golob, 2003; Hair et al., 2010). Given this advantage, SEM is used in this research in order to explore the expected interrelations between travelers' use of travel information and the telecommunication functionalities of ICT.
- The aim of *formal model development* is to develop a formal integrative behavioral model to measure the effects of travel information and teleactivities (including their potential interactions) enabled by different forms of ICT on accessibility. A (random) utility-based theoretical framework[10] (Ben-Akiva and Lerman, 1985; McFadden, 1974; Train, 2003) that defines accessibility as the utility outcome of a set of activity-travel choices is adopted to develop an accessibility model in this research. The accessibility model is developed from an individual's perspective and no random utility component is included.

[9] Note that the adopted methods are not without limitations. The details are elaborated in *Chapter 2*.

[10] Note that for the accessibility model, an individual's perspective, rather than an analyst's perspective, is adopted. Utility is only considered as random when an analyst's perspective is adopted, since analysts are unable to observe and measure all utility components perceived by individuals. Hence, expected utility theory is adopted for the representative individual accessibility model. On the contrary, the choice model variant that is specified based on the accessibility model from an analyst's perspective operationalizes accessibility as the expected maximum utility of the choice set within the random utility paradigm.

A choice model variant is further specified from an analyst's perspective that considers random utility components unobservable to analysts. The framework is based on two theories. First, the utility theory that defines accessibility as the maximum utility of an individual's activity-travel choice is adopted to develop the representative individual accessibility model. Secondly, the random utility theory is adopted to specify the choice model from the representative individual accessibility model. (Random) utility-based accessibility measures have the advantages in terms of their theoretical soundness, behavioral realism, and usability for economic evaluation (Geurs and van Wee, 2004). In addition, the advantage of random utility-based accessibility measures being operationalized as LogSum via discrete choice models enables a tractable way to model travelers' choices. Discrete choice models, because of their advantage of quantitatively modeling complex behavioral choices, have been, to a dominant extent, used to model travelers' behaviors and choice-making (including studies related to ICT) (see, e.g. Chorus et al., 2013; McFadden, 2001). In particular, uncertainties with regard to alternatives that an individual may face when making decisions are explicitly considered in the model development in this research. In addition, the model development follows the approach adopted in the constraint multinomial logit (CMNL) model (Martínez et al., 2009). That is, the accessibility model developed in this thesis include constraint-related utility components into utility function to capture one major ICT effect – i.e., ICT could help people to relax or even avoid constraints (e.g., teleshopping enables people to do shopping outside the opening hours of shops) and, in turn, affect people's accessibility. Furthermore, in line with the value of travel information specified by Chorus et al. (2010, 2013), the accessibility model conceptualizes the utility of travel information as the anticipated expected utility to be derived from the traveler's choice set after having received the information. Finally, a mixed-logit model structure is applied in the choice model to capture the correlations between the choices related to travel, travel information, and teleactivities, due to the flexibility of mixed-logit models in accommodating the correlations in analysts' unobserved factors and approximating any random utility model (McFadden and Train, 2000; Train, 2003).

- The aim of *travel simulator experiment for data collection and estimation of model based on simulator data* is to use the data collected via a travel simulator experiment to estimate the choice model and test the validity of the model. Collecting data for subjects' choices and behavior via a simulator study to calibrate and validate models has been popular and proven to be effective in travel behavior research (see e.g., Chen and Mahmassani, 1993; Chorus et al., 2013; Koutsopoulos et al., 1995; Mahmassani and Jou, 2000). Due to its limited costs and flexibility in creating and simulating, a simulator study has the advantage in studying people's complex choice behaviors under specific conditions. Therefore, simulator studies are often seen as a cost-effective option to collect data for model estimation and validation. In particular, the choice process with regard to a traveler's use of ICT that is considered in this research involves uncertainties and constraints related to alternatives, and two forms of ICT and potential interactions. Using a travel simulator experiment to collect data to estimate the developed model that captures such choice process is considered the most cost-effective option. In addition, it allows for a systematic assessment to what extent the expected interaction between the two forms of ICT – the "I" and the "C" in ICT – plays a role in traveler's choice-making. Therefore, in this research, a tailor-made simulator is developed. The data collected from the simulator experiment is used to estimate the discrete choice model, which is specified based on the accessibility model, for traveler's use of ICT under conditions of risk and constraints.

Intermezzo: an induced reference simulator experiment and comparison of the stated preference- and induced preference-experiments

In addition to the stated preference experiment, a so-called *induced preference* experiment is also conducted. Although it is not directly related to the research goals of this thesis, the induced preference experiment is conducted because it offers a unique opportunity to explore the usefulness of this approach as an alternative paradigm to the conventional stated preference approach in collecting travel choice data for travel behavior research.

The novel feature of the induced preference experiment is that it was designed to induce preferences among participants by explicitly relating the fee they received for participating in the experiment to the choices they made during the experiment. Depending on the type of simulator context, each alternative is *monetized*. As such, participants faced a so-called *"induced preference"* experiment. The stated preference experiment, while being otherwise exactly the same as the induced preferences experiment, offered participants a fixed fee for participating (in line with the stated preference-paradigm that is central to a majority of empirical discrete choice studies in transportation).

The decision to have a subsample of participants make their choices under induced preference conditions are due to the fact that the choice model that is to be estimated is rather involved from a behavioral viewpoint. For example, as will become clear in *Chapters 4* and *5*, the utility of travel information acquisition in the model is hypothesized as the utility of being able to choose from the set of travel and teleactivity options after having received the information. In combination with the presence of constraints of various degrees of "hardness", the developed model makes fairly large demands on individuals' capabilities to grasp the subtle relations that potentially influence decisions to acquire information, choose a particular route, or conduct teleactivity. Experimental economics studies have convincingly argued that, in situations where complicated decision-making mechanisms are tested empirically as in this thesis, the employment of induced preference experiments may help increase levels of involvement and motivation among participants[11] (e.g., Davis and Holt, 1993; Smith, 1976) and facilitate the estimation of choice models (Harrison and Rutström, 2009). Although it is a popular method in other fields, the induced preference approach is rarely used in the field of transport itself. Notable exceptions include: Denant-Boèmont & Petiot (2003), who studied travelers' acquisition of travel information using the experimental economics-approach; Ben-Elia et al. (2008), who studied the impact of information on travelers' route choices; and Ziegelmeyer et al. (2008), who studied the impact of information on congestion in a multi-traveler game-theoretical setting. To the best of the author's knowledge, the study conducted in this thesis is the first – at least in the field of transport – to compare results obtained from an induced preference experiment with results obtained from a conventional stated preference experiment. Note that it obviously does not make sense to compare the two experiments in terms of behavioral

[11] But note that other studies present more mixed evidence in that regard (e.g., Camerer and Hogarth, 1999).

parameters (like travel time- and cost-related parameters) directly, since parameters obtained from the induced preference experiment reflect the incentive scheme designed by the researcher. However, as reported in the *Epilogue* of this thesis, a number of other comparisons can be made to gain further insight into the usefulness of the induced preference approach as an alternative paradigm for collecting travel choice data.

1.5 Research focus and scope

This section presents a general overview of the focus and the scope of the studies conducted in this thesis. These will be elaborated upon in each related chapter in the remainder of the thesis.

Literature overview

The *literature overview* is comprised of following three parts:

- An overview of the accessibility measures in the literature which focuses on a) the physical accessibility measures that do not consider any ICT-related factors; and b) the models that have been developed to measure ICT's effects on accessibility. The accessibility measures that are irrelevant to physical activities or travel, such as measures of accessibility to information in terms of only technical measures (e.g., server capacity, network bandwidth), are outside the scope of the overview.
- An overview of ICT's (potential) effects on accessibility which focuses on a) the effects of teleactivities on travel behavior; b) the effects of travel information on travel behavior; and c) ICT's effects on accessibility. The overview focuses on short-term and direct effects of ICT on travel behavior and accessibility. The long-term effects of ICT on travel behavior and accessibility are outside the focus of the overview. In addition, the overview does not focus on specific types/services/devices of ICT.
- An overview of the models and methods for studying ICT choice and ICT's effects on travel behavior which focuses on a) related theories and conceptual models; b) related data collection methods; and c) related data analysis methods/models. Similarly, the focus is on the models and methods for studying short-term and direct effects of teleactivities and travel information on travel behavior.

Web-survey for data collection and statistical analyses of survey data

The *web-survey and statistical analyses* have the following focus and scope:

- The types of ICT that are considered in this study are confined to travel information and teleworking, respectively. Specific types of travel information (e.g., a particular type of information concerning a train schedule, route or traffic information, etc.), and other types of teleactivities, such as teleshopping, are not explicitly considered in the study;
- The survey is conducted among a sample of Dutch commuters and people travelling for education purposes. The term *"commuters"* is used for both categories in the remainder of this thesis. The survey, in particular, selects people who commute by car regularly or at least have prior experience of doing so;

- The study focuses on commuters' preferences for pre-trip travel information and teleworking at home before their morning commute;
- The study focuses on the exploration of the interrelation between travelers' preferences for travel information and telecommunication functionalities of ICT, and does not aim to (fully) explain travelers' preference for teleworking and travel information and to exhaust all possibly relevant factors.
- In addition, the study does not aim to forecast market shares for ICTs given certain contextual conditions, but rather wishes to study determinants of preferences for travel information and teleworking.

Formal model development

Based on the conceptualization of accessibility in this thesis (section 1.3), the following focus and scope is adopted for the *formal model development* (the representative individual accessibility model and the discrete choice model that is specified based on the accessibility model).

a) Scope for accessibility conceptualization and operationalization in the research:

- First, the research focuses on accessibility that is relevant to the realm of *travelers' physical activity-travels*. Accessibility related to freight transport (e.g. Lim and Thill, 2008; Thomas et al., 2003) is not considered in this research. The research also excludes digital accessibility (e.g. Batty and Miller, 2000; Dodge, 2000; Tranos et al., 2013) that measures the accessibility to information on the web and is irrelevant to physical activities or travel behavior.
- Secondly, the research focuses on *individual* accessibility rather than aggregate accessibility, and, consequently, ignores interactions between people in the context of ICT-use (see, Janelle (1995), Miller (2005a), Kwan (2007) and Soo (2009) for examples of such interactions between people in the context of ICT-use);
- Thirdly, the research focuses on *potential* accessibility rather than the so-called experienced or realized accessibility that conceptualizes and operationalizes accessibility as the evaluation of a chosen alternative after the choice has been made (i.e. experienced or realized accessibility) (e.g. Chorus and de Jong, 2011; Kahneman et al., 1997; Scott, 2000);
- Finally, the research focuses on *short-term* accessibility rather than long-term accessibility. When long-term accessibility is discussed, aspects such as change in land-use, residential and work location may play important roles (e.g. Eliasson, 2010; Neuteboom and Brounen, 2011; Van Wee, 2002). This research adopts a short-term time horizon and focuses on the relationships between ICT, choices for short-term travel and accessibility.

b) Scope for travel behavior and decision-making:

- First, following the adopted (R)UM theoretical framework, the research assumes travelers to be (expected) utility-maximizing rational agents who make decisions according to the rule of utility-maximization (Ben-Akiva and Lerman, 1985; McFadden, 1974; Train, 2003). Such a perspective differs from those that assume travelers are decision-makers according to other rules such as (cumulative) prospect theory (see, Kahneman and Tversky, 1979; Tversky and Kahneman, 1992) and random regret minimization theory (see, Chorus, 2010, 2014; Chorus et al., 2008);

- Secondly, in line with the short-term time horizon adopted for the accessibility concept, the research focuses on the first level of interactions – the short-term interactions between ICT and activity engagement and travel. The second and third-order interactions, referring to changes in land-use, residential and work location, and possible transformations of social norms and values, are excluded (see Salomon, 2000 for the distinction of first-, second- and third-order interactions). The indirect-interactions – the impact of ICT on travel supply (e.g., intelligent transportation system) are also excluded from the research.

- Thirdly, fitting with the research's aim of providing a generic model for measuring ICT's effects on accessibility, the research adopts a generic perspective in analyzing traveler's behavior, rather than focusing on specific travel choices regarding, for example, route choice, departure time choice, mode choice, scheduling and rescheduling of activities, and time allocation to activity durations.

- Finally, the reverse effects of accessibility on ICT-use are not considered in the research. Accessibility, especially if a long-term time horizon is adopted, may affect people's travel behavior and ICT-use. For example, low accessibility to a work location from a residential location may stimulate teleworking (see, e.g. Berechman and Paaswell, 2001; Coppola and Nuzzolo, 2011; Lee et al., 2010 for discussions on the effects of accessibility on the spatial distribution of activities and travel choice). Although it is an interesting topic, it is excluded from the research.

Travel simulator experiment for data collection and estimation of models based on simulator data

The *travel simulator experiment and model estimation* have the following focus and scope:

- The simulator is designed according to the data requirement for model estimation, with a hypothetical morning-commute environment. In the experiment, travelers are provided with the option to acquire travel information and the option to telework, in addition to a set of routes from home to work with uncertain commuting time, under various arrival time constraints.

- The experiment is conducted among a sample of Dutch commuters who commute by car regularly or at least have prior experience of doing so;

- The stated preference data collected from participants who were offered with a fixed fee for participating are used for model estimation in order to test the validity of the developed model and to get related estimates for derivation of insights into travelers' use of ICT under conditions of risk and constraints;

- The induced preference data collected from the participants whose fee for participation is coupled with their choices are used for model estimation. The results are compared with the results from the stated preference data to study the usefulness of the induced preference approach for collecting travel choice data.

1.6 Outline of this thesis

Figure 1-1 presents an overview of this thesis, where the links (input-output) between different chapters are also presented by arrows. The contribution and the main content of each chapter, and the links between the chapters are as follows.

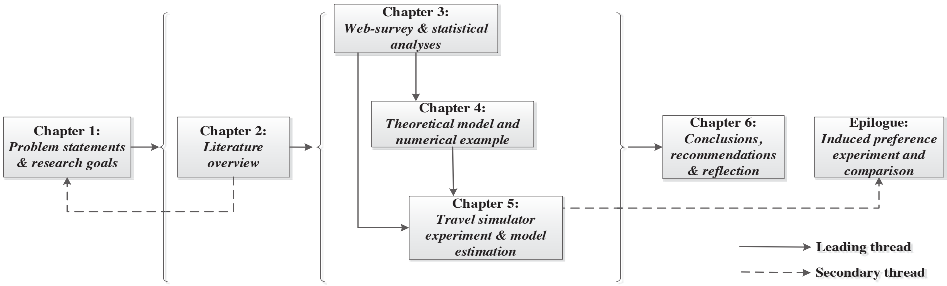

Figure 1-1: Outline of this thesis

Chapter 2 *presents an overview of literature related to ICT and accessibility.*

The overview aims to form a theoretical and knowledge basis for the research presented in *Chapters 3 to 5* as well as to derive knowledge relevant to future research. As explained above, this chapter presents an overview of three main categories. First, this chapter presents an overview of the accessibility measures present in the literature, including a) the physical accessibility measures that do not consider any ICT-related factors; and b) the models that have been developed to measure ICT's effects on accessibility. Secondly, the chapter presents an overview of the findings on ICT's (potential) effects on accessibility, including a) the effects of teleactivities on travel behavior; b) the effects of travel information on travel behavior; c) several important factors that are relevant to ICT use and ICT's effects on travel behavior; and d) ICT's effects on accessibility. In addition, this chapter presents an overview of the models and methods used in the study of ICT choice and ICT's effects on travel behavior, including a) related theories and conceptual models; b) related data collection methods; and c) related data analysis methods/models. The overview provides knowledge relevant to follow-up studies (which will be presented in the following chapters of this thesis). The overview also assists in identifying the problem statement, formulating the research goals, choosing the research methods, and defining the focus and scope of the research in this thesis.

Chapter 3 *presents an empirical study based on a web-survey.*

The study aims to explore and to gain empirical insights into the possible interrelated nature of travel information and telecommunication functionalities of ICT. The web-survey was conducted among Dutch commuters. Structural equation modeling (SEM) was used to analyze the data to answer the questions – a) whether (and to what extent) a correlation exists between travelers' preferences for teleworking and travel information, and b) what are the relations between travelers' preferences for teleworking and travel information and other factors that could be of influence, such as travelers' perception of the reliability of commuting time, the availability and reliability of travel information, the availability of teleworking and the quality of teleworking environment and facilities. The results of the study provide empirical insights into the possible interrelations between the "I" in ICT and the "C" in ICT that are relevant to the follow-up formal model development presented in *Chapters 4* and *5*.

Chapter 4[12] *presents a representative individual behavioral model developed to measure the effects of different forms of ICT – information-related technologies for travel information and telecommunication-related technologies for teleactivities, including their potential interactions – on accessibility.*

The developed model aims to fulfill the research goal to provide for the lack of a formal integrative model for measuring the effects of different forms of ICT on accessibility. The chapter first presents the conceptualization of the model based on the utility-based theoretical framework. This is followed by the formal derivation of the conceptualization into a quantitative model. The model measures the effects of different forms of ICT on accessibility when the decision-maker is faced with risky alternatives and constraints. Numerical examples are presented that provide a first sign of the model's face validity, and also reflect the combined effects of travel information and teleactivities on accessibility in different situations. The developed representative individual model is further translated into a discrete choice model-format variant in *Chapter 5*.

Chapter 5[13] *presents an econometric (discrete-choice-based) specification of the developed representative individual model for measuring ICT's effects on accessibility, and the model estimation results based on the data collected via a travel simulator experiment (stated preference experiment).*

This chapter aims to translate the developed accessibility model (*Chapter 4*) into an estimable discrete choice model, and aims to collect data to estimate the choice model in order to test the validity of the developed model and to get related estimates for derivation of insights into travelers' use of ICT under conditions of risk and constraints. This chapter commences with the translated choice model. This chapter then introduces the travel simulator experiment where travelers are provided with the options to acquire travel information and to telework, in addition to a set of routes with uncertain commuting times, under various arrival time constraints. The estimation results that are presented next show the capability of the model in capturing the behavioral mechanisms that may be present in the experiment.

Chapter 6 *draws together the main conclusions of the research, and gives recommendations with a special focus on the SAR-program, and reflects on the research.*

This chapter first draws the main conclusions of the research according to the two research goals addressed in *Chapter 1* of this thesis. Secondly this chapter gives recommendations for

[12] Note that in this thesis, as is common practice, *Chapter 4* is presented in a way, without any adaptation, as the published paper: Lu, R., Chorus, C., & Van Wee, G.P., (2014). The effects of different forms of ICT on accessibility – a behavioural model and numerical examples. *Transportmetrica A: Transport Science,* 10(3), 233-254.

[13] *Chapter 5* and the *epilogue* have formed the basis of the paper in press: Lu, R., Chorus, C., & Van Wee, G.P. (2014). Travelers' use of ICT under conditions of risk and constraints: an empirical study based on stated and induced preferences. *Environment and Planning B: Planning and Design*, 41(5), 928-944.

future research and recommendations for policy makers with a special focus on the SAR-program. This chapter finishes with a reflection on the research.

The epilogue *presents the study of the induced preference experiment and the comparison of the results of the induced and stated preference experiments*.

The study aims to explore the added-value and limitations of using an induced preference approach for data collection in travel behavior research. The study uses the same discrete choice model described in *Chapter 5* and the same simulator used in the stated preference experiment (also in *Chapter 5*), but collects induced preference data to estimate the model. The epilogue first introduces the incentive scheme adopted in the induced preference experiment, and then presents the model estimation results based on the induced preference data. The comparative study of the results between the induced- and stated preference experiments is then presented. The epilogue closes with a discussion concerning the usefulness of the induced preference approach for data collection in travel behavior research.

2 Accessibility in the ICT age: a literature overview

Abstract

This chapter provides *an overview of literature related to ICT and accessibility*. The overview aims to form a theoretical basis for the research in this thesis as well as to derive knowledge that is expected to be of relevance to future research. The chapter presents overviews of three categories of literature. First, this chapter presents *an overview of the accessibility measures in the literature*, including a) the physical accessibility measures that do not consider any ICT-related factors; and b) the models that have been developed to measure ICT's effects on accessibility. Secondly, the chapter presents *an overview of ICT's (potential) effects on accessibility*, including a) the effects of teleactivities on travel behavior; b) the effects of travel information on travel behavior; c) several important factors that are of relevance to ICT use and ICT's effects on travel behavior; and d) ICT's effects on accessibility. Thirdly, this chapter presents *an overview of the models and methods for the study of ICT choice and ICT's effects on travel behavior*, including a) related theories and the conceptual models; b) related data collection methods; and c) related data analysis methods/models. The relevance of all these overviews to the research in this thesis is also discussed.

2.1 Introduction

This chapter provides an overview of literature related to ICT and accessibility. As mentioned in *Chapter 1*, an overview of this literature is necessary in order to provide a first step in the understanding of ICT's effects on accessibility and to form the theoretical and knowledge basis for future research. In particular, the following three aspects are considered important. First, in order to derive knowledge for developing a model for measuring ICT's effects on accessibility, it is important to have an overview of the accessibility measures in the literature. Secondly, to have an overview of the (potential) effects of ICT on accessibility that are identified in the literature is, for obvious reasons, critical for both scientific and practical purpose. Thirdly, it is also interesting to have an overview on the models and the methods that are used in the literature for the study of travelers' choices of ICT and ICT's effects on travel behavior. The reason, as argued in *Chapter 1*, is that it is believed that traveler behavior should be taken into consideration when analyzing ICT's effects on accessibility. Any accessibility measures that do not consider traveler behavior not only lack theoretical rigor but also are of limited practical relevance. The overview of the related models and methods for studying travelers' choices of ICT and ICT's effects on travel behavior may provide extra insights for future research.

Based on these arguments, this chapter presents a literature overview of the three above-mentioned aspects. The general aim of the overview is twofold.

- First of all, the overview aims to derive knowledge from previous studies in order to provide the theoretical basis for the research described in this thesis.
- Secondly, the overview aims to derive knowledge that is expected to be of relevance to future research.

More specifically, this chapter first presents an overview of the *accessibility measures* in the literature with regard to their theoretical perspectives (the accessibility definitions or the theories that the measures are developed based on), and their scopes of applications based on their advantages and disadvantages. In addition, an overview of the models that have been developed to date to measure ICT's effects on accessibility is provided. The derived knowledge aims to contribute to the development of the model for measuring ICT's effects on accessibility in the research in this thesis. Secondly, this chapter presents an overview of the findings about *ICT's (potential) effects on accessibility* from relevant studies in the literature. Although an overview of ICT's effects on accessibility is also provided, the focus of the overview is on travelers' choices of ICT and ICT's effects on travel behavior. There are two reasons to focus on travelers' choices of ICT and ICT's effects on travel behavior. On the one hand, it is, as argued before, important to consider traveler's behavior when accessibility is concerned[14]. On the other hand, relatively few studies exist in the literature directly discussing ICT's effects on accessibility compared to the large body literature on ICT's effects on travel behavior. This overview aims to provide insights into ICT's (potential) effects on accessibility that are expected to be of both scientific relevance and practical implications. Thirdly, this chapter provides an overview of the *theories/conceptual models, data collection methods,* and *data analysis methods/models* that are used in the studies of travelers' choices of ICT and ICT's effects on travel behavior. The relevance of the overview of these three aspects to this thesis and to future research is elaborated in each section.

The remainder of this chapter is organized as follows. Section 2.2 first introduces the methodology and the scopes for the literature overview. Section 2.3 presents the overview of the accessibility measures in the literature. Section 2.4 provides the overview of the findings on ICT's (potential) effects on accessibility. Section 2.5 presents the overview of the models and the methods for the study of travelers' choices of ICT and ICT's effects on travel behavior. Section 2.6 concludes this chapter.

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[14] Also see, for example, Salomon (1998) for supporting arguments for the importance of considering travelers' choices and preferences in discussing ICT's effects.

2.2 Methodology and scopes for the literature overview

This section first introduces the methodology and the scopes for this literature overview. In general, key references were selected first. Various databases such as Google Scholar and Scopus were also used to search literature. A snowball approach was used later: reference lists from the appraised papers that are obtained from the various databases were used for further literature search. References that cited the appraised papers were also checked. Note, however, that this overview does not aim to present a complete list of all the relevant studies in the literature. Rather, the overview aims to provide examples of relevant studies as starting points for more in-depth literature search, and focuses on the derivation of the key methods and insights related to the three addressed aspects.

In particular, the overview of the accessibility measures is first based on several notable extensive reviews in the literature (Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004; Handy and Niemeier, 1997; Miller, 1999; Neutens et al., 2010). The references cited in these papers are used to search further useful references. In addition, combinations of key words such as “virtual accessibility”, “e-accessibility”, “ICT accessibility" or “hybrid accessibility” were initially used to search studies related to the accessibility measures that consider ICT-related factors. The reference lists of the derived literature were used for further search. The search results were assessed based on the criteria whether or not the measure is related to physical activities or travel behavior. Given the research aim of this research, the accessibility measures that are irrelevant to physical activities or travel behavior are beyond our scope (e.g., the measures of accessibility to information in terms of only technical measures such as server capacity and network bandwidth).

A similar methodology is applied to the search of literature on ICT’s effects on travel behavior and accessibility. Notable related studies in the literature were reviewed first, for example, the teleactivities-related studies by Salomon (1985; 1986), Mokhtarian and Salomon (1994, 1996a, b), Handy and Mokhtarian (1996) and Andreev et al. (2010), and the travel information-related studies by Polak and Jones (1993), Emmerink et al. (1995), Kenyon and Lyons (2003), and Chorus et al. (2006b). The reference lists of these articles were used for further literature search. Combinations of key words such as “travel behavior”, “route/mode/departure time choice”, “ICT”, “travel information”, “teleactivities”, “teleworking/telecommunication”, “teleshopping”, “teleleisure”, “travel behavior model” and “activity-based model” were also used to search related literature. Note that this overview of ICT’s (potential) effects on accessibility focuses on the studies dealing with short-term or direct effects of travel information and teleactivities in general on traveler’s behavior and accessibility. Hence, studies related to, for example, travelers’ choices of specific types/services/devices of ICT, or long-term effects of ICT on travel behavior and accessibility, are not taken into consideration.

The literature overview of the models and methods for the study of travelers’ choices of ICT and ICT’s effects on travel behavior is conducted using the same methodology as introduced above. Substantial parts of the literature used for the overview of ICT’s effects on travel behavior were also used for the overview of this part. Similarly, the focus of this overview is also on the models and methods that have been used by studies dealing with short-term or direct effects of travel information and teleactivities in general on traveler’s behavior.

2.3 Accessibility measures: a literature overview

2.3.1 Introduction

This section provides an overview of the accessibility measures in the literature. Before the overview is presented, the distinction between "accessibility" and "access" should be clarified. Strictly speaking, *accessibility* should be defined from the perspective of locations/activities, while *access* should be defined from the perspective of people. That is, a location/activity is accessible to people and a person has access to a location/activity (Geurs and van Wee, 2004). However, the terms "accessibility" and "access" are often used indiscriminately in the literature (Van Wee et al., 2013). This literature overview follows this trend and uses the term "accessibility" for both perspectives.

In spite of the acknowledged importance to society, it has been pointed out that accessibility is often a poorly-defined, misunderstood or narrowly-perceived concept (Geurs and Ritsema van Eck, 2001). It is partly because accessibility, as an abstract entity, is difficult to translate into a single universal notion. As a result, many researchers are reluctant to make any kind of tautological definitions (Martinez, 1995). Rather, it is often used given specific focus or context. In addition, it is not unanimous as to which accessibility measure outperforms others because each accessibility measure has its advantages and disadvantages. Many transport and land-use plans were evaluated on the so-called *proximity-based* accessibility measures in terms of the aspects such as travel time/cost for travelers, transport system throughput or service level of transport infrastructure (see e.g., Kouwenhoven, 2008; Linneker and Spence, 1992). These measures, despite their easiness in operationalization and interpretation, have been criticized for the lack of theoretical soundness and methodological advancement (Geurs and van Wee, 2004). These measures may be not sensitive enough to appraise the outcome difference between different policy measures for the cases that involve factors such as people's characteristics and preferences/behavior, and the attractiveness of activities and opportunities at locations. Due to these shortcomings, alternative types of accessibility measures have been developed to incorporate other factors into the measures than only infrastructure-related aspects. These measures include i) *activity-based* accessibility measures that consider accessibility of locations from the activity perspective (e.g., Handy and Niemeier, 1997; Song, 1996), ii) *space/time-based* accessibility measures that consider microscopic accessibility at an individual level (e.g., Kwan, 1998; Miller, 1991), and iii) *utility-based* accessibility measures that are defined within utilitarian paradigm (e.g., Ben-Akiva and Lerman, 1985; de Jong et al., 2007). These measures, which advance infrastructure-based accessibility measures from a theoretical or methodological perspective, are rapidly gaining interests and recognition among researchers, practitioners and policy makers. However, these measures are often considered less favorable, particularly among policy-makers, than the infrastructure-based measures in terms of operationalization, interpretability and communicability (Geurs and van Wee, 2004).

Given the wide range of accessibility measures, it is believed to be important to give a literature overview of these measures in order to derive knowledge for model development in this thesis. Since several notable extensive literature reviews already exist (see, e.g. Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004; Miller, 1999; Neutens et al., 2010), rather than to repeat the work, this section gives a brief literature overview in a categorization of all these measures into *proximity*-based, *space/time*-based, *activity*-based, and *utility*-based measures[15]. The overview focuses on the discussion of the theoretical perspectives of these measures, and the scopes of application based on the advantages and disadvantages of each measure from the perspective of the research interest of this thesis. Note, however, that these four categories are not mutually exclusive; there are accessibility measures that are developed within utility-based paradigm but based on other types of accessibility measures[16]. For example, Miller (1999) developed a composite utility-based and space/time-based model that measures accessibility as the benefits of the opportunities within the space-time prism. Martinez (1995) and Martinez & Araya (2000) developed the balancing factor benefit measure that defines accessibility based on the spatial interaction framework (Coelho and Wilson, 1976; Wilson, 1976), but conceptualizes from the point of user benefit – i.e., accessibility is formalized as the net benefits of activities at locations accessible to people with spatial interaction. The balancing factor benefit measure considers accessibility as the expected user benefits from the trip interactions, namely the trip generated, trip attracted and the trip between. Dong et al. (2006) developed a utility- and activity-based accessibility measure that measures accessibility to all activities in which an individual engages. In addition to these accessibility measures developed in the physical realm without considering any virtual factors of ICT, given the interest of this research, this section also presents an overview of the models that consider virtual factors of ICT (e.g., virtual access to activities, information effects) into the definitions or formalizations for measuring ICT's effects on accessibility.

The remainder of this section 2.3 is organized as follows. Section 2.3.2 presents the overview of the physical accessibility measures that do not consider any ICT-related factors. Section 2.3.3 presents the overview of the models that have been developed to measure ICT's effects on accessibility. Section 2.3.4 summarizes this section and also reflects on the relevance of this literature overview to the research described in this thesis.

2.3.2 An overview of physical accessibility measures in the literature

Proximity-based measures

Proximity-based accessibility measures, which are also known as infrastructure-based or connectivity measures, define accessibility as the measure of physical proximity between locations. Indicators related to transport systems, such as travel distance, travel time, travel cost, travel speed, density of networks, congestion level, and location distributions, are often used (see, e.g. Geertman and Van Eck, 1995; Talen and Anselin, 1998; Wang et al., 2009). Some of these measures are only related to infrastructure supply, while others also include demand factors (e.g., travel time and chance of congestion depend on both supply and demand) (Van Wee et al., 2001). Proximity-based accessibility measures have advantages in operationalization and communication because it is relatively easy to collect necessary data

[15] Different ways of terminology of these accessibility measures than the presented ones can be found in the literature. Examples of these alternative terms will be introduced when these measures are introduced in the section 2.3.2.

[16] Note that some papers (e.g. Geurs and van Wee, 2004) also categorize these hybrid models as utility-based models. Given their hybrid features, this overview does not categorize them as utility-based measures, nor as other types of measures.

for these measures and also relatively easy to explain these measures. However, they are often only suitable for appraisal of the direct effect of traffic and transport policy measures related to infrastructure development, traffic management, and pricing mechanisms, since these measures do not consider, for example, people's preferences and behavior and factors related to activities/opportunities at locations. Take an example that when the accessibility to job opportunities for the citizens at a certain region needs to be evaluated, using proximity-based measures would be not suitable. The narrow scope of these measures also results in that they may be not sensitive enough for evaluation of spatial planning policies or ICT-related transport policies, which requires consideration of people's preferences and behavior.

Space/time-based measures

Different from the accessibility measures defined from location perspective, space/time-based accessibility measures (also often named as people-based measures) analyze accessibility from the perspective of individuals or households, and describe to what extent people can reach locations or engage in activities (see, e.g. Dijst, 2004; Forer and Huisman, 2000; Kwan, 1998; Lenntorp, 1977; Miller, 1999; Neutens et al., 2012a). Space/time-based measures are developed based on the space-time prism (STP) theory of Hägerstrand (1970) – individual/household's engagement of activities is subject to the spatial and temporal constraints caused by a set of chronologically ordered successive activities the time and space of which are difficult to alter. The space-time prism, which describes the potential reachable areas of activities at given pre-defined spatial and temporal constraints, is regarded as a measure for the accessibility for individual or household. Space/time-based accessibility measures, due to the recognition of space-time dimensions in individual/household's activity-travel patterns, allow for more sensitive assessment of individual variations in accessibility. Compared to proximity-based accessibility measures, space/time-based measures prove to be effective in reflecting people's activity-travel behavior into accessibility. One example of effects that can be captured via space/time-based measures but not via proximity-based measures is the constraints of people's available time budget for conducting activities on people's accessibility – a person may only have 30 minutes to do grocery shopping because of his or her work, and the effects of the available time to the person for shopping on his or her accessibility to the supermarkets in his or her region cannot be captured via proximity-based measures. However, the disadvantages of space/time-based measures lie in the difficulty to be operationalized and communicated. Using space/time-based measures often requires large amount of data at individual levels, which is difficult to collect, despite the development in GIS and spatial modeling (Kwan, 1998). It is therefore difficult to apply space/time-based measures to population groups or to a large geographical scale (Geurs and van Wee, 2004). In addition, due to their focus on short-term behavior, using space/time-based measures to evaluate transport and spatial planning policy measures is often restricted particularly when medium or long-term effects are concerned (Waddell, 2011).

Activity-based measures

Different from the space/time-based accessibility measures focusing on an individual level, some studies define accessibility as the reflection of the set of activities or opportunities available at particular locations at a more aggregate level. Such an activity-based definition is widely used for the appraisal of accessibility to different activities or opportunities such as jobs, retails, education, health services, and recreational facilities (see, e.g. Andersson and Klaesson, 2006; Kotavaara et al., 2011; Osland, 2010). A range of activity-based accessibility measures (sometimes also named as location-based measures) have been developed, for example contour accessibility measures (Breheny, 1978), potential accessibility measures

(Handy, 1994; Joseph and Bantock, 1982) and balancing-factors measures (Wilson, 1971). These measures are developed based on the so-called attraction theory that considers both the attraction of activities at locations (e.g., the number of the activities at locations) and the interactions between people and activities (e.g., the travel time needed for people to reach the activities) (Hansen, 1959; Weibull, 1976). Although the different measures developed based on attraction theory have their own advantages and disadvantages, in general, activity-based measures are considered both theoretically and practically superior to infrastructure-based measures in particular in terms of usability for evaluation of policy measures. Due to the consideration of attraction of activities at locations and the interaction between people and activities, activity-based measures are more policy-sensitive than infrastructure-based measures for evaluation of accessibility, for example, of the shops at a location. However, compared to space/time-based measures, activity-based measures do not consider spatial-temporal constraints people may face and hence may over-estimate the accessibility of the potential activities or opportunities reachable to people. These shortcomings limit the usability of activity-based measures into certain contexts, in particular, when individual characteristics or population variations are considered important. For example, activity-based measures cannot capture the effects of people's time budget on their accessibility.

Utility-based measures[17]

Utility-based measures are founded on economic theory. Two streams of utility-based measures can be distinguished – *generalized cost measures* and *random utility-based measures* (also named as LogSum-measures)[18].

One stream of measures is so-called *generalized cost measures*, which are recently introduced as new accessibility measures for the Netherlands (Hoogendoorn-Lanser et al., 2012). Generalized cost measures estimate the generalized cost for traveler's journey between locations. The generalized cost includes not only monetary costs such as the fares of public transport journeys or the fuel costs for car journeys, but also non-monetary costs, which are expressed in monetary terms, related to the aspects such as travel time, comfort, and quality during journeys (see, e.g. Groot et al., 2011; Hilbers et al., 2007). Generalized cost measures have advantages in operationalization and communicability. Data can be collected at reasonable costs. These measures can be expressed as comparable indices as well as absolute values, making it relatively easy to explain these measures to practitioners and policy makers. General cost measures are also considered with high policy relevance for appraisal of transport policies. For example, they are applicable to different transport modes, enabling comparison of accessibility between modes. These measures can provide insights into both the average accessibility of each traveler and the overall accessibility of the complete traffic flow (Hoogendoorn-Lanser et al., 2012). However, while it is relatively easy to convert some non-monetary factors such as value of time into monetary costs, it is a complex and not unanimous process to convert others (e.g., comfort, quality) into monetary costs

[17] Note that, as introduced in section 2.3.1, there are composite accessibility measures that are developed within utility-based paradigm but based on other types of accessibility measures.

[18] Note that the perspective for utility-based measures is not consistent across studies in the literature. For example, while some studies consider generalized cost measures also a type of utility-based measures (see, e.g. Hoogendoorn-Lanser et al., 2012), some studies use utility-based measures only to indicate random-utility measures (see, e.g. Crozet et al., 2012).

(Hoogendoorn-Lanser et al., 2012). Choosing appropriate converting coefficients for particular contexts is difficult. Using different converting coefficients in generalized cost measures to evaluate one same transport or spatial planning policy may result in different, or even contradictory, results. In addition, generalized cost measures cannot be used to effectively measure accessibility to activities/opportunities, as generalized cost measures largely focus on travels between locations only. This type of measures in turn seems not suitable for appraisal of spatial planning policy measures. Finally, it is also debatable whether generalized cost measures shall be considered as measures of accessibility or as measures of people's valuation of accessibility.

Another stream of utility-based measures defines accessibility as the utility outcome of a set of activity-travel choices. These random utility-based measures are developed based on the utility theory from the perspective of user benefits within random utility paradigm (Ben-Akiva and Lerman, 1979, 1985). The accessibility within the random utility paradigm is formalized as the expected maximum utility that an individual can derive from a set of activity-travel alternatives (when analysts' perspective is adopted)[19] (see, e.g. Handy and Niemeier, 1997; Niemeier, 1997; Sweet, 1997). These random utility-based measures outperform the other accessibility measures in theoretical soundness and behavioral realism. These measures consider individual's choice-making and therefore capture individual's behavior in the measures. An additional advantage of these measures lies in their usability in economic evaluations. The random utility-based measures can be translated into LogSum-measures[20] and be linked to micro-economic theory, allowing for calculations of consumer surplus for economic evaluations. Compared to other types of accessibility measures, these random utility-based measures are able to compute transport-user benefits of transport and land-use projects or policies. Random utility-based measures also show diminishing returns – the non-linear relationships between accessibility improvements and user-benefit changes. In addition, the random utility-based measures, which can be analyzed via discrete choice models, have advantages in operationalization. Because of the advantage in quantitatively modeling complex behavioral choices, discrete choice models have been used in modeling traveler behavior and decision-making to a dominant extent (McFadden, 2001). However, despite these advantages, random utility-based measures are relatively difficult to interpret and communicate (Geurs and van Wee, 2004). The random utility theory is not easy to understand and this results in difficulty to communicate these measures to, especially, practitioners and policy-makers who do not have knowledge of this theory. It is also not without question whether random utility-based measures can be essentially considered as measures of accessibility or better as measures of people's valuation of accessibility (i.e., user benefits) (Geurs and Ritsema van Eck, 2001). In addition, while random utility-based measures are often used assuming decision-theory equivalent to decision-utility, there is a discrepancy between what these measures of accessibility aim to measure (experienced utility) and what they actually measure (decision-utility) (Chorus and de Jong, 2011).

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[19] Note that when an individual's perspective is adopted (in this case, there is no unobserved utility components by analysts), the accessibility should be defined as the maximum utility that an individual can derive from a set of activity-travel alternatives (see, Ben-Akiva and Lerman, 1985).

[20] When the random utility component is i.i.d. Gumbel distributed, the accessibility can then be written as the LogSum of the deterministic utilities of the alternatives in the choice set (see, Ben-Akiva and Lerman, 1985).

2.3.3 Models that measure ICT's effects on accessibility

Notwithstanding the obvious values of these above-presented accessibility measures, these measures are not yet suitable and readily applicable to measuring the effects of ICT on accessibility. These measures are developed in the physical realm and do not consider any ICT-related factors into formalizations. These traditional physical accessibility concepts developed within the physical realm needs to be also re-defined. According to these traditional physical accessibility measures, a workplace for an individual may be considered with low accessibility due to serious congestion on the way from the individual's home to the workplace. But the workplace might be considered by the individual very accessible because of the option for him or her to connect to his or her workplace digitally via telecommunication technologies (e.g., remote desktop). The physical accessibility measures hence become insufficient to capture the actual accessibility to the workplace perceived by the individual in this case. Via information-related technologies, an individual may get to know another less congested route to his or her workplace via travel information than the one he or she takes regularly, resulting in an increase in accessibility as well. The fact that ICT increasingly leads to change of people's travel behavior and in turn accessibility results in a strong need for models that are able to measure ICT's effects on accessibility.

However, to the best of the author's knowledge, still few formal or quantitative models that are able to measure ICT's effects on accessibility exist in the literature yet to date, despite the increasing efforts to incorporate ICT-related factors into accessibility measures.

One strand of the few efforts focuses on extension of space/time-based accessibility measures via the introduction of new conceptualizations of space-time into classical time-geographical concepts. For example, Janelle (1995) developed a framework to classify communication modes based on spatial and temporal constraints. Spatial constraints require either physical presence or telepresence, whereas temporal constraints require either synchronous or asynchronous communication. Based on Janelle's framework, Miller (2005a) introduced two new time-geographic objects – portals and message windows – into the classical time-geographic concept, and incorporated indirect (virtual) interaction into the time-geographic measurement theory. Dijst (2004) discussed the effects of ICT on accessibility based on a conceptual framework that distinguishes space-time accessibility into a) the space-time prism potentially accessible (i.e., opportunities which are exclusively accessible from a spatiotemporal perspective), b) the prism perceptually accessible (i.e., opportunities which are exclusively accessible from a perceptual perspective), and c) the prism potentially and perceptually accessible (i.e., opportunities which are accessible from both a spatiotemporal and a perceptual perspective. Kwan (2007) proposed a conceptual model called hypertext. The hypertext model assumes that each individual has several nodes connecting to different social networks, while each link represents the possibility of interactive coordination between individuals. Kwan argued that the hypertext model may be a useful framework for conceptualizing the effects of real-time interactivity enabled by mobile communications and social networks on urban travel. Different from the traditional accessibility measures, these conceptual models take into consideration the effects of the virtual interactions enabled by ICT (e.g., telecommunication between individuals) on individual's space-time prism in physical realm – the potential reachable areas of activities to the individual given spatial and temporal constraints. These conceptual models form a basis for further formalizations of these models in order to quantitatively measure the accessibility change caused by ICT. However, the difficulty of using these models in practice is that these models are developed largely at a conceptual level. The lack of mathematical formalization restricts the capabilities of these conceptual models being operationalized in practice. In addition, these models mainly focus on telecommunication and its effects on people's space-time prism. This limits their ability to measure, for example, the effects of information on accessibility, or the effects of the changes in travel disutilities due to ICT-use during traveling on accessibility.

The very recent development of Geographic Information System (GIS) increases the applicability of the extended time-geographic frameworks that incorporate virtual realm. Ren and Kwan (2007) employed information cubes into the traditional GIS-based physical space-time prism to represent the activity opportunities in cyberspace that a person has access to during a specific amount of time. The volume of the cubes – the size of the opportunities – is determined by the time spent on using the internet, the connection speed and the number of websites accessed. Couclelis (2009) further expanded the ontology of Ren and Kwan's framework by explicitly distinguishing the purposes of activities (e.g., social activities, self-entertainment activities) and the means (i.e., transport and communication-related means) necessary to achieve the activity purposes. A similar GIS-based framework that implements both physical and virtual prisms in a 3-dimensional (2D space+1D time) environment can be found in the study of Shaw and Yu (2009). However, despite the progress in the applicability of these frameworks thanks to GIS, one difficulty of implementing these frameworks is that a large amount of individual data is often required. The need for extra data about individual's behavior related to virtual activities (e.g., individual telecommunicates with multiple people via multiple channels simultaneously) even increases the difficulty. In addition, the confidentially and privacy issues related to the collection of large amount of individual data also restrict the implementation of these frameworks in a large scale (Couclelis, 2009). Although synthetic data may be adopted in some cases (e.g., to illustrate how the framework works), the difficulty in collecting real data still limits the application of these frameworks in empirical case studies. Moreover, these frameworks that focus on short-term behavior of travelers are not quite suitable to study medium- or long-term traveler behavior (e.g., travelers' learning from ICT). Another challenge that remains yet to be addressed, pointed out by Neutens et al. (2011), is that these developed time-geographic frameworks are not able to measure the effects of ICT in reducing disutilities or even generating positive utilities for physical travels via, for example, enabling people to multitask during travels (see, e.g. Jain and Lyons, 2008; Lyons and Urry, 2005). Not only are people's activity spaces changed because of ICT, but individuals' valuation of travel time is also changed – the disutility of travel might decrease or travel might not be a disutility for traveler any more. As a result, the traditional space-time accessibility definition as the extent to which people can reach locations or engage in activities might need to be reconsidered as well. The current practice of using time-space paths to represent physical travels cannot capture the change of individual's valuation of travel time because of ICT and thus may not be able to sufficiently capture the effects of ICT on accessibility.

Other examples extend or modify traditional accessibility measures via the inclusion of certain ICT-related factors into the measures. For example, Scott (2000) used functional travel time, instead of actual travel time, in the traditional doubly constrained gravity accessibility measures for the study of the supply and demand of jobs and workers. Scott defined the functional travel time as the costs related to spatial interactions of jobs and workers. The functional travel time, different from the actual travel time, considers the interactions enabled by telecommunication technologies. The actual travel time between places may be high because of congestion, while the functional travel time between the places may be low due to high level of telecommunications between the places. Shen (2000) developed a model to measure job accessibility with competition by distinguishing job seekers who have telecommunication capabilities and who have not. The model, developed based on the traditional gravity accessibility measure, also distinguishes the job opportunities accessible via transportation or telecommunications. Shen's model was later applied by Muhammad et al. (2008) in a study of the job accessibility under the influence of ICT in the Netherlands. Ettema and Timmermans (2007) discussed the effects of travel information on accessibility based on the framework of utility-based space-time accessibility (Miller, 1999) and the travel time scheduling framework (Noland and Small, 1995). These attempts to include ICT-related factors into the traditional physical accessibility measures theoretically increase the applicability of the traditional accessibility measures when ICT-related factors need to be considered. These models are also practically feasible – i.e., data can be collected at reasonable costs, and accessibility can be quantified via mathematical functions. However, the application of these models, given the scopes, are restricted to the study of the effects of certain *specific* ICTs (e.g., travel information) on accessibility, or ICT's effects on *specific* categories of accessibility (e.g., job accessibility).

2.3.4 Summary and relevance to the research described in this thesis

This section 2.3 first provides an overview of the physical accessibility measures in the literature (section 2.3.2), and second provides an overview of the models that have been developed to measure ICT's effects on accessibility (section 2.3.3). The overview aims to derive knowledge from the literature for the model development in this thesis and also for future studies.

Summary

A range of physical accessibility measures have been developed in the literature. In this overview, they are categorized into four but not mutually exclusive types – a) *proximity-based*, b) *space/time-based*, c) *activity-based*, and d) *utility-based* measures. Table 2-1 provides an overview of these four types of accessibility measures, including a brief introduction of these measures and a summary of the advantages and limitations of these measures from a general perspective in terms of the criteria such as operationalization, communicability, theoretical soundness and behavioral realism, and suitability for policy evaluation. It is apparently that there is no single criterion to judge which type of accessibility measure is the best. Each type of accessibility measure has its own advantages and limitations. In general, the measures that are theoretically advanced are considered to be (relatively) difficult to operationalize or communicate. This often leads into a choice dilemma in practice. Several authors provide a series of systematic criteria for evaluation of accessibility measures (see, e.g. Geurs and van Wee, 2004; Hoogendoorn-Lanser et al., 2012; Neutens et al., 2010). While this overview does not aim to elaborate on these criteria, interested readers may refer to these studies for details. But despite their merits as basis for further model development, these physical accessibility measures do not consider any ICT-related factors and therefore are not (yet) readily applicable to measuring ICT's effects on accessibility.

Hence, this overview also provides an overview of the models that have been developed to measure ICT's effects on accessibility. However, it seems that to date few models that are able to measure ICT's effects on accessibility yet exist. Among these few models, three categories of models can be distinguished. One category of models introduces new conceptualizations of space-time into classical time-geographic concepts. Despite their obvious values, these models are, however, developed largely at a conceptual level and only focus on telecommunication. The second category of models analyzes ICT's effects on accessibility via Geographic Information System (GIS)-based time-geographic frameworks. The development of GIS increases the applicability of space-time accessibility measures to study ICT's effects.

But the limitations of space-time accessibility measures still remain and limit the applicability of these GIS-based frameworks into certain studies. The third category of models attempts to include certain ICT-related factors into physical accessibility measures. These models are practically feasible in operationalization, but their applicability is also limited given their focus on certain *specific* ICTs or *specific* categories of accessibility. Table 2-2 provides an overview of these few models, including a brief summary of the advantages and limitations of these models in application to the study of ICT's effects on accessibility.

Relevance to the research described in this thesis

While the overview is expected to be of relevance to future studies in general, it is in particular of relevance to this research. It helps identify the gap in the literature and form the theoretical framework for the model development in this thesis.

As already argued in *Chapter 1*, random utility theoretical framework – random utility-based measure is adopted in the formal model development in this thesis. The reasons of adopting RUM theoretical framework are twofold. On the one hand, as argued, it is critical to take into consideration travel behavior in the development of model for measuring ICT's effects on accessibility. On the other hand, as concluded from the overview, random utility-measures are advantageous in terms of theoretical soundness, behavioral realism, operationalization, and usability for economic evaluation. Hence, the random utility theoretical framework is adopted for model development in this thesis. In addition, it seems that no existing model in the literature considers both travel information and telecommunication/teleactivities in measuring ICT's effects on accessibility, while interactions can happen between them from a traveler's behavioral perspective. As also argued in *Chapter 1*, not only do most ICT devices have both travel information- and telecommunication-related facilities (e.g., tablets that can be used to check travel information and can also be used to do teleworking), but a traveler's use of travel information and telecommunication facilities can also be mutually influenced, or be driven by the same set of factors. Take for example the situation where a traveler chooses to work from home after having received travel information that his/her route to work is severely congested. Or consider the example where the mere fact that a telework-option is available to a traveler makes that he/she is more inclined to acquire travel information in the morning (given that he/she knows that depending on the received information, he/she has the option to decide to work from home). Failure to consider such possible interaction associated with travelers' usage of travel information and telecommunication facilities may result in a biased estimation of the effects of ICT on travel behavior and in turn on accessibility. In light of these arguments, there is a need for a generic, integrative and quantitative model that is able to measure the effects of different forms of ICT – *information-related technologies for travel information and telecommunication-related technologies for teleactivities, including their potential interactions* – on accessibility. This forms one primary aim of this research (see *Chapter 1*). The utility-based model developed in this thesis to measure the effects of different forms of ICT on accessibility is presented *Chapters 4* and *5*.

Table 2-1: A summary of physical accessibility measures in the literature

Categories	Introduction	Advantages[21]	Limitations
Proximity-based measures	Proximity-based measures define accessibility as a measure of physical proximity between locations via indicators related to transport systems (e.g., travel distance, travel time, travel cost) (see, e.g. Geertman and Van Eck, 1995; Talen and Anselin, 1998; Wang et al., 2009).	• advantage in operationalization – easy to collect data; • advantage in communicability – easy to explain; • suitable for appraisal of direct effects of traffic and transport policy measures.	• do not consider people's preferences and factors related to activities /opportunities at locations; • not sensitive enough for evaluation of spatial planning policies or ICT-related transport policies, where people's preferences and behavior are considered important.
Space/time-based measures	Space/time-based measures analyze accessibility from the perspectives of individuals or households, and describe to what extent people can reach locations or engage in activities (see, e.g. Dijst, 2004; Forer and Huisman, 2000; Kwan, 1998; Lenntorp, 1977; Miller, 1999; Neutens et al., 2012a).	• recognize the space-time dimensions in individuals'/households' activity-travel patterns; • able to assess individual behavior and variations in accessibility; • suitable for evaluation of policies related to traveler behavior (e.g., policies to promote use of ICT among people).	• difficult to operationalize – require large amount of data at individual levels; • difficult to apply in a large scale; • difficult to evaluate people's preferences (e.g., attitudes, valuations); • focus on short-term behavior and not useful to analyze medium- or long-term effects.

[21] Note that, as introduced in section 2.3.1, there are *composite* accessibility measures that are developed within utility-based paradigm but based on other types of accessibility measures. These composite measures hence may have the advantages and limitations of both types of measures.

Activity-based measures	Activity-based measures define accessibility as the reflection of the set of activities or opportunities available at particular locations at an aggregate level. Examples of activity-based measures include contour accessibility measures (Breheny, 1978), potential accessibility measures (Handy, 1994; Joseph and Bantock, 1982) and balancing-factors measures (Wilson, 1971).	• consider attraction of activities or opportunities at locations and the spatial interactions; • suitable for assessment of accessibility to activities or opportunities at locations (e.g. jobs, retail, education, health services, and recreational facilities).	• do not consider space-time variations of individuals; • may over-estimate the accessibility of activities or opportunities accessible to people; • difficult to evaluate people's preferences (e.g., attitudes, valuations); • difficult to evaluate population variations.
Utility-based measures	Utility-based measures, which are founded on economic theory, can be distinguished into two streams: • *General cost measures*: define the generalized cost for travelers' journey between locations as accessibility (see, e.g. Groot et al., 2011; Hilbers et al., 2007; Hoogendoorn-Lanser et al., 2012); • *Random utility-based measures*: defines accessibility as the utility outcome of a set of activity-travel choices based on random utility theory (Ben-Akiva and Lerman, 1979, 1985).	*General cost measures:* • advantage in operationalization – relatively easy to collect data; • advantage in communicability – relatively easy to explain; • suitable for appraisal of transport policies. *Random utility-based measures:* • advantage in theoretical soundness and behavior realism; • advantage in economic evaluations; • advantage in operationalization via discrete choice models; • suitable for economic evaluation of transport and spatial planning policies.	*General cost measures:* • complex to convert non-monetary factors into monetary costs; • not suitable for spatial planning policies or ICT-related transport policies, when people's preference and behavior, and activities/opportunities should be considered; • ambiguity (measures of accessibility or measures of people's valuation of accessibility); *Random utility-based measures:* • difficult to be interpreted and communicated; • ambiguity (measures of accessibility or measures of people's valuation of accessibility); • discrepancy between what these

			measures aim to measure (experienced utility) and what they actually measure (decision utility).

Table 2-2: A summary of the models that measure ICT's effects on accessibility

Categories	Examples of studies		Advantages	Limitations
Introduction of new conceptualizations of space-time into classical time-geographic concepts	Janelle (1995)	developed a framework to classify communication modes based on spatial (i.e., physical presence or telepresence) and temporal constraints (synchronous or asynchronous communication).	• consider virtual interactions in individual's space-time prism.	• conceptual models only; • lack of mathematical formalization; • mainly focus on telecommunication.
	Miller (2005a)	introduced two new time-geographic objects – portals and message windows – into the classical time-geographic concept, and incorporated indirect (virtual) interaction.		
	Dijst (2004)	distinguished the space-time accessibility into a) the space-time prism potentially accessible, b) the prism perceptually, and c) the prism potentially and perceptually accessible and discussed ICT's effects on these prisms.		
	Kwan (2007)	proposed a conceptual model called hypertext which conceptualizes the effects of real-time interactivity enabled by mobile communications and social networks on urban travel.		
Geographic Information System (GIS)-based time-geographic frameworks that	Ren and Kwan (2007)	employed information cubes into the traditional GIS-based physical space-time prism to represent the activity opportunities in cyberspace that a person has access to during a specific	• progress the applicability of space-time accessibility measures that incorporate virtual	• difficulty to operationalize – require large amount of data on individual level & extra data of ICT behavior; • difficult to apply in a large

incorporate virtual realm		amount of time.	realm.	scale; • difficult to evaluate people's preference (e.g., change of valuations of travel time disutilities due to ICT-enabled multitasking); • focus on short-term behavior and not useful to analyze medium- or long-term effects (e.g., learning from ICT).
	Couclelis (2009)	expanded Ren and Kwan's framework by explicitly distinguishing the purposes of activities (e.g., social activities, self-entertainment activities) and the means (i.e., transport and communication-related means) necessary to achieve the activity purposes.		
	Shaw and Yu (2009)	developed a similar GIS-based framework that implements both physical and virtual prisms in a 3-dimensional (2D space+1D time) environment.		
Include certain ICT-related factors into physical accessibility measures	Scott (2000)	used functional travel time, instead of actual travel time, in the traditional doubly constrained gravity accessibility measures for the study of the supply and demand of jobs and workers.	• increase the applicability of traditional accessibility measures for ICT-related study; • practically feasible in operationalization.	• limited to the study of the effects of certain *specific* ICTs (e.g., travel information) on accessibility, or ICT's effects on *specific* categories of accessibility (e.g., job accessibility).
	Shen (2000)	developed a model based on traditional gravity accessibility measure to measure job accessibility with competition by distinguishing job seekers who have telecommunication capabilities and who have not and the job opportunities accessible via transportation or telecommunications.		

	Ettema and Timmermans (2007)	studied the effects of travel information on accessibility based on the framework of utility-based space-time accessibility (Miller, 1999) and the travel time scheduling framework (Noland and Small, 1995).		

2.4 ICT's (potential) effects on accessibility: a literature overview

2.4.1 Introduction

This section provides an overview of the findings on ICT's (potential) effects on accessibility. This section first focuses on ICT's effects on travel behavior, and secondly presents an overview of the ICT's impacts on accessibility.

The reasons that this overview primarily focuses on ICT's impacts on travel behavior is based on the following arguments. First, literature has paid much more attention on ICT's effects on travel behavior than on ICT's effects on accessibility. While it has often been claimed that ICT has impacts on accessibility, however, limited studies can be found in the literature. In contrast, as pointed by Van Wee et al. (2013) who present a systematic overview of potential impacts of ICT on accessibility and address challenges for future research in the area of ICT's impact on accessibility, much more literature is about ICT's impact on travel behavior. Secondly, travel behavior is obviously closely related to accessibility, as reflected by the accessibility concepts of almost all types of accessibility measures (see section 2.3.2). In particular when ICT is involved, the changes of travel behavior due to ICT-use would directly result in a change of accessibility. Take for an example that an individual who used to commute to work every day but often encountered peak-hour congestion substitutes commuting with teleworking sometimes in order to avoid congestion. The individual's accessibility to his/her work in this example, because of the change of his/her travel behavior, also changes. The findings that have been identified in the literature about ICT's effects on travel behavior are therefore believed to be of importance to analyze how ICT could affect accessibility. Thirdly, as argued earlier and also related to the second point, taking into consideration travelers' choices and preferences in accessibility measures is important from both a theoretical and a practical perspective. Accessibility measures that do not consider travelers' choices and preferences may not only over-estimate the actual accessibility for people or the accessibility of locations/activities, but also may lack policy sensitivity. This argument also applies to the model development in this research presented later in this thesis.

In combination of all these arguments, the overview first focuses on the findings about ICT's impacts on travel behavior. In particular, two strands of related studies in the literature can be distinguished, as argued in Van Wee et al. (2013) – one strand having looked into the acquisition of travel information and its impact on travelers' mode-, route- and departure time choices, and another strand having focused on the impact of telecommunication facilities on individuals' choices to engage in physical travel in the first place. In this section, an overview of the impacts of travel information on travel behavior and an overview of the impacts of teleactivities on travel behavior are presented, respectively.

An overview of the findings on ICT's effects on accessibility is also given, despite relatively little literature on this topic. The reason to have this overview is obviously related to this research.

The remainder of this section 2.4 is organized as follows. Section 2.4.2 presents the overview of ICT's effects on travel behavior, including the effects of both teleactivities and travel information on travel behavior. Section 2.4.3 presents the overview of ICT's effects on accessibility. Section 2.4.4 summarizes this section and reflects on the relevance of this literature overview to the research described in this thesis.

2.4.2 ICT's effects on travel behavior

This section first presents the overview of the effects of teleactivities on travel behavior (section 2.4.2.1), followed by the overview of the effects of travel information on travel behavior (section 2.4.2.2). In addition, this section also introduces some important factors that may affect travelers' usage of ICT (section 2.4.2.3).

2.4.2.1 Teleactivities and travel behavior

Substitution, complementarity, modification, or neutrality

One stream of studies on the effects of teleactivities on travel behavior focuses on whether or not teleactivities substitute, generate, or modify travels (Mokhtarian, 1990; Salomon, 1986)[22]. A large part of literature focuses the study on one of the following types of teleactivities[23] – mandatory activities (e.g., teleworking/teleconferencing for work or work-related activities), maintenance activities (e.g., teleshopping), and discretionary activities (e.g., teleleisure) (Andreev et al., 2010).

Since Nilles (1975) first coined the term "teleworking" in the literature, early research largely focuses on the effects of teleworking on people's individual's engagement into work and commuting, partly due to the high expectations of substitution effects of teleworking on travels (Van Wee et al., 2013). However, mixed findings have been found of the effects of teleworking on people's travels at different levels (e.g., individual, organizational or societal levels) and in different contexts (e.g., number of commuting trips, vehicle miles travelled (VMT), traffic congestion, and traffic peak period). A majority of the studies found that teleworking leads to a reduction, to some extent, of individual travels in the short term in terms of various travel characteristics (e.g., number of trips, vehicle miles travelled (VMT), traffic congestion) (see Andreev et al., 2010 for a recent review of the literature that found subtitution effects of teleworking). When the long-term effect is concerned, it is suggested by some studies that the complementary effect is more likely to occur due to the induced travels and residential relocation (Mokhtarian, 2000). However, the long term effect of teleworking on travels still remains blurred due to the difficulty for long-term data collection (Andreev et al., 2010).

With the increasing penetration of ICT into almost all types of activities, research interests into the effects of other types of activities on travels grow quickly. Three main categories of activities can be found in related literature – telemeeting, teleshopping and teleleisure, which are discussed below, respectively.

In general, telemeeting, which is often considered as an alternative to face-to-face meeting, appears to be complementary to commuting or business travels. Organizations often consider

[22] Salomon (1986) and Mokhtarian (1990) identified four types of relationships between teleactivities and physical travels: a) teleactivities substitute travels (substitution), b) teleactivities generate travels (complementarity), c) teleactivities modify travels (modification), and d) teleactivities do not have effects on travel in the short term (neutrality).

[23] Note that the three addressed types of teleactivities are not mutually exclusive. For example, teleshopping may be perceived by an individual as maintenance and discretionary at the same time. See, for example, Andreev et al. (2010) for a detailed discussion on this.

telemeeting as an additional way of expanding organizational efficiency and facilitating the maintenance of relationships with, in particular, geographically remote customers/partners rather than simply as a travel-saving means to substitute face-to-face meetings (see, e.g. Aguiléra, 2008; Bennison, 1988; Julsrud et al., 2012). Rhoads (2010) also pointed out that face-to-face meeting is currently still a superior method of communication for many business and organization-related activities, although Rhoads expected that telemeeting would play a larger role than it currently does in business and collaborative environments. Denstadli et al. (2012), based on a survey of Norwegian business travelers, found that telemeeting is a central choice for meetings with partners and collaborators located at remote sites. However, they also found that face-to-face meetings and telemeetings operate complementarily in collaborations over distance. The benefits of telemeeting do not seem to making face-to-face meetings redundant in modern work organizations in relation to reduce travels. Other studies (see, e.g. Haynes, 2010; Larsen et al., 2008) also pointed out that face-to-face meetings and in turn business travels are still crucial in creating new business connections and engaging in informal conversations. As such, many face-to-face meetings cannot be readily replaced by telemeetings, and a large share of telemeeting is not initiated as an alternative to a face-to-face business meeting. However, studies on the relationships between telemeetings and travels are relatively sparse in comparison to the studies on teleworking, due to the difficulty in data collection and the low diffusion of teleconferencing (Andreev et al., 2010).

A majority of the studies about the impact of teleshopping on in-store shopping and related travels have found that the effect of teleshopping on travels is, in general, more likely to be complementary rather than substitutes – teleshopping may substitute for in-store shopping at the margin, but both forms of shopping will continue to expand and co-exist. Mokhtarian (2004) and Couclelis (2004) identified the typical elements of a shopping process, including: a) being aware of the need or want of a product; b) information gathering of options; c) searching and browsing; d) seeking advice/expert help; e) inspecting alternatives; f) deciding on an item to be purchased; g) deciding on a vendor; h) purchasing a product; i) tracking the status of an order; j) getting an item to delivery point (e.g., home); k) returning/exchanging an item, and l) searching post-sales services. Not only the task to travel to stores to purchase the products may be affected via teleshopping, other sub-tasks (e.g., b, c, e, g, l) of shopping behavior could be also affected by ICT. For example, product information is becoming more available/accessible to people online. By searching for information via the Internet, people reduce their travels associated with information acquisition. The information-gathering behavior via internet may, ultimately, affect people's choice between teleshopping and in-store shopping. Rotem-Mindali and Salomon (2009) found in their study a general higher proportion of information gathering via the Internet than purchasing via the Internet, and information gathering via the Internet ultimately stimulates purchasing via the Internet. Farag et al. (2007) found in their study that people's online searching behavior positively affects the frequency of shopping trips, which in turn positively affects the frequency of online shopping. The study by Weltevreden and Rotem-Mindali (2009) on a nationwide sample of 3000 Dutch e-shoppers showed that customer-to-customer e-commerce led to an increase in both personal travel and freight transport. The study conducted by Cao et al. (2012) concluded that online searching frequency has positive impacts on both online and in-store shopping frequencies and online buying positively affects in-store shopping.

Concluded from the relatively small number of studies on teleleisure activities, it seems that teleleisure activities may substitute certain types of physical leisure activities to a certain extent, such as watching a movie online rather than in a cinema. But in general, teleleisure activities and physical leisure activities will coexist (see, e.g. Hjorthol, 2002; Senbil and Kitamura, 2003; Wang and Law, 2007). However, investigation of the impacts of teleleisure on travels is yet understudied compared to teleworking and teleshopping. ICT's impacts on mandatory and maintenance activities, such as teleworking and teleshopping, are often considered more important than ICT's impacts on discretionary activities (Mokhtarian et al., 2006). It is also because of the myriad discretionary activities and hence investigation of leisure-related travels is more complex than of mandatory or maintenance travels (Andreev et al., 2010).

In sum, the substitution effect of teleworking seems more prevalent in the short term, while the impacts of other ICT-enabled teleactivities such as telemeeting, teleshopping and teleleisure on travels seem to be more likely to be complementary, rather than substitutional. However, the relationships between teleactivities and physical activities and in turn travel behavior are not uni-dimensional, but differ according to different contexts. In addition, other factors such as travelers' social need for physical presence, socio-demographics, and ICT-use capabilities, which will be discussed further in section 2.4.2.3, also play important roles in affecting traveler's choices of teleactivities and travels. It is difficult to infer whether or not teleactivities substitute, generate, or modify travels without referring to the study contexts. Another difficulty to draw a complete picture of the relationships between teleactivities and travels results from the lack of theories and data, in particularly for the study on the impact of telemeeting and teleleisure or when long term perspective is adopted (Andreev et al., 2010). Furthermore, the options nowadays available to people to do multiple teleactivities in daily lives increase the complexity of the discussion of the relationships between teleactivities and travel behavior. For example, a traveler who may often do in-store shopping on his/her way back from office to home, may choose to do teleshopping on the days when he/she teleworks from home in order to avoid travelling at all. The impact of traveler's choice of one teleactivity on his/her subsequent choice of another teleactivity and in turn on travels are not yet clear due to the lack of literature. Finally, the emergence of new types of ICT-enabled activities that do not have a clear-cut functional equivalent in physical world, such as online gaming and online community, seems to have led and will lead to more challenges to investigate the relationships between teleactivities and travels (Hjorthol and Gripsrud, 2009). In sum, it appears that the relationships between teleactivities and travels cannot be simply summarized as only substitution, complementarity, modification or neutrality, given the influences from the factors such as activity types, contexts, and travelers' characteristics. The investigation of the relationship becomes even more difficult when it is concerned with multi-activities or when long-term perspective is adopted. Our understanding towards the relationships between teleactivities and travels seems to be still at an early stage.

The way of conducting activities

Another stream of literature focuses on how ICT affects the way people conduct activities and in turn people's travel behavior.

Some studies recognize that teleworking changes the forms of people's working practice and work-hour arrangements. Examples of ICT-enabled working practice not only include whole-day teleworking – people telework from home whole day and substitute commuting, but also include part-day homeworking – people combine working from home and working at the office on the same day (see, e.g. Haddad et al., 2009; Lyons and Haddad, 2008). ICT enables people to work not only at home, but also at regional teleworking centers, or during travelling (see, e.g. Yeraguntla and Bhat, 2005). People's work-hour arrangements are also changed. Because of the options to do teleworking, it is becoming more flexible for people to make their work schedules (see, e.g. Alexander et al., 2010a; Golden, 2012; Vana et al., 2008). Such increased flexibility because of ICT in terms of the time and space of work being organized nowadays results in great changes of people's commuting behavior.

Some studies focus the discussion of ICT's impact on a general yet similar concept called "*fragmentation*". The concept of fragmentation is introduced by Couclelis (2000) based on the belief that ICT could lead to reorganization of activities, in general, in the space, the time, and the manner in which activities are conducted. The concept of fragmentation explicitly structures ICT's effects along three dimensions – time, space, and manner – and points out that the weakened associations between activity, time, and place because of ICT facilitate the disintegration of activities into smaller subtasks, which can then be performed at different times or at different locations (Alexander et al., 2011). It has been found out that there exist positive relations between ICT and fragmentation, but the relations differ for the kind of ICT and type of activity, and the dimensions investigated. ICT ownership and usage are associated more directly with temporal fragmentation than with spatial fragmentation, but the relation with temporal fragmentation is not straight-forward but rather complex (see, e.g. Alexander et al., 2010b; Hubers et al., 2008; Lenz and Nobis, 2007; Srinivasan and Raghavender, 2006). However, since the first introduction of the concept, the studies have been mainly conceptual, while only a limited number of studies have tried to study the fragmentation effects empirically (see, Alexander et al., 2011; Hubers et al., 2008; Lenz and Nobis, 2007 for the only three notable empirical studies in the literature to date). The understanding of the activity fragmentation facilitated by ICT is still preliminary.

Another related yet important concept is referred to "*multitasking*", which has been considered as another major effect of ICT by many studies (see, e.g. Kenyon and Lyons, 2007; Kwan et al., 2007; Laurier, 2004; Lyons and Urry, 2005). It has been argued that failure to consider multitasking would lead to a misunderstanding of ICT's impact on activity participation and in turn on travels. This argument is based on both the conceptual expectation that ICT-based multitasking (e.g., teleworking while traveling) enables greater activity participation without recourse to additional physical travels, and the empirical findings of high percentage of multitasking behavior in people's activity participation and travels (see, Kenyon and Lyons, 2007). The types of activities and the constraints imposed by other activities or resources available to people are of relevance to multitasking. For example, multitasking is found not evenly distributed across activity types. Rather, it varies in both quantity and nature by activity type. The extent to which multitasking is possible and desirable may depend on the factors of the degree of locational dependence, continuity of engagement and active attention (Kenyon and Lyons, 2007). However, due to the limited number of studies, especially the lack of empirical evidence, it is not clear yet whether or not these factors may, (and if positive: to what extent), offset the anticipated benefit of ICT-enabled multitasking in facilitating greater activity participation and reducing physical travels.

In sum, in light of these findings about ICT's impact on the way people conduct activities, it can be argued that the impact of ICT on travel behavior will not be fully understood if these effects are not taken into consideration. Alexander et al. (2011) argued that to explicitly address multitasking and consider subtasks of activities in the study of activity fragmentation would provide a more complete representation of the activities under study. However, it seems that relatively few studies, especially empirical studies, can be found in the literature explicitly discussing these effects. It is rather complex to consider all these types of effects at the same time and analyze how the changes of the way people conduct activities lead in the change of people's travel behavior. These various effects, although they are identified by different studies in the literature, could be even correlated. ICT provides the opportunity to travelers to conduct activities during traveling, which may lead to the fragmentation of travelers' daily activities. Such interrelation increases the complexity in the investigation of the impact of ICT on travel behavior. In addition, the study context, such as type of activities, characteristics of activities, and constraints faced by people such as space-time constraints, are also of relevance and also increase the complexity of studies.

Effects on disutilities of physical travels and space-time constraints

Related to, but also different from, the discussion of ICT's impact presented above, the discussion of ICT's impact on travel behavior in some other studies is mainly concerned with how teleactivities reduce disutilities of physical travels and how teleactivities relax space-time constraints.

Not only may teleactivities substitute or generate physical travels, but they may also reduce disutilities of travel or even generate positive utilities for travel. This argument is made based on the possibility enabled by mobile ICTs for travelers to conduct teleactivities whilst traveling. Teleactivities could even enrich travel by generating positive utilities during travel (Lyons and Urry, 2005). As travel environments become more equipped or equippable for working or socializing via mobile ICTs, traveling longer distances becomes more acceptable (Jain and Lyons, 2008). Because of the possibility to do activities during travel, travelers may perceive travels with positive utilities. As such, the conventional belief of travels as disutilities to travelers and the value of travel time should be altered. However, such concept of travel with positive utility because of ICT seems to be seldom measured empirically or formally quantified, an exception being the study of Mokhtarian and Salomon (2001). The average reported ideal one-way commuting time in their survey study was around 16 minutes, while hardly any survey participants desired a 0-2 min commuting time. Their results suggest that entirely eliminating commuting does not resonate with most people as a desirable aspect of telecommuting. However, this study did not focus on whether ICT-enabled activity-engagement during travelling plays an important role in determining travelers' desire for commuting time. To the best of the author's knowledge, no empirical studies explicitly explore whether and to which extent the increasing opportunities for people to engage into different activities during travelling due to ICT would alter travelers' perception towards physical travels and in turn affect travelers' choices of physical activities and teleactivities.

Some studies focus on how teleactivities affect the space-time constraints for people to conduct activities and travels. It has been widely acknowledged that ICT could lead to time-space convergence for travelers, which results in the relaxation of space-time constraints (see, e.g. Dijst, 2004; Janelle and Gillespie, 2004; Kwan, 2002; Mokhtarian, 1990). But empirical studies also found that the extent to which ICT could lead to constraints relaxation differs. Schwanen and Kwan (2008), for instance, found, through an empirical research with data from Columbus (Ohio, USA) and Utrecht (the Netherlands), that the Internet and mobile phones relax temporal constraints to a stronger degree than they enhance spatial flexibility. In addition, not all space-time constraints have been relaxed or lifted by the use of ICT (Neutens et al., 2011). Some constraints may persist (e.g., the need to take children to schools), while new types of constraints for ICT-use may come into existence (e.g., the availability of Wi-Fi for mobile connection) (Schwanen and Kwan, 2008). However, due to sparse empirical studies, our insights are still blurred in several respects, including to which extent ICT could relax constraints and to which extent such constraint-relaxation differs according to aspects such as type of activity, type of constraint and the related social, cultural, institutional and physical contexts.

2.4.2.2 Travel information and travel behavior

Another strand of ICT-relevant studies is about the effects of travel information on travel behavior (Van Wee et al., 2013). Compared to the number of quantitative studies on the effects of teleactivities on travel behavior, a greater number of quantitative studies – mathematical models and empirical studies – can be found in the literature on the effects of travel information on travel behavior. This could be partly because, compared to travel information which could also be provided by old types of ICTs such as radio and television, teleactivities are relatively new – they only become possible and common since the introduction and penetration of new types of ICTs such as Internet and smart phones. The transport community thus has a relatively longer history in studying the effects of travel information on travel behavior. Given that the aim of this overview is to provide a general overview rather than a detailed and exhaustive review of all travel information-related studies, a general discussion of the literature is presented below.

Regardless of the study context, in general, the way how travel information affect travel behavior lies in its ability to increase traveler's awareness of activity-travel alternatives, or help travelers update their perception of characteristics of available activity-travel alternatives (Chorus et al., 2006b). The change of travelers' knowledge level (either of the number of available alternatives or of the characteristics of alternatives) may lead to the change of travel behavior such as route-, mode- and departure time-choice, and activity-travel rescheduling decisions (see, e.g. Bogers, 2009; Ettema and Timmermans, 2006; Lappin and Bottom, 2001; Sun et al., 2012; Wang and Khattak, 2011). In addition, given the ongoing rapid development of ICT, recent research into the effects of travel information has been more directed from static descriptive travel information towards the so-called advanced personalized, dynamic, real-time and prescriptive information. Note, however, that Chorus (2012c) pointed out that these labels are quite confusingly used in the literature to indicate what kind of travel information is under study.

Travel information acquisition/usage and the effects of travel information on travel behavior are also associated with various influencing factors. Not only the characteristics of travel itself (e.g., duration and reliability of travel time, and travel costs) (see, e.g. Ettema and Timmermans, 2006; Peirce and Lappin, 2004; Polak and Jones, 1993), but also other aspects play important roles, such as trip purpose and context (e.g., business trips, expected congestion, arrival time constraints) (see, e.g. Emmerink et al., 1995; Hato et al., 1999), types and characteristics of travel information (e.g. availability and relevance of travel information) (see, e.g. Kenyon and Lyons, 2003; Khattak et al., 2008), travelers' characteristics (e.g., gender, car-users) (see, e.g. Abdel-Aty et al., 1997; Chorus et al., 2006b), travelers' cognition and knowledge level (e.g., awareness of the available alternatives) (see, e.g. Adler and Blue, 1998; Chorus and Timmermans, 2009), travelers' habitual behavior and learning (e.g., habitual choice of route, and usage of travel information) (see, e.g. Aarts et al., 1997; Ben-Elia and Shiftan, 2010), and contextual and national factors (e.g., differences between different locations) (see, e.g. Polak and Jones, 1993). Several extensive literature reviews in the area of travel information usage and the effects on travel behavior can be found in the literature and be referred to for more in-depth discussion upon this topic (see, e.g. Chorus et al., 2006b; Lappin and Bottom, 2001).

2.4.2.3 Usage of ICT and some important factors

A range of factors that are relevant to ICT use and ICT's effects on travel behavior has been identified in the literature. However, not aiming at an exhaustive review of all kinds of attributes that might be of relevance, this section focuses on several factors that are commonly discussed in the literature and considered as the most important ones. This section aims to provide insights into the roles of these factors in determining ICT-usage.

First, it is widely acknowledged that travelers' socio-demographic characteristics such as age, gender, education and income play important roles in affecting travelers' usage of ICT. For example, Krizek et al. (2005a), via a household survey in three metropolitan cities in USA, found out that younger, and more educated individuals with access to the Internet at home are more likely to substitute non-work travels with the use of ICT. De Graaff and Rietveld (2007) found that individual characteristics, especially age and education, seem to be more important than ICT availability or commuting time in affecting travelers' choices between working from home and out-of-home in their study. Male, highly educated, and high-income travelers are more likely than others to use travel information (see, e.g. Petrella and Lappin, 2004), and are also more likely to own a home computer and to work at home than people with low income and education (see, e.g. Hjorthol, 2002). The impact of teleactivities on people's activity-travel patterns is found significantly different between men and women (see, e.g. Ren and Kwan, 2009; Schwanen and Kwan, 2008).

Attitudinal factors such as travelers' preferences are also identified by literature as key determinants of travelers' use of ICT. For example, individuals that are characterized as control seekers and technology savvy people are relatively more aware of travel information (Polydoropoulou et al., 1997) and more prone to use travel information (Lappin and Bottom, 2001). Krizek et al. (2005b) conducted a household survey about people's participation in teleactivities including teleshopping, telebanking and other financial transactions via the internet and found positive relationships of attitudinal factors such as pro-technology and anti-travel and negative relationships of people's concern about Internet security towards people's participation into these teleactivities. Attitudinal factors sometimes are found even more important than some other factors in affecting travelers' use of ICT. For example, Mokhtarian and Salomon (1997) found out that attitudinal factors are more important than socio-demographics in affecting travelers' choice of telecommuting.

People's social and psychological need for physical presence and physical interaction is often considered as a critical factor that may determine travelers' decisions whether or not to conduct teleactivities to substitute travels. Lyons (2002) pointed out that teleactivities may be effective in meeting functional requirements (e.g., shopping to replenish household food stock), but they may fall short of meeting other social or psychological requirements (e.g., going out for shopping to see and meet people). If teleactivities are inadequate to fulfill people's needs, substitution of physical travels may not take place, or travelers may engage into other physical activities and travels in order to satisfy their social and psychological needs. Similar arguments can be found in some other studies. Co-presence is considered as an essential part of producing and maintaining social networks (Jain and Lyons, 2008; Urry, 2002), and face-to-face encounters are thus more preferable than ICT-based virtual encounters in some situations. For example, face-to-face meetings are considered by travelers preferable when meetings involve persons external to the firms where travelers work, even if such meetings can be conducted via ICT (Arnfalk and Kogg, 2003). Face-to-face contact is necessary to create mutual trust and thus face-to-face meeting is preferred in business (Aguiléra, 2008).

On the one hand, these social and psychological needs for physical presence and physical interaction affect people's usage of ICT. But on the other hand, people's increasing social networks because of ICT also interacts with individual's needs for physical presence and physical interaction, which may ultimately affect individual's social travels. The emerging new ways of communications enabled by ICT increase the size of social networks and also change the way in which people maintain their social relationships (e.g., individual getting more acquaintances or keeping contacts with friends via online social platforms) (Aguiléra et al., 2012; Urry, 2012). Such change of individuals' social networks may alter the way people conduct related activities and travels to meet individuals' social and psychological needs (Larsen et al., 2006; Smoreda and Thomas, 2001). However, the understanding of how the changes in social networks permitted by ICT may affect people's travel behavior is not yet fully clear (Aguiléra et al., 2012). Due to the difficulty to collect ample data for analyzing the relationships between individual's social needs, social life, ICT-use, and personal travels, empirical findings are still scare. To date, to the best of the author's knowledge, very limited empirical studies are available in the literature: Carrasco and Miller (2006, 2009) showed, via analysis of the data from a project named "connected lives study" conducted in Toronto, that ICT use in general increases propensity to perform social activities out of home, but the effects are very media specific. Van den Berg et al. (2013) conducted an empirical study among 747 respondents via a two-day social interaction and travel diary and a questionnaire. They found that more Internet interactions result in a larger social network, and the Internet interactions have a negative effect on social travel distance. The mixed findings suggest the rather complex relationships between individuals' social need, ICT use, social networks and physical travels. The new possibilities for people to meet their social needs via either physical travels or ICT-enabled telecommunications, or combinations of both, lead to complex configuration of social networks that may in turn result in new yet various transformations of travel behavior (Aguiléra et al., 2012).

Another related factor is concerned with people's capabilities such as capability to use ICT equipment and perceptual capability. People's capability to use ICT equipment can be easily conceived of relevance to people's choice of ICT – the usage of ICT may be constrained by individual capabilities (see, e.g. Golob and Regan, 2001; Lamont et al., 2013; Wiegmans et al., 2003). People's perceptual capability in terms of people's knowledge level and awareness of available alternatives and opportunities may induce willingness to acquire travel information first (see, e.g. Chorus et al., 2013). Note, however, that these individual capabilities may also be altered because of ICT. For example, as mentioned above, travel information could lead to changes in travelers' perceptual capabilities – increase traveler's awareness of activity-travel alternatives, or help travelers update their perception of characteristics of available activity-travel alternatives (Chorus et al., 2006b).

In addition to the factors discussed in this section, other factors can be also of relevance. For example, individuals' decision strategy differs (see, e.g. Chorus et al., 2006b for a literature review of dominant theories on travelers' decision strategies). As such, people's choices of ICT would also differ. Travelers' experiences and learning over time is another example of the factors that have been often discussed in travel behavior studies (see, e.g. Bogers, 2009) and can be straightforward conceived of relevance when travelers' usage of ICT in the mid- or long-term is concerned. These factors, although they are not discussed in this section and have been identified to be of relevance for travel behavior, may also play roles in affecting the relationships between ICT-use and travel behavior.

2.4.3 ICT's effects on accessibility

The literature overview presented in section 2.4.2 focuses on ICT's effects on travel behavior. This section presents an overview of ICT's effects on accessibility.

As mentioned before in section 2.4.1, compared to the ample literature on ICT's effects on travel behavior, much less literature can be found directly discussing the effects of ICT on accessibility. One possible reason is that, as pointed out before in section 2.3.3, very few formal and quantitative models that are able to measure ICT's effects on accessibility exist in the literature yet to date, which indirectly limits the number of empirical studies as well. To the best of the author's knowledge, there are only few notable exceptions of studies that implement these models in empirical studies. Muhammad et al. (2008) applied Shen's model and Hansen's model (see section 2.3 of this chapter) in a study of the job accessibility under the influence of ICT in the Netherlands. They concluded that under the influences of ICT, job accessibility in the Netherlands had improved and would further improve in the future. Ren and Kwan (2007) introduced information cubes into traditional GIS-based time-geographic framework to explore people's accessibility to cyberspaces and used 3D geovisualization methods to represent the data collected through an activity-Internet diary survey in the Columbus metropolitan area (Ohio, USA) in 2003 and 2004. Their study measures the accessibility to cyberspace opportunities in terms of the time spent on using the Internet, connection speed and the number of websites accessed. The results show that men tend to have greater accessibility to cyberspace opportunities and also more likely to use the Internet for recreational activities than women. However, despite these findings, our understanding of the effects of ICT on accessibility is still limited. This particularly applies to empirical insights because of the lack of models to be used for studies and empirical studies. As pointed out by Neutens et al. (2011), "*there is still a preeminent need of new analytical frameworks and methodologies for better understanding the implications of ICT use for accessibility measurement*."

2.4.4 Summary and relevance to the research described in this thesis

This section 2.4 provides an overview of the findings on ICT's (potential) effects on accessibility, first on ICT's effects on travel behavior (section 2.4.2) and secondly on ICT's effects on accessibility (section 2.4.3). This section aims to provide insights into ICT's (potential) effects on accessibility that are expected both of scientific relevance and practical implications.

Summary

First, this section provides an overview of the effects of teleactivities on travel behavior. One stream of studies on the effects of teleactivities on travel behavior focuses on whether or not teleactivities substitute, generate, or modify travels – the SCMN relationship – in short term. In general, teleworking seems to have substitution effects on travel, while the impacts of other teleactivities such as telemeeting, teleshopping and teleleisure on travel seem to be more likely to be complementary, rather than substitutional. But the relationships between teleactivities and physical activities and in turn travel are not uni-dimensional, but differ according to different contexts. Another stream of studies discusses how ICT changes the way people conduct activities, and in turn travel behavior. Examples of such effects include that teleworking changes the forms of working practice and work-hour arrangements, resulting in changes of people's commuting behavior. ICT leads to fragmentation of activities in the space, the time, and the manner in which activities are conducted. ICT also provides travelers with the opportunities of multitasking (e.g., teleworking while traveling), leading into greater activity participation and changes of travel behavior. It has been argued that the impact of ICT on travel behavior will not be fully understood if these changes of the way people conduct activities are not taken into consideration. Some other studies focus the discussion of ICT's impact on travel behavior mainly on how teleactivities reduce disutilities of physical travels.

Because of the possibility to do activities during travel, travelers may perceive travels with less disutilities or even positive utilities, resulting in change of value of travel time. In addition, some studies also pointed out that ICT could relax space-time constraints. But due to the sparse empirical studies, our insights with respect to the extent to which teleactivities could reduce disutilities of physical travels and relax space-time constraints are still blurred.

Secondly, the section presents an overview of the effects of travel information on travel behavior. The way how travel information affects travel behavior lies in its ability to increase travelers' awareness of activity-travel alternatives, or help travelers update their perception of characteristics of available activity-travel alternatives. In addition to the characteristics of travel itself such as travel time and travel costs, many other factors may also play roles in affecting travel information acquisition/usage. Such factors include trip purpose and context, types and characteristics of travel information, travelers' characteristics, travelers' cognition and knowledge level, travelers' habitual behavior and learning, and contextual and national factors (see section 2.4.2.2 for references of examples of studies).

Thirdly, this overview also discusses several important factors that are relevant to ICT use and ICT's effects on travel behavior. The addressed factors include travelers' socio-demographic characteristics, attitudinal factors, people's social and psychological need for physical presence and physical interaction, and people's capability to use ICT equipment and perceptual capability.

Finally, this section also presents an overview of ICT's effects on accessibility. Hardly any empirical studies exist in the literature explicitly studying ICT's effects on accessibility, with only a few exceptions. Our understanding of the effects of ICT on accessibility is still limited, in particular empirical insights, because of the lack of analytical frameworks and methodologies and empirical studies.

Relevance to the research described in this thesis

This overview is expected to be of scientific relevance and practical implications. It is in particular of relevance to this research, as this overview first helps identify the research gaps in the literature and secondly provide insights into the (potential) effects on accessibility.

First, concluded from the literature overview, there is still a need for new models to measure the effects of ICT on accessibility. In particular, travel behavior, given its importance, should be taken into consideration. That is, any new developed models for measuring ICT's effects on accessibility should take into consideration travelers' choices and preferences in the model development. The overview reveals various effects of ICT on travel behavior, which may result in changes of accessibility as well. A model for accessibility measurement without considering travelers' choices and preferences would overlook some important (potential) effects of ICT on accessibility, resulting in bias or lack of sensitivity in the measurement of accessibility.

Secondly, as argued in *Chapter 1*, interactions can happen between travel information and teleactivities from a traveler's behavioral perspective. Not only do more ICT devices have both travel information- and telecommunication-related facilities, but also a traveler's use of travel information and telecommunication facilities can be mutually influenced, or be driven by the same set of factors[24]. However, from the literature overview, it has been found that most studies focus on either teleactivities or travel information. It seems that no literature explicitly considers the possible interactions associated with traveler's choices of travel information and telecommunication facilities. Only a few authors point out that travel information could possibly affect travelers' choices of conducting teleactivities rather than making a trip. It is addressed in the literature (Lyons, 2001) that the first short-term choice a traveler needs to make is whether or not a trip is needed or wanted, given the option to do teleactivities because of ICT. It is not inconceivable that information showing poor travel conditions could induce trip makers to cancel their intended trips (Khattak et al., 1999; Lappin and Bottom, 2001). However, to the best of the author's knowledge, no other studies, in particular empirical ones, exist that investigate such possible interactions between teleactivities and travel information[25]. To consider the joint and interrelated nature of travel information and teleactivity functionalities of ICT in model development for accessibility measurement becomes important to avoid biased estimation of the effects of ICT on accessibility.

In sum, it can be argued that there is a need for a generic, integrative and quantitative model that takes into account traveler behavior and is able to measure the effects of different forms of ICT – *information-related technologies for travel information and telecommunication-related technologies for teleactivities, including their potential interactions* – on accessibility. Developing such a model forms one research aim of this thesis.

However, note that, as will become clear later in *Chapter 4*, not all types of ICT's effects are taken into consideration in the model development in this thesis. First, the overview aims to provide insights of relevance not only to this thesis but also to future studies and practice. The scope hence is wider than what is taken into consideration in the research described in this thesis. For example, the effects of ICT on the forms of working practice and work-hour arrangements are not considered in this thesis. Secondly, given the complexity of the topic, it seems impossible to include all types of ICT's effects into one model, while still keeping the tractability of the developed model at an acceptable level. As such, a rather general perspective is adopted in the model development in this thesis. The model developed in this thesis neither aims to include all types of ICT's effects, nor aims to particularly focus on one type of ICT's effects. Rather, the aim is to provide a generic, integrative and quantitative model that considers both teleactivities and travel information, including their potential

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[24] For example, a traveler chooses to work from home after having received travel information that his/her route to work is severely congested. Or consider the example where the mere fact that a telework-option is available to a traveler makes that he/she is more inclined to acquire travel information in the morning (given that he/she knows that depending on the received information, he/she has the option to decide to work from home).

[25] Note, however, that if the concerned information is not only travel-related but also activity-related (e.g., information of the products people need to buy), the fact that information may affect people's choices of teleactivities would be straightforward to conceive. Dijst (2004) pointed out that information may lead people to reevaluate the available opportunities and subsequently affect people's choices of activities and trips. The studies on ICT's effects on subtasks of people's shopping behavior, which have been presented before (section 2.4.2.1), also provide empirical evidence that people's online-information-gathering behavior ultimately affects people's choice between teleshopping and in-store shopping (see, e.g. Farag et al., 2007; Rotem-Mindali and Salomon, 2009).

interactions, for accessibility measurement. The focus of the model will be on several key effects of ICT (see *Chapter 4* of this thesis for details of the developed model).

2.5 Models and methods for the study of ICT choice and ICT's effects on travel behavior: a literature overview

2.5.1 Introduction

This section provides an overview of the *models* and the *methods* for the study of travelers' choices of ICT and ICT's effects on travel behavior in the literature. It should be made clear that three types of models and methods are included in this overview. First, *theories/conceptual models* are used to refer to related *theories* and *conceptual models*[26] (with or without recourse to mathematical functions) that have been applied and developed for the study of choices of ICT use and their effects on travel behavior. Secondly, *data collection methods* refer to methods for related data collection (e.g., survey, simulator). Thirdly, *data analysis methods/models* are used to refer the methods/models for related data analysis (e.g., discrete choice model - DCM, structural equation model - SEM)[27]. Note that the *models* in the third category are different from the above-mentioned *conceptual models* that are not data related.

The aim of the overview is twofold. First, it aims to derive knowledge of research methods from previous studies and as such to provide inspiration for the research presented in this thesis. Secondly, since not all methods in the literature will be used for this research, the overview of the methods in the literature also aims to provide references that are expected to be of relevance for future related research.

More specifically, the rationale to give an overview of the research methods found in the literature to study traveler's choices of ICT use and the effects of ICT use on travel behavior is primarily based on the following main reason. As argued before, measuring ICT's effects on accessibility without considering traveler behavior (travelers' choices of ICT use and their effects on travel behavior) may overlook some effects of ICT use and may result in biased estimation upon ICT's effects on accessibility. In order to avoid this, to consider traveler behavior (e.g., travelers' choices of ICT) is necessary in the model development in this research that is presented in *Chapter 4* (also including the phases of data collection and model estimation). This argument also applies to any future research in this field.

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[26] One may consider theories and conceptual models to be different. However, it is sometimes difficult to clearly distinguish between a theory and a conceptual model. For example, a conceptual model may be developed based on a theory, while a theory may also have a model framework. Hence, this overview uses one term theories/conceptual models to refer both theories and conceptual models without clearly distinguishing whether a theory or a conceptual model should be named otherwise.

[27] Suppose a study that develops a conceptual model framework for a SEM study of the relations between travelers' search of product information and their choice of teleshopping, and subsequently collects data via a survey and uses SEM to analyze the data in order to analyze the relations defined in the conceptual model. For this example, the developed framework is a theory/conceptual model, survey is a data collection method, and SEM is a data analysis method/model.

In particular, the overview focuses on the following three aspects: a) the *theories/conceptual models* in the literature, including related theories and conceptual models that have been applied or developed for the study of travelers' choice of ICT and ICT's effects on travel behavior, b) the *data collection methods* that have been used for data collection in empirical studies, and c) the *data analysis methods/models* that have been used in related studies for data analysis.

To have an overview of these three aspects is expected to be of relevance to the research described in this thesis. In short, first, to have an overview of the first aspect aims to contribute to the addition of knowledge (to the knowledge derived from the overview of accessibility measures in the literature – see section 2.3) for the model development in the research presented in *Chapters 3, 4, 5* in this thesis[28]. Secondly, the overview of the second aspect aims to provide insights into the advantages and limitations of the main methods for data collection. The derived insights contribute to the selection of data collection method(s) in the research described in this thesis. Thirdly, the overview of the methods that have been used in related studies for data analysis aims to provide insights into the characteristics and applicability of these models/methods. The derived insights help to choose data analysis method(s)/model(s) in the research that is presented in this thesis. The relevance of the overview to the research presented in this thesis is elaborated later in section 2.5.6.

Following the similar arguments, the overview of the three aspects is also expected to be of relevance for future studies. The scope of the models and the methods that are included in the overview is based on the consideration of not only whether or not the model/method is relevant to this research, but also whether it would be relevant for other types of research in future. A wider range of models/methods than what will be used in this research can be found in the literature. The models/methods vary in terms of the factors such as study context, focus, advantages and limitations, and applicability. The overview hence aims also to provide a general picture of the models/methods that might be of relevance to this field, which forms the secondary aim of this overview – to provide insights for future related studies in respective of model development, data collection and data analysis.

The overview is structured into two strands – the models/methods focusing on teleactivities and those focusing on travel information. Furthermore, in light of the enormous body of literature, this overview neither aims at an exhaustive list of all the models/methods that have been used in the literature nor aims to elaborate on all the details of each model/method (e.g., the illustrative frameworks of conceptual models, the formulations of mathematical models, the details of how data collection methods are implemented, or the details of data analysis methods). Instead, this overview aims to provide a starting point for more in-depth searches of the models and methods used in the literature, useful for both the research presented in this thesis as well as future research in general.

The remainder of this section 2.5 is organized as follows. Section 2.5.2 first provides an overview of the theories and the conceptual models about individual acceptance and use of technologies that have been developed in the literature irrelevant to travel behavior. The

[28] The model development in this thesis includes development of a structural equation model (*Chapter 3*), a model for measuring ICT's effects on accessibility (*Chapter 4*) and a translated choice model of the accessibility measuring model (*Chapter 5*). See the following chapters of this thesis for more details.

reason to include such an overview, although travel behavior is beyond their scope, is that these theories and models can be (potentially) employed to study travelers' intention and/or usage of ICT in transport field. Section 2.5.3 presents an overview of the theories and models that have been developed in the literature for the study of ICT choice and ICT's effects on travel behavior. Section 2.5.4 further presents an overview of the methods that have been used in the literature for data collection. Section 2.5.5 presents an overview of the data analysis methods/models in the literature. Section 2.5.6 concludes this section 2.5 by summarizing the main derived insights from this overview and reflecting on the relevance of this overview to the research presented in this thesis.

2.5.2 User acceptance and use of ICT[29]: theories/conceptual models

One stream of research that can be considered of relevance is not directly related to travel behavior – does not consider any ICT effects on travel behavior – but focuses on individual acceptance of ICT in general by using intention and/or usage as dependent variables. Research in this area, although travel behavior is beyond their research scope, has resulted in several prominent models that can be (potentially) employed to study travelers' intention and/or usage of ICT in transport field. Figure 2-1 shows the basic conceptual framework, formulated by Venkatesh et al. (2003), underlying the class of models explaining individual's acceptance and use of ICT.

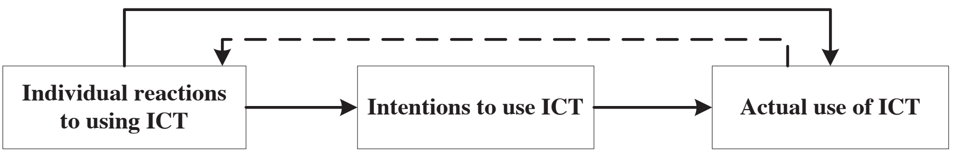

Figure 2-1: Basic conceptual framework underlying models of user acceptance and use of ICT (Venkatesh et al., 2003)

Table 2-3 provides an overview of several key relevant theories. These theories are grounded in psychology or sociology and some of these theories are developed with general applicability to virtually any human behavior; however, all of these theories have been commonly applied to study user acceptance and use of ICT. Some of these theories are also used as basis for development of other models of user acceptance and use of ICT, which are discussed later.

[29] Note that some studies reviewed in this section use the term *technologies* instead of *ICT*, while the technologies in most of these studies actually refer to information and communication technologies.

Table 2-3: Theories[30] of user acceptance and use of ICT

Theory	Introduction
Theory of Reasoned Action (TRA)	Theory of Reasoned Action (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975) defines relationships between beliefs, attitudes, norms, intentions and behavior. According to this theory, an individual's behavior (e.g., use or rejection of technology) is determined by one's intention to perform the behavior, and this intention is influenced jointly by the individual's attitude (i.e., an individual's feelings about performing the behavior) and subjective norm (i.e., the individual's perception that most people who are important to him/her think he/she should or should not perform the behavior). TRA is one of the most fundamental and influential theories of human behavior, and has been used to predict a wide range of behaviors.
Theory of Planned Behavior (TPB)	Theory of Planned Behavior (Ajzen, 1991) extends TRA by adding a third antecedent of intention – perceived behavioral control (i.e., the perceived ease or difficulty of performing the behavior) – to TRA. Perceived behavioral control is determined by the availability of skills, resources, and opportunities, as well as the perceived importance of those skills, resources, and opportunities to achieve outcomes.
Thiandis' Theory of Interpersonal Behavior (TIB)	Triandis' Theory of Interpersonal Behavior (Triandis, 1977) also includes intention as an immediate antecedent of behavior, but differs from TRA and TPB by adding habit as another mediate antecedent. Both influences are moderated by facilitating conditions. According to Triandis, behavior is a function partly of the intention, partly of the habitual responses, and partly of the situational constraints and conditions. The intention is influenced by attitude (i.e., beliefs about outcomes, and evaluation of outcomes), social factors (i.e., norms, roles and self-concept) and affect (i.e., emotions).
Innovation Diffusion Theory (IDT)	Innovation Diffusion Theory (Rogers, 2003) is a theory that seeks to explain how, why, and at what rate new ideas and technologies spread through cultures. Diffusion is a process by which an innovation is communicated through certain channels over time among the members of a social system. IDT has been used to study a variety of innovations since the 1960s. IDT posits five characteristics of innovations that affect their diffusion: relative advantage, compatibility, complexity, trialability, and observability (Dillon and Morris, 1996).
Motivation Theory (MT)	Motivation theory explains human behavior via describing human's motivation. It has its roots in physiological, behavioral, cognitive, and social areas (see Vallerand, 1997 for a review of the fundamental tenets of motivation theory). In general, motivation can be divided into two

[30] One may consider that some theories, if not all, are also conceptual models. For example, one may consider Theory of Reasoned Action (TRA) as a model as well, because TRA has a model framework as well. However, *theories* are used by the authors in their studies and hence this overview keeps the way of this terminology.

	types: intrinsic motivation and extrinsic motivation. Intrinsic motivation is driven by an interest or enjoyment in the task itself, rather than any external pressure. Extrinsic motivation refers to the performance of an activity in order to attain an outcome.
Social Cognitive Theory (SCT)	Social Cognitive Theory (Bandura, 1977, 1978, 1982, 1986) is based on the premise that environmental influences such as social pressures or situational characteristics, cognitive and other personal factors including personality and demographic characteristics, and behavior are reciprocally determined. Thus, human behavior in a given situation is affected by both cognitive and personal factors, and environmental or situational characteristics, which are in turn affected by the behavior.

These theories have been applied in the study of people's acceptance and use of ICT. For example, the Theory of Planned Behavior has been applied for analysis of individual acceptance and usage of ICT in many studies, where the perceived behavioral control is treated as perceptions of internal and external constraints on behavior (see, e.g. Harrison et al., 1997; Mathieson, 1991; Taylor and Todd, 1995). Thompson et al. (1991) applied Thiandis' Theory of Interpersonal Behavior to their study of PC utilization. Thompson et al. did not adopt intention as an antecedent of PC utilization but considered factors influencing the utilization of personal computers, including job-fit with PC use, complexity of PC use, long-term consequences of PC use, affect toward PC use, social factors influencing PC use, and facilitating conditions for PC use. Moore and Benbasat (1991) adapted the characteristics of innovations in the Innovation Diffusion Theory and refined a set of constructs that could affect individual technology acceptance, including relative advantage, ease of use, image, visibility, compatibility, and results demonstrability, and voluntariness of use. These constructs were also used by other studies later (see, e.g. Agarwal and Prasad, 1997, 1998; Karahanna et al., 1999). Derived from Motivation Theory, intrinsic motivation (e.g., perceived enjoyment of using technologies) and extrinsic motivation (e.g., perceived usefulness of using technologies) were also often used as influencing constructs for study of usage of technologies (see, e.g. Davis et al., 1992; Teo et al., 1999). Compeau and Higgins (1995a, b) applied and extended Social Cognitive Theory to study computer use (see also Compeau et al., 1999).

In addition, one or more of these theories have been used as basis for further development of models of user acceptance and use of ICT. Several prominent models are introduced as follows.

The most famous and most used models for the study of user acceptance and usage of ICT are probably the *Technology Acceptance Models (TAMs)*[31]. The original *Technology Acceptance Model (TAM)* was developed based on the Theory of

[31] The term TAMs is used to indicate the class of Technology Acceptance Models (TAM, TAM2, the model of determinants for perceived ease of use based on TAM, and TAM3).

Reasoned Action (Bagozzi et al., 1992; Davis et al., 1989). But TAM, designed to apply to the usage of computer-based technologies, replaces many of TRA's attitude measures with two technology acceptance measures – perceived ease of use (i.e., the degree to which a person believes that using a particular system would be free from effort) and perceived usefulness (i.e., the degree to which a person believes that using a particular system would enhance his or her job performance) (Davis et al., 1989). The TAM has been continuously studied and expanded, three major upgrade being a) *TAM2* (Venkatesh and Davis, 2000), b) *the model of determinants for perceived ease of use* (Venkatesh, 2000), and c) *TAM3* (Venkatesh, 2008). *TAM2* extends TAM by adding subjective norm, which is included as a direct determinant of behavioral intention in TRA and the subsequent TPB, in addition to perceived usefulness and perceived ease of use in TAM. TAM2 was tested in both voluntary and mandatory settings in the empirical study conducted by Venkatesh and Davis (2000), and the results of the test in mandatory setting strongly supported TAM2 – that is, subject norm does exert a significant direct effect on usage intentions for mandatory systems. *The model of determinants for perceived ease of use* (Venkatesh, 2000) extends TAM by identifying two main groups of antecedents for perceived ease of use: anchors (i.e., general beliefs about computers and computer usage) and adjustments (beliefs that are shaped based on direct experience with the computer system). The model was tested by Venkatesh (2000) and the obtained results supported for the included variables in explaining perceive ease of use for a given system. *TAM3* is proposed based on TAM2 and the model of determinants of perceived ease of use (see Venkatesh, 2008 for details).

Another well-known theory/model, named the *Unified Theory of Acceptance and Use of Technology (UTAUT)*[32], was developed by Venkatesh et al. (2003) for a study of individuals' acceptance and usage of new technologies at their workplaces. The UTAUT model contains four core determinants of intention and usage, and up to four moderators of key relationships. The four core determinants are: a) performance expectance (i.e., the degree to which an individual believes that using the technologies will help the individual to gain in performance); b) effort expectancy (i.e., the degree of ease associated with the use of the technologies; c) social influence (i.e., the degree to which an individual perceives that important others believe the individual should use the technologies); and d) facilitating conditions (i.e., the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the technologies). The four moderators of the relationships between the four determinants and individual's intention to use technologies are: a) gender; b) age; c) experience; and d) voluntariness of use (i.e., the degree to which use of technologies is perceived as being voluntary or free of will). The UTAUT model was developed through a review and consolidation of the constructs that earlier research had employed to explain user acceptance and usage of technologies. The model includes constructs that were proposed or used in Theory of Reasoned Action, Technology Acceptance Model, Motivational Model, Theory of Planned Behavior, Combined TAM and TPB, Model of PC Utilization, Innovation Diffusion Theory, and Social Cognitive Theory. The subsequent validation of

[32] Note that Venkatesh et al. used the name Unified *Theory* of Acceptance and Use of Technology (UTAUT), although a related model framework is developed in the study.

UTAUT model in a longitudinal study by Venkatesh et al. (2003) showed that the model accounted for about 70% variance in behavioral intention and about 50% in actual use.

These above-presented models have been frequently used for study of user acceptance and usage of ICT in non-travel-related research, and can be also (potentially) applied into transport context to study travelers' choices of ICT and in turn the effects of ICT on travel behavior. However, it should be noted that these models also have their strengths and limitations in terms of theoretical assumptions or practical effectiveness.

The main strength of these models lies in their parsimony in linking individuals' usage of or intention to use technologies with a number of key constructs. For example, TAMs, which have been successfully applied in many studies, explain behavioral intention and usage through perceived usefulness, ease to use and subject norms (in TAM2 and TAM3). Literature also shows that these models are able to model user acceptance and usage of technologies via these several key constructs that are included in each model.

However, although it is unreasonable to expect these models with a limited number of constructs to fully explain users' acceptance and use across a wide range of technologies in any situations, or in any types of decision makers, the parsimony of these models results in several shortcomings. *Inter alia*, the direct linkage between intention and usage in particular, for example, in TAMs is quite heavily criticized for its over-simplified assumption. The intention-usage linkage overlooks the time gap in-between and thus may fail to consider many intervening factors occurring during the time gap. The static linkage is also not sufficient to model the cases that decision makers may try to use the technologies prior to final decision, which may change the orientation of decision makers towards their perception and intention in a dynamic way (see, e.g. Bagozzi, 2007; Benbasat and Barki, 2007; Chuttur, 2009). In addition, the focus of these models on only a number of antecedents of intentions or usages may lead to ignorance of many other essential influential factors, such as group, cultural or social aspects relevant to technology acceptance. The UTAUT model developed by Venkatesh et al. (2003) presents a well-meaning framework that consolidates multiple constructs from the earlier models and thus provides a higher explanatory power of the possible relationships between many factors and user intentions and usage in reality. However, the UTAUT model includes a large number of independent variables (41 independent variables for predicting intentions and 8 independent variables for predicting behavior), leading to the criticism of the practical effectiveness of the UTAUT model (see the arguments by Bagozzi (2007)). Such criticism related to the practical effectiveness is also shared with other models. It is necessary for researchers to identify the unique determinants of constructs and measure each construct each time whenever the models are applied, if not all the time, according to the particular study contexts. The need for context specificity in applying these models overshadows the strength of these models in parsimony, and results into the lack of general actionable guidance in particular for practitioners to apply these models.

2.5.3 Choice of ICT and the effects on travel behavior: theories/conceptual models

This section moves the attention back to the literature related to travelers' choice of ICT and ICT's effects on travel behavior. First, this section presents an overview of the theories and conceptual models that have been developed in the literature, the focus being on teleactivities (section 2.5.3.1) and travel information (section 2.5.3.2), respectively. As introduced before, the particular aim of this overview is to provide knowledge both for the research described in this thesis and, maybe even more importantly, for future research (given a much wider breadth of theories and models to be presented in this section than what would be relevant and adopted for the research described in this thesis).

2.5.3.1 Teleactivities

One of the earliest yet one of the most prominent frameworks expressing the relationships between teleactivities and travels is the SCMN (substitution, complementarity, modification or neutrality) framework developed by Salomon (1986) and Mokhtarian (1990). This framework forms a significant and important basis for the research about ICT's effects on travels. A substantial number of studies in the literature on travelers' choices of teleactivities and their effects on travels are based on the SCMN framework. These studies, although they differ in the employed research method(s) (e.g., conceptual discussion, or empirical study) or the study context (e.g., study of teleworking, teleshopping, or teleleisure), all focus the discussion on whether teleactivities substitute, generate, modify or do not affect people's travels (see section 2.4.2 in this chapter for a literature overview of related studies).

However, later literature increasingly recognizes that teleactivities may not uni-dimensionally substitute, generate, modify, or do not affect travels, but rather have fundamental impacts on people's way of conducting activities. For example, ICT provides the option for people to do teleworking not only at home, but also at teleworking center, or during travelling. People's work schedule has been also substantially changed as a result of teleworking. Some people may not adopt teleshopping to replace in-store shopping, but tend to search product information via Internet first. ICT also leads to fragmentation of people's activities, and relaxes certain space-time constraints of activities and travels while some constraints may remain or arise. ICT-enabled multitasking during traveling may reduce disutility or even generate positive utility of travel for some people. These ICT effects on people's way of conducting activities in turn result in more complicated relationships between ICT and travels than the SCMN relationships. The importance of considering these effects when ICT's effects on travel behavior are studied is hence increasingly recognized. (See section 2.4.2 for a literature overview and a detailed discussion of these ICT effects). The traditional SCMN framework hence becomes not sufficient, resulting in recent research attention increasingly towards development of models where one or more of these effects are considered or particularly studied.

Based on the above arguments, the following overview presented in this section starts with the theories/conceptual models that have been developed for study of adoption of teleactivities and continues with the theories/conceptual models where one or more of these addressed effects are considered or particularly studied. In particular, an overview (see Table 2-4) is first presented of the most prominent theories/conceptual models that have been developed in the literature with regard to a) teleworking, b) teleshopping, c) telemeeting, d) teleleisure, e) fragmentation, and f) multitasking[33]. A general reflection of these theories/conceptual models in terms of their relevance for further research and practical application is given next.

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[33] Note that, as introduced, ICT may *reduce disutility* or even *generate positive utility of travel*. However, to the best of the author's knowledge, while there are related empirical studies, no related models exist in the literature.

Table 2-4: Theories/conceptual models for study of choices of teleactivities and their effect on travel behavior

Teleactivities	Examples of theories/conceptual Models		
	Literature	**Focus and scope[34]**	**Details**
Teleworking	Mokhtarian and Salomon (1994)	a model that identifies key elements of individual's decision of teleworking	The model developed by Mokhtarian and Salomon identifies three key elements of individual's decision of teleworking, including constraints, facilitators, and drives, and the relationships among them. The major types of constraints (if negative) or facilitators (if positive) include internal psychological factors, and external factors related to awareness, organization and job. The major identified types of drives are work, family, leisure, ideology, and travel. This model has been used by a number of empirical studies of individual's choices of teleworking and the effects of teleworking on travels (see, e.g. Mokhtarian and Salomon, 1996a; Wilton et al., 2011).
	Yeraguntla and Bhat (2005)	a taxonomy for teleworking (teleworking arrangement) along three dimensions	Yeraguntla and Bhat further developed a taxonomy for teleworking (teleworking arrangement) along three dimensions, including: a) telework-locations (e.g., home-based, or regional center-based); b) extent of teleworking – frequency of teleworking (e.g., full-time, part-time, several days a month or partial day); c) communication protocol – e.g., some teleworkers are required to stay electronically connected during business hours; while communication for some teleworkers is through emails, phone conversations and periodical video-conference meetings. The taxonomy of teleworking provides a conceptual framework for a number of studies on how teleworking could affect the forms of people's work-arrangement and in turn travels (see, e.g. Alexander et al., 2010a; Singh et al., 2013; Vana et al., 2008; Yeraguntla and Bhat, 2005).

[34] Different terms are used in this overview (e.g., taxonomy, framework). But they all can be and hence are categorized as conceptual models in the overview.

	Brewer and Hensher (2000)	a model of joint decision of adoption of teleworking between both employers and employees	Adopting a different perspective that considers the adoption of teleworking as a joint decision between both employers and employees, Brewer and Hensher developed a framework within which multiple agents (i.e., employers and employees) make choices of participating in distributed work. Ideas in discrete choice theory and game theory were combined to define a set of choice experiments, in which employees and employers interacted in arriving at a choice in a distributed work context. The stated choice experiments were later empirically investigated by Brewer and Hensher in the context of telecommuting options with an exploratory sample of employers and employees in Sydney, Australia.
Teleshopping	Mokhtarian (2004) & Couclelis (2004)	Two frameworks of the typical subtasks of a shopping process	Mokhtarian identified the typical elements of a shopping process and discussed the possible effects of teleshopping on these elements and travels. The elements include desire, information gathering/receiving, trial/experience, evaluation, selection, transaction, delivery/possession, display/use, and return. Couclelis also decomposed shopping activity into a number of subtasks and conceptually discussed whether some of the subtasks can be virtually conducted. The subtasks outlined by Couclelis include: a) being aware of need or want of a product; b) information gathering of options; c) searching and browsing; d) seeking advice/expert help; e) inspecting alternatives; f) deciding on an item to be purchased; g) deciding on a vendor; h) purchasing a product; i) tracking the status of an order; j) getting an item to delivery point (e.g., home); k) returning/exchanging an item, and l) searching post-sales services. These two frameworks form the basis for the research where other subtasks (e.g., gathering product information) of shopping process than the task of purchasing product only are also taken into consideration (see, e.g. Cao and Mokhtarian, 2005; Farag et al., 2007; Rotem-Mindali, 2010; Rotem-Mindali and Salomon, 2009).

Telemeeting	Rhoads (2010)	theories of face-to-face communication	Relatively fewer studies of choices of telemeeting/teleconferencing exist than studies of choices of teleworking and teleshopping. While the majority of the studies on telemeeting/teleconferencing are based on empirical studies, one notable study that conceptually discussed choices of telemeeting/teleconferencing is from Rhoads. Rhoads explored theories of face-to-face communication to examine the reasons why computer-mediated communication had not yet had the predicted effect of substantially substituting face-to-face meetings. The reviewed theories that are used in Rhoads' study include: a) media richness theory; b) media synchronicity theory, and c) social dynamic media theories. Rhoads also identified, based on the synthesis of the lessons from literature, the factors such as trust and reciprocity, conflict, and leadership that play roles in the determination of the usage of virtual communication in business and collaborative environments.
Teleleisure	Mokhtarian et al. (2004); Mokhtarian et al. (2006)	a taxonomy of leisure activities	Mokhtarian et al. (2004; 2006) provided a conceptual exploration of the potential impacts of ICT on leisure activities and the associated travels. A taxonomy of leisure activities was developed. Four kinds of ways by which ICT can affect leisure activities and travel were identified: a) replacement of a traditional activity with an ICT counterpart, b) generation of new ICT activities (that may displace other activities), c) ICT-enabled reallocation of time to other activities, and d) ICT as a facilitator of leisure activities. In addition, 13 dimensions of leisure activities that are especially relevant to the issue of ICT impacts were proposed. The 13 dimensions include: location (in)dependence, mobility-based versus stationary, time (in)dependence, planning horizon, temporal structure and fragmentation, possible multitasking, solitary versus social activity, active versus passive participation, physical versus mental, equipment/media (in)dependence, informal versus formal arrangements required, motivation, and cost. The conceptual framework suggested that the primary impact of ICT on leisure is to expand an individual's choice set; however, whether or not the new options will be chosen depends on the attributes of the activity.

Fragmentation	Hubers et al. (2008) & Alexander et al. (2011)	quantitative indicators along three dimensions to assess the extent to which ICT leads into temporal fragmentation and spatial fragmentation	Hubers et al. (2008) and Alexander et al. (2011) developed a series of quantitative indicators along three dimensions to assess the extent to which ICT leads into temporal fragmentation (i.e., episodes of an activity conducted at different times) and spatial fragmentation (i.e., episodes of an activity conducted at different locations). The three dimensions are: a) number of fragments an activity is divided into (e.g., a person conducted three subtasks for a piece of work at three different times to complete the work, and the three indicates the number of the temporal fragments for the work); b) distribution of fragment size (e.g., if a person spent 6 hours on work at the office and 2 hour on work at home, the fragmentation is less than if the person spent 4 hours on work at the office and 4 hours on work at home); c) configuration of fragments in terms of dispersion of fragments across space and time (e.g., the case that a person conducted work twice in the morning and in the afternoon is considered more disperse than the case that the person conducted work twice in the morning only) and shape and orientation of configuration of fragments (i.e., reflection of the distribution of locations where an activity is conducted). These indicators were used respectively on two datasets from two activity-travel-diary studies and the results show the usefulness of these indicators to ex-post evaluate the resulted fragmentation caused by use of ICT.
Multitasking	Circella et al. (2012)	a conceptual framework for the systematic analysis of multitasking behavior	Circella et al. (2012) developed a conceptual framework for the systemic analysis of multitasking behavior. They used two dimensions “share of time” and “share of resources” to develop a typology of multitasking in terms of four types of multitasking: - monotasking (i.e., no multitasking); - switching; - interleaving; - overlaying; They introduced polychronicity – the corresponding degree of preference for

			doing multiple activities simultaneously in the framework. This polychronicity is measured as a time- and context-dependent vector, rather than as a single score. They also discussed the heterogeneous nature of resources and the importance of the time scale and time granularity used for measuring multitasking.

Without the intention of comparing the strengths and weaknesses of each presented theory/model, several general remarks are relevant when these theories/models are used as a basis for further model development or for applications. First, it can be concluded from the overview that there is no general model for travelers' choices of all kinds of teleactivities and all kinds of effects of teleactivities on travels. Given the broad breadth and complexity of the topic, it is unreasonable to expect that there exists a general model that is able to capture choices of any type of activities and all kinds of effects of teleactivities and travels. Secondly, it should be noted that each of the presented models is developed with specific context. Great care should hence be taken of the model's focus coherent to the context of the study when any of these models is to be used as a basis for further model development or to be applied. First, each of these models is particular for specific type of teleactivities or focuses on certain specific effects. The models developed for one particular type of teleactivity or particular effects cannot be simply applied to the study on other types of teleactivities or other kinds of effects (e.g., to use the model for adoption of teleworking for study of adoption of teleshopping). In addition, these presented models focus on short-term behavior (i.e., travelers' short-term choices of teleactivities and short-term effects from teleactivities). Finally, these models are developed for studies of choices and effects at disaggregate levels (i.e., individual or household)[35]. It is hence not appropriate to apply these models for studies where long-term or aggregate choices and effects are concerned.

2.5.3.2 Travel Information

The long history of research on travel information has resulted in a variety of related models for travelers' acquisition of travel information and its effect on travel behavior. There are also already detailed literature review available in the literature (see, e.g. Chorus, 2012d; Chorus et al., 2006b; Lappin and Bottom, 2001; Watling and Van Vuren, 1993). Rather than to repeat the work, this section first provides a brief overview of the theories/conceptual models with reference to some examples of related studies in the literature. A general reflection of these theories/conceptual models in terms of their relevance for further research and practical application is given next.

Table 2-5 provides an overview of the theories and the models that have been developed for study of choices of travel information and the effect on travel behavior. Three categories of

[35] Although long-term behavior and aggregate effects are beyond the scope of the overview, it has been found that literature has paid relatively little attention to the (possible) long-term effects of teleactivities, or the effects of teleactivities at aggregate levels. Several examples of the few models that consider the long-term or aggregate effects of ICT include: Mokhtarian (1998) proposed a multiplicative model for forecasting the demand for telecommuting and the resulting transport impacts at an aggregate level. Wiegmans et al. (2003) developed a conceptual model that incorporates ICT's long-term indirect effect in addition to the short-term direct effects of ICT on mobility. One mediator factor "trends/conduct" was proposed for ICT's long-term effect on travels. Choo and Mokhtarian (2007) developed a model that conceptualizes the causal relationships between the following variables to explore the aggregate relationships between telecommunications and travel. The variables include eight endogenous variable categories (travel and telecommunication demands, transportation and telecommunications system infrastructures, land use, travel and telecommunications costs, and economic activity) and one exogenous variable category (socio-demographics). Each variable category is comprised of a set of individual variables. The model was implemented by Choo and Mokhtarian for a structural equation modeling analysis of a national time series dataset spanning 1950-2000 in the US.

models that are developed based on different decision theories are included: a) utility-based models that are developed based on expected utility theory or random utility theory; b) (cumulative) prospect theory-based models that are developed based on (cumulative) prospect theory; and c) random regret minimization models that are developed based on random regret minimization theory.

Table 2-5: Theories/conceptual models for study of choices of travel information and the effect on travel behavior

Categories	Theories and models	Examples of studies	
Utility-based models	*Expected utility theory (EUT)-based models* describe how people make choices between alternatives based on their expected utilities (Von Neumann and Morgenstern, 1947). In EUT-based models, decision makers are uncertain about the consequences (outcomes) of their decisions, but the uncertainty from analysts' perspectives is not considered in classical forms of EUT-based models[36]. *Random utility maximization (RUM)-models* underline people as rational agents to maximum their (expected) utility. Different from EUT-models which are deterministic, RUM-models adopt non-deterministic approach, where analysts are uncertain about the alternatives' utilities because of unobserved utility components (Ben-Akiva and Lerman, 1985; McFadden, 1974; Train, 2003).	Denant-Boèmont and Petiot (2003)	a EUT-based model (without recourse to discrete-choice framework) for individual's acquisition of travel information and individual's sequential decision-making of travel mode, route and departure time
		Arentze and Timmermans (2005)	a utility-based measure of expected information gain based on a Bayesian model of mental maps and belief updating
		Ettema and Timmermans (2006)	a model of departure time choice under travel time uncertainty and information on the earlier EUT-based departure time choice model (see, Noland and Small, 1995)

[36] Note that classical EUT-based models, which focus on the characterization of decision makers' attitude towards risk, take account neither of multi-attribute choice contexts nor of analyst's uncertainty (unobserved utility components). But there are models that combine the elements of not only EUT but also RUT – that is, consider not only decision makers' expected valuation of risk alternatives but also analysts' unobserved utility components. While different approaches can be found in the literature, one common yet probably the most pragmatic approach is to add random error terms to the expected utility components, resulting in a discrete-choice framework (see, e.g. Batley and Daly, 2004; de Palma et al., 2008; de Palma and Picard, 2005; Liu and Polak, 2007).

		de Palma and Picard (2006)	a EUT-based model (without recourse to discrete choice framework) to analyze the impact of information on risk-averse drivers who maximize their expected utility (rather than minimizing expected travel time)[37]
		Chorus et al. (2009)	a model of traveler response to advice (prescriptive information) based on the premises of Bayesian expected utility decision-making
		de Palma et al. (2012)	a EUT-based utility model (without recourse to discrete choice framework) built on the model of de Palma and Picard (2006) by assuming that information is costly and by considering the derivers decisions on whether to purchase information
		Sun et al. (2012)	a EUT-based heterogeneous choice model (discrete-choice framework used) for activity-travel decisions that incorporates the effects of information on activity-travel rescheduling decisions
		Chorus et al. (2013)	a RUM-model of traveler sequential response to pre-trip information

[37] Note that this study assumed that the information is pre-given to all drivers and did not consider drivers' decision of acquiring information and the learning process.

			acquisition; traveler decides to acquire information based on the utility of the anticipated travel choice situation after the information is received
(Cumulative) prospect theory-based models	*(Cumulative) prospect theory ((C)PT)-based models*, as descriptive models of people's actual choice behavior, describe how people choose between probabilistic (risk) alternatives and evaluate losses and gains with respect to some reference point based on transformed cumulative probabilities (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992).[38]	Han et al. (2005)[39]	a model that integrates prospect theory and Stackelberg games to model strategic dyad behavior of information providers and travelers
		Gao et al. (2010)	a CPT-based route choice model to explain travelers' strategic adapted behavior according to real-time information when travelers are revealed traffic conditions *en route* in stochastic networks
		Ben-Elia and Shiftan (2010)[40]	a learning-based model of route-choice behavior when information is provided in real time: they first developed a RUM-model and a CPT-variant which uses gains and losses in travel time as lagged variables in the model

[38] Note that discrete choice framework has been also adopted in a prospect-theoretic application to travel behavior research (see, e.g. Avineri and Prashker, 2003; De Blaeij and Van Vuuren, 2003; Schwanen and Ettema, 2009). However, the practice of using discrete choice framework for PT-based applications is not without criticisms (e.g., see Timmermans, 2010).

[39] Note that not all components of PT (i.e., reference dependence, diminishing sensitivity, and probability weighting) are included in this study. Only the probability weighting element of PT is integrated into their model.

[40] Although the model is presented in the category of PT-based models, note that, as addressed in the introduction, they first developed a RUM-model, as the main model, and later developed a PT-based model variant.

Regret minimization models	*Regret minimization models* describe people's choices under uncertainty as a process of minimizing the anticipated regret when choosing between alternatives. A wide variety of regret based approaches to model behavior exist. In the travel behavior research community, the Random Regret Minimization approach has arguably been the most used approach. In the original specification of the RRM model, the anticipated regret was defined as the difference between the outcome yielded by a given choice and the best outcome that could have been achieved from non-chosen alternatives (Chorus et al., 2008). In the new form of RRM-model[41] (Chorus, 2010), regret is postulated to be anticipated with respect to all foregone alternatives that perform better than the considered one in terms of one or more attributes. The unobserved regret by analysts is captured by the random error components in RRM-models.	Chorus et al. (2006a)[42]	a regret based (but not RRM)-model, where the notion of regret is deployed as a determinant of decision, to analyze the value of travel information for satisficing and maximizing travelers, respectively.
		Chorus et al. (2008)	a RRM-model (the 2008 variant) for travel choice; this model was empirically estimated on data from a multimodal travel simulator, where participants could choose between travel alternatives with risky travel times and costs, and the option of travel information acquisition.
		Chorus (2010)	a new form of RRM-model (the 2010 variant) for travel choice; this model was empirically estimated, *inter alia*, based on a dataset about travel information acquisition choices.
		Chorus (2014)	a formal model of traveler acquisition of ex-post information that captures the interplay between a traveler's

[41] Another difference between the old RRM-model (2008 variant) and the new RRM-model (2010 variant) is that in the new RRM-model, the model specification's likelihood function is smooth and thus can be estimated using standard discrete-choice software packages, while the old form of RRM-model features a non-smooth likelihood function (Chorus, 2010).

[42] Note that although the literature (Chorus et al., 2008) is referred in this thesis as the origin of the RRM-model of travel choice (the 2008 variant), the notion of regret had been employed as a determinant of decision in this study (Chorus et al., 2006a).

			inclination to minimize both the anticipation of regret associated with the current choice situation and future choice situation (based on the RRM approach).

Utility-based models, because of the theoretical elegance and practicality of EUT & RUM theories (McFadden, 1974; Von Neumann and Morgenstern, 1947) and their firm root in economic axioms (Small and Rosen, 1981), have been dominantly used for travel information-related studies. However, the premises of EUT and RUM theories are not without criticism, resulting into development of alternative behavioral paradigms for study of choice behavior. *Inter alia*[43], (cumulative) prospect theory and random regret minimization theory have recently gained the most attention in travel behavior research and have been also used for travel information-related studies in particular. The effectiveness of these decision theories for study of choice behavior has been long and well debated not only outside but also within travel behavior research community itself. Rooted in these different decision theories, the models hence have their advantages and limitations. While this overview neither aims to repeat the discussions nor aims to participate into the debate, for more in-depth insights into the advantages and limitations of these models, interested readers can refer to several studies (see, e.g. Chorus, 2012d; de Palma et al., 2008; Starmer, 2000; Timmermans, 2010).

In addition, note that, given the focus of overview on short-term behavior (short-term choices of travel information and effects on travel behavior), models such as learning-related models (e.g., reinforcement learning, Bayesian learning) for study of traveler's dynamic learning behavior from travel information are not included (see, e.g. Avineri and Prashker, 2005; Ben-Elia et al., 2013b; Bogers, 2009 for examples of learning models).

Finally, it seems that only utility theory has been adopted for the study of choices of teleactivities (see section 2.5.3.1 and section 2.5.5 for relevant references). To the best of the author's knowledge, (C)PT-based models and RRM-models have not (yet) been adopted for study of choices of teleactivities, although it does not necessarily imply that they cannot be (potentially) applied to the studies of teleactivities.

2.5.4 Choice of ICT and the effects on travel behavior: data collection methods

This section provides an overview of the methods that have been used for data collection in the literature for study of choice of ICT and the effects on travel behavior. It starts with an overview of these data collection methods, with reference to the examples of the studies using these methods. More importantly, a discussion of the advantages and the limitations of these methods from a general perspective (rather than a perspective of relevance of these methods to the research described in this thesis) is provided next. The overview and the discussion are expected to contribute to the two-level aim addressed in the introduction – to derive knowledge with regard to data collection methods for the research described in this thesis and for future other research.

The main data collection methods in the literature for study of choice of ICT and ICT's effects on travel behavior can be classified into several categories:

- **Interviews**: often used by studies about ICT choices and travels to get in-depth understanding of interviewees' ICT-use and travels in terms of the aspects such as motivations, determinants, constraints, experiences, etc.

[43] Examples of other behavioral paradigm include: fuzzy logic (Zadeh, 1965), elimination by aspects (Tversky, 1972), bounded rationality (Gigerenzer and Selten, 2002; Mahmassani and Chang, 1986), decision field theory (Stern, 1999).

- **Activity-travel diary and/or questionnaire survey**[44]: often used for quantitative research. Activity-travel diary requires subjects to record the information (revealed-preference data) of activities (e.g., teleactivities) and travels over the course of a period in a *diary*, for example, types of activities, location for activities, time, origins and destinations of travels, and travel modes. Questionnaire surveys (e.g., paper-and-pencil or web-based questionnaire; one-time or panel survey) are often used to collect stated-preference (SP) or revealed-preference (RP) data about the information of travelers' choices of ICT and travels in terms of the aspects such as attitudes, preferences, needs, usage of ICT, etc.

- **Simulator experiment**: used to collect SP data with regard to experiment subjects' choices and behavior in a developed simulator environment (e.g., a hypothetical online shopping environment or travel network with information provision). Simulator experiments can, to some extent, be considered as a mix of SP-approach and RP-approach, because it seeks to imitate the real-world environment in a simulator setting, and to represent the key characteristics of the real-world environment.

- **Field observation**: used to collect real world information (e.g., actual arrival time of public transit), or to gain a close observation with travelers' behavior in a natural environment (e.g., to observe traveler's multitasking behavior during travelling). The method is often undertaken with an intensive involvement of observers in participating activities, or travelling with the study subjects over a period of time. The collected information of the observed subjects' behavior is then used for follow-up qualitative or quantitative research. Note that the method does not involve the interactions with travelers (e.g., ask travelers questions) and hence is different from, for example, on-site questionnaire survey (see the second point).

Table 2-6 provides several examples of the studies using these methods, with additional information about: a) the category of the study – teleactivities (C) or travel information (I); b) the focus of the study; and c) a brief introduction of the method used in the study.

[44] The reason that these two methods are presented together is that in a substantial number of studies, the two methods are used in combination. However, they will be discussed separately in terms of the advantages and limitations of each method later in this section.

Table 2-6: Data collection methods and examples of the studies

Method	I/C	Focus[45]	Examples of studies and data resource[46]	
Interviews	C	Teleworking	Lyons and Haddad (2008)	interviews with 25 individuals who adopt partial working in the UK
			Wilton et al. (2011)	interviews with 32 employees in an educational institution in Canada
		Telemeeting	Arnfalk and Kogg (2003)	interviews among the participants of a survey in two companies in Sweden
			Larsen et al. (2008)	interviews with 24 young professionals in the UK
			Haynes (2010)	Interviews with 72 people among 30 Irish software companies and 12 sector experts
		Multitasking	Axtell et al. (2008)	interviews among a sample of the participants of a survey among 350 business passengers on a rail line in the UK
		Disutility associated with travel	Jain and Lyons (2008)	a discourse study of six gender-defined focus groups in the UK
	I[47]	/	/	/
Activity-travel diary and/or questionnaire survey	C	Teleactivities in general	Mokhtarian and Meenakshisundaram (1999)	a panel survey (activity-travel and communication diary) among 91 participants in the city of Davis, California

[45] Note that the listed studies about teleactivities are distinguished according to the focus of the study – the studied teleactivity type or effects, while the studies about travel information are not in particular distinguished in this overview, given the focus of the overview on travel information in general.

[46] Note that some of the listed examples of studies used secondary data.

[47] No study in the literature, to the best of the author's knowledge, has adopted interview as main data collection method for studies about traveler's acquisition of travel information and the effects of travel information on travel behavior.

			Hjorthol (2002)	Norwegian national personal travel survey (NPTS) 1997/1998 and a connected mail back survey of the use of ICT at home
			Choo and Mokhtarian (2007)	US national time series data 1950-2000 about vehicle-related data (e.g., VMT) & number of local telephone calls in 50 states
			Nobis and Lenz (2009)	a panel survey for the years 2004 and 2007 in Germany
			Lee-Gosselin and Miranda-Moreno (2009)	the first wave of a panel survey in Quebec city
		Teleworking	Pendyala et al. (1991)	a travel diary study of State of Californian Telecommuting Pilot Project (two wave panel data: 1st wave: 252 employees & 2nd wave: 219 employees)
			Mokhtarian and Salomon (1996b)	a self-administrated questionnaire survey among 628 participants in city of San Diego
			Mokhtarian and Bagley (2000)	an attitudinal survey among 188 participants of the Neighborhood Telecenters Project, US
			Vilhelmson and Thulin (2001)	National Survey of ICT use in Sweden in 1997, 1998 and 1999 & Swedish National Travel Survey
			de Graaff (2004) & de Graaff and Rietveld (2004)	two waves (no panel) of a survey (diary during a week) in the Netherlands in 1995 and 2000
			Haddad et al. (2009)	a third wave of a four-wave longitudinal survey among 570 full-time employees in the UK
		Teleshopping	Gould et al. (1998)	an activity and travel diary (multi-day) in the Portland Metropolitan area in 1994-1995
			Van Slyke et al. (2004)	a survey among 507 respondents in three public North American universities
			Farag et al. (2007)	a shopping questionnaire and a two-day travel diary in four municipalities in the Netherlands
			Weltevreden and Rotem-	an online survey among 3000 Dutch e-shoppers

			Mindali (2009)	
			Cao et al. (2012)	a shopping survey in the Minneapolis-St. Paul seven-county metropolitan area in 2008-2009
		Telemeeting	Arnfalk and Kogg (2003)	a web-based survey at two companies in Sweden in 2000
			Lu and Peeta (2009)	a stated-preference survey in 116 business firms in Taiwan technology industry
			Denstadli et al. (2012) & Julsrud et al. (2012)	a quantitative survey among 1411 Norwegian air business travelers
		Teleleisure[48]	Handy and Yantis (1997)	a household survey among 3000 households in three cities in the US
			Senbil and Kitamura (2003)	a mail-out and mail-back survey among 766 individuals in the Osaka metropolitan area
			Krizek et al. (2005a)	three different mail-out and mail-back surveys among the households living in Seattle, Kansas city, and Pittsburgh
			Wang and Law (2007)	the third Travel Characteristic Survey (travel diary) of Hong Kong in 2002 and an additional survey
		Multitasking	Kenyon and Lyons (2007)	an "accessibility diary" survey in six locations in the south west of England
			Gripsrud and Hjorthol (2012)	a questionnaire survey among rail passengers during weekdays in Norway
		Space-time constraints	Robinson et al. (2000)	a survey of 3993 adults in US to study time displacement of social activities as a result of Internet or computer use
			Harvey and Macnab (2000)	a survey in 1998 in Canada to examine the real-time communications associated with Internet connectivity in terms of spatial-, temporal-

[48] Note that the studies presented in this category also considered mandatory and/or maintenance activities. But these studies are among the relatively fewer empirical literature that also studies the effects of ICT on leisure activities. These studies are hence presented here in the category of teleleisure.

				and coupling constraints
			Schwanen and Kwan (2008)	activity diary data in Columbus (Ohio, USA) and activity diary data and interviews structured around completed diaries in Utrecht (the Netherlands) for study of the relationship between Internet, mobile phone use, and space-time constraints
		Disutility associated with travel	Mokhtarian and Salomon (2001)	a questionnaire survey study among 1900 respondents in the San Francisco Bay area, the US
			Lyons et al. (2007)	a national mail-back questionnaire survey of 26221 rail passengers in Great Britain
	I	/	Abdel-Aty et al. (1997)	a computer-aided telephone panel survey among Los Angeles area morning commuters about their routes, their awareness of alternate routes, their awareness of traffic conditions, and their use of available pre-trip and/or en-route travel information & a follow-up mail-back survey among a sub-sample of the panel survey
			Polydoropoulou et al. (1997)	a survey among the users and non-users of SmarTraveler (an ATIS that provides real-time location-specific traffic and transit information in the greater Boston area) about the frequency of use and willingness to pay
			Hato et al. (1999)	a mail-back questionnaire survey of 1907 drivers on the Tokyo Metropolitan Expressway network in which drivers can make use of traffic information from multiple sources in choosing their route
			Dia (2002)	mail-back questionnaires of 167 peak-period automobile commuters in Brisbane (82 questionnaires for pre-trip response to unexpected congestion information & 85 for en-route response to unexpected congestion information)
			Peirce and Lappin (2004)	wave 10 of the longitudinal Puget Sound Transportation Panel survey in Seattle, where respondents were asked to complete a 48-hour travel diary and also recorded the impact of information acquisition on specific travel choices & a supplemental survey on awareness of information sources and use of technologies

			Khattak et al. (2008)	2006 Great Triangle Household Travel survey among 5107 households in north Carolina; the survey included questions on access and use of traffic information
			Zhang et al. (2008)	2006-2007 University of Maryland campus transportation panel survey data about how travelers responded to the ShuttleTrac system (i.e., a real-time bus arrival information system for the university's shuttle service)
			Joh et al. (2011)	an activity-travel diary survey conducted on two consecutive days in Korea; the survey consisted of three sections: socio-economic characteristics, activity-travel diary data and information acquisition data
			Wang and Khattak (2011)	an activity-based travel survey where household members were asked to record their trips for a specified 24h period using a specially designed travel diary, including their use of travel information (pre-trip and en-route information)
Simulator experiment	C	Teleworking	Brewer and Hensher (2000)	an interactive choice experiment for work-arrangement choices
		Teleshopping	Childers et al. (2001)	an online shopping simulator experiment
	I	/	Polak and Jones (1993)	a computer-based stated preference survey conducted among 344 respondents in Birmingham and 322 respondents in Athens, respectively, about their acquisitions of pre-trip information in different situations
			Mahmassani and Liu (1999)	a dynamic interactive travel simulator for laboratory studies of user responses under real-time information
			Katsikopoulos et al. (2000)	two experiments (one paper-and-pencil and one driving simulator) on travelers' route choice between a route with a certain travel time and an alternative route with a range of travel times with provision of travel time information
			Denant-Boèmont and	an experimental game in which individuals choose between alternative

			Petiot (2003)	congested transport modes to try to arrive at a destination at a given time; each subject can also buy information about traffic levels; experimental economics technique was applied
			Avineri and Prashker (2006)	a laboratory route-choice simulator experiment to evaluate the effect of feedback on decision-making under uncertainty, with and without provided information about travel times
			Bogers (2009)	a travel simulator experiment conducted among 2500 people for data collection of their route choices with provision of en-route information and/or ex-post information
			Ben-Elia and Shiftan (2010)	a laboratory controlled experiment where participants made a long series of binary route choices relying on real-time pre-trip information and learning from the feedback information
			Sun et al. (2012)	an web-based interactive travel simulator experiment to collect data on how respondents reschedule activities and/or collect travel information for a set of hypothetical travel situations
			Ben-Elia et al. (2013a)	a simulator experiment about travelers' route choices under three different levels of information accuracy (36 participants, and 20 repetitions)
			Chorus et al. (2013)	a multimodal travel simulator with an abstract multimodal travel network and provision of three types of information – a) provide estimates for the uncertain attributes of known alternatives; b) generate formerly unknown travel alternatives; and c) warn the traveler if the travel time of an alternative about to be undertaken greatly exceeds their expectations
Field observation	C	Multitasking	Ohmori and Harata (2008)	on-board direct observations of commuters' activities on a total of 11 weekdays in 2003 on the Odakyu Odawara line, Japan

			Waerden et al. (2009)	on-board direct observations of travelers' activities on a railroad line between two cities in the Netherlands, Tilburg and Deurne
	I	/	Watkins et al. (2011)[49]	on-site survey and observation of the riders who were waiting at 14 bus stops in the vicinity of the University of Washington in Feb. 2010 – the on-site survey conducted by one questioner asked the waiting riders about, *inter alia*, what they use to (or not) find out the bus schedule and what type of device they use to access the information; the on-site observation recorded information such as gender, arrival time at the bus stops and age group

[49] Note that this study both used the data from the on-site survey for the study of impact of mobile real-time information on the perceived and actual wait time of transit riders, and used the data collected via the on-site observation.

Table 2-6 shows that interviews are not often used as a research method. While the method has been adopted by some studies on teleactivities, no study in the literature, to the best of the author’s knowledge, has adopted it as the main data collection method for travel information-related research. In contrast, activity-travel diary and questionnaire survey are more often used for data collection. Simulator experiment, which is also often adopted, is however more commonly found in the studies about travel information acquisition and the effect of travel information on travel behavior. Field observation has been rarely used in the literature, except for several examples using it as a method for studying multitasking behavior during travelling or a complementary method for some extra information. The varying frequencies of the usage of these methods in the literature, to some extent, reflect the different applicability of each method for particular studies.

More importantly, each method has its own advantages and limitations, which directly determine the applicability and effectiveness of the method in data collection for different studies. Without the intention of being exhaustive, a brief discussion of the advantages and limitations of these methods from a general perspective (rather than a perspective of relevance of these methods to the research described in this thesis) is presented below.

Interview

The possibly greatest advantage of interviews is the ability to gain detailed insights into the interviewees’ experience of ICT usage, and their attitudes towards ICT usage and travels. Not only can researchers learn via interviews about the status of interviewees’ choices (e.g., whether or not interviewees telework), researchers can also gain insights into interviewees’ experience and their processes of choice-making – for example, how interviewees perceive and change their attitudes towards ICT-usage, how events (e.g., experiences of using ICT) affected interviewees’ thoughts and feelings, and what would motivate them to make certain choices (Seidman, 1988). Researchers can get in-depth understanding of the process of interviewees’ decision-making, whereas other types of methods (e.g., questionnaire survey, activity-travel diary) are only (or predominantly) able to collect information of the status of interviewees’ choices (e.g., whether interviewees telework, or frequency of teleworking). Another advantage of interviews lies in their adjustable form. Researchers can tailor the questions according to given circumstances in order to get rich and full information that is needed for the research. Researchers can also clarify interview questions when respondents do not fully understand the questions and thus avoid misinterpretation by respondents. In addition, the richness of results from interviews, once reported or presented, gives readers an easier understanding of the experiences of respondents and a greater chance to identify with the interview respondents (Weiss, 1994).

However, the information collected via interviews may be insufficient to be used to answer certain research questions such as the effect size of certain types of facilitators or constraints on the adoption of teleworking. In addition, given the sample uniqueness of each interview, the results of interviews can also be difficult to be compared across respondents and to be generalized across populations. Moreover, there can be complications with planning and conducting interviews and analyzing interview data (Weiss, 1994). For example, it might be difficult to recruit sufficient respondents that meet the requirements of research. Subjective or objective disturbances may interfere in the process of interview, resulting in researchers’ biases or mistakes in recording the interview answers. The process of coding might be very time-consuming and also expensive.

Activity-travel diary[50]

One advantage of activity-travel diaries is that they provide multi-dimensional data that combine spatial, temporal and attribute information (Yu and Shaw, 2008). Via these data, it is possible to gain insights into people's daily activities and travel, as well as the possible interactions between different people and local geographic and social context. Once ICT-usage is addressed in the diary, the contextual data with regard to people's daily use of ICT and the resulting interactions with activity participations and travels help improve the understanding of people's daily activity-travel behavior and usage of ICT and its effects on people's travel behavior (Kenyon, 2006). Another related advantage of activity-travel diaries lies in their high external validity, as the revealed-preference data collected via activity-travel diaries reflect the choices that are actually made or the behavior that is actually performed by travelers in real life.

However, conducting an activity-travel diary is often expensive and time-consuming. In addition, the collected revealed-preference data may exhibit insufficient variations, or even collinearity, due to the lack of variation of real-life situations. It may hence result in difficulties in statistical analysis and parameter estimation (Train, 2003). Researchers also have relatively limited controllability of the process of recording data by participants. Moreover, sometimes the recording error resulted from the design of the diary may offset the validity of the data. For example, free-format diaries often suffer from high degrees of recording errors because they offer little guidance to diary participants with respect to specifying activities and locations. Individuals are sometimes unwilling to report certain activities and also often tend to under-report short trips and the number of stops during a multi-purpose (Miller, 2005b). Another limitation of activity-travel diaries is that they cannot be used to study the use of transportation and ICT that are not (yet) available to travelers in real life.

Questionnaire survey

In general, the advantage of using a questionnaire survey to collect data lies in its low-cost, flexible, and efficient nature (Chorus, 2007). Researchers can tailor-make the questions in surveys in order to collect aimed information and data, and it is relatively cheap to design and conduct questionnaire surveys[51]. Researchers can also adopt different formats such as paper-and-pencil-based, telephone-based, or web-based survey. Another prominent advantage of

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[50] Activity-travel diary and questionnaire survey were presented together above when the examples of related studies are provided, since a number of studies in the literature adopted both methods in combination. However, given the different characteristics of the two methods, the advantages and limitations of the two methods are discussed separately here.

[51] A comparison of the method questionnaire survey with the other two methods – activity-travel diary and simulator experiment firstly reveals that it is usually more demanding to design a simulator (e.g., a complicated computer-based simulator with dynamic user interface) in terms of time, cost, and resource than to design a questionnaire survey. Secondly it is also usually more time-consuming and more expensive to conduct an activity-travel diary than to conduct a questionnaire survey.

questionnaire survey is that researchers can collect both a) revealed-preference (RP) data, such as participant's frequency of doing teleactivities or acquiring travel information in the survey; and b) stated-preference (SP) data, such as which of the hypothetical alternatives presented in the survey participant would choose in real life, or participant's needs, willingness-to-pay, attitudes or preference for alternatives. In particular, this method has different advantages and limitations when questionnaire survey is used to collect SP data or RP data, respectively.

When questionnaire survey is used to collected RP data (e.g., to study participants' habits of ICT-use), the data has high external validity. In addition, collecting RP-data via surveys is often cheaper than doing so via activity-travel diaries, since diaries ask participants to record for a continuous period of time and hence often last longer. However, RP-data collected via surveys are often less resourceful than those collected via activity-travel diaries. It is difficult to collect spatial, temporal and attribute information of people's activity-travel behavior via surveys. In addition, RP-data collected via surveys may also suffer from the lack of variations, and also cannot be used to study the usage of unavailable transportation and ICT.

When questionnaire survey is used to collected SP data (e.g., to explore participants' stated choices or valuations of travel or ICT), researchers can tailor-design the alternatives in the choice set or control the experiment conditions in order to ensure sufficient variations in the choices or preferences attributable to explanatory variables. It is also effective to use surveys to collect data with regard to people's subjective attitudes towards or perceptions of travels and ICT-use, whereas such kinds of data are difficult to be collected via RP-methods (Hensher, 1994). Another advantage of SP-survey is that it enables researcher to study people's preferences and valuation of the ICTs that are not (yet) available to survey respondents. However, by far the most notable limitation of SP-data is its limited external validity. When participants are asked to indicate their choices or preferences of presented hypothetical alternatives, participants have to imagine the hypothesized choice situations and think what they would choose as in a real-life situation. This would also occur when participants are asked to report (e.g., rate in a Likert-scale) their participants' subject norms, attitudes and perceptions, etc. Another drawback of SP-survey concerns its static nature. It is hence not appropriate to use SP-survey for data collection when, for example, sequential choices (e.g., sequential information acquisition) or learning (e.g., learning from ex-post information) are concerned.

Simulator experiment

Simulator experiments are often used to collect SP data with regard to experiment subjects' choices and behavior in a developed simulator environment that seeks to imitate the real-world environment, and to represent the key characteristics of the real-world environment. As such, simulator experiment, to some extent, can be considered as a mix of SP-approach and RP-approach. Due to relatively limited costs and high flexibility in creating and simulating, simulator studies have advantages in studying people's complex choice behaviors under certain specific conditions and therefore are a cost-effective method for empirical model estimation and validation (Bonsall, 2004; Chorus, 2007; Chorus et al., 2013; Mahmassani, 2006). Simulator experiments have the advantages of SP-methods. Experimenters have a higher control of simulator experiments during both the design phase and implementation phase. Simulator can be tailor-made – e.g., what kinds of settings, choice set compositions, alternatives, and attributes to be included – according to the aim of research. Experimenters also have a high control (e.g., control experiment time; track progress of implementation) in the phase of implementation if simulator study is conducted in a laboratory setting. It is also an effective method for studying people's choices and preferences of the ICTs that are not (yet) available on the market. In addition, given their dynamic feature, simulator experiments have advantage in studying people's sequential choices and learning behavior. Moreover, because simulators are often designed in such a way to mimic and represent real-life environments, compared to traditional SP-surveys, simulator experiments have a higher external validity. However, simulator studies may still limit in their realism, due to laboratory setting, thus resulting in less external validity compared to activity-travel diaries, although the ongoing advances in making simulator environments more realistic help increasing the external validity of the collected data.

Field observation

The advantage of field observations lies in their ability to collect objective information with high external validity – to avoid bias or errors from participants (e.g., participants' recording errors of activity-travel diaries, misinterpretation of questions in surveys, or misunderstanding of simulator environment). However, field observations, due to their particular feature, are relatively narrow in their applicability scope for data collection and hence have been rarely used. To be best of author's knowledge, only few examples used field observations to study multitasking behavior during travelling or use it as a complementary method for collecting extra information. Another limitation of field observations is that the method is often time consuming and labor-demanding. Researchers are often required to intensively get involved in participating activities, or travelling with study subjects over a period of time. Hence, the method is often conducted in a small scale, restricting the generality of findings concluded from field observation. In addition, the collected data via field observations, as RP-type, may suffer from little variations. It is also not an appropriate method for data collection related to unavailable ICTs.

To conclude, Table 2-7 provides a summary of the discussed advantages and limitations of the presented data collection methods from a general perspective, and the use frequencies of the method in the literature. The overview of these methods aims to provide insights into data collection methods for the research presented in this thesis and future research. In short, each presented data collection method has its own advantages and limitations, and hence may be more suitable in one case while less in another. Selection of appropriate data collection method is better to be made according to particular study. The relevance of this overview to the data collection that is conducted in this thesis is detailed in following section 2.5.6.

Table 2-7: A summary of the advantages and limitations of the discussed data collection methods (from a general perspective)

Methods		Advantages	Limitations	Usage in the literature[52]
Interview (qualitative interview)		• in-depth information about people's behavior • adjustable form during interview • result presentation relatively easy for readers to understand and identify with	• insufficient to answer questions related to effect sizes of causalities, etc. • limited generality of results • complications with planning and conducting interviews and analyzing interview data	• C: sometimes • I: no study found
Activity-travel diary		• multi-dimensional contextual data that combine spatial, temporal and attribute information • high external validity	• expensive and time-consuming • data with insufficient variations for statistical analysis or parameter estimates • relatively limited controllability of recording process by participants • recording errors • not for study of ICTs unavailable to travelers in real life	• C: commonly • I: sometimes
Questionnaire survey[53]	revealed-preference	• cost-effective in design and implementation • high external validity	• less resourceful than activity-travel diary RP-data	• C: commonly • I: commonly

[52] In this column, a general indication of the usage frequency of the method is given. "C" indicates the frequencies of using the method for research on teleactivities (the "C" in ICT), and "I" indicates the frequencies of using the method for research on travel information (the "I" in ICT).

[53] The discussion presented above first discussed the advantages of questionnaire surveys in general compared to other discussed types of data collection methods, including a) the cost-effectiveness in design and implementation; and b) the ability to collect both RP data and SP data. But it is essential to distinguish the cases of using a questionnaire survey to collect RP data and SP data in the detailed discussion of the advantages and limitations of questionnaire survey. Hence, this table presents a summary of the advantages and limitations of using a questionnaire survey to collect RP- and SP-data, respectively.

	(RP)		• data with insufficient variations for statistical analysis or parameter estimates • not for study of ICTs unavailable to travelers in real life	
	stated-preference (SP)	• cost-effective in design and implementation • flexibility and effectiveness in designing questions (e.g., alternatives, attribute values) to ensure sufficient data variations • able to collect subjective data (e.g., attitudes, subjective norms) • able to collect data for study of ICTs unavailable to travelers in real life	• limited external validity • static nature (hence not for study of, e.g., sequential choice making, learning behavior)	
Simulator experiment		• (relatively) cost-effective • flexibility and effectiveness in creating and simulating • controllability of design and implementation • able to collect data for study of ICTs unavailable to travelers in real life • dynamic • higher external validity than SP-surveys	• realism of simulator	• C: sometimes • I: commonly
Field observation		• objective information with high external validity	• narrow scope of application • time-consuming and labor-demanding • limited generality of results • data with insufficient variations	• C: rarely • I: rarely

2.5.5 Choice of ICT and the effects on travel behavior: data analysis methods/models

This section provides an overview of the methods/models used for data analysis for study of choice of ICT and effects on travel behavior. Similar as how the overview of the data collection methods/models is presented, the overview of the data analysis methods/models starts with a brief introduction of these methods/models with references to examples of these studies, followed by a reflection on these methods/models in terms of the characteristics and applicability of these methods/models. The overview and the reflection are expected to contribute to the two-level aim addressed in the introduction – to derive knowledge with regard to data analysis methods/models for the research presented in this thesis and for future other research.

A range of data analysis methods/models for study of choice of ICT and effects on travel behavior can be found in the literature. While the used methods/models vary from case to case, they can be generally categorized into three types[54]: a) *discrete choice models (DCM)* such as binominal/multinomial models, Poisson models, b) *structural equation models (SEM)*, and c) *singular equation approaches (SEA)* such as descriptive statistics analysis, correlational analysis, factor analysis, ANOVA/MANOVA and regression analysis[55]. Table 2-8 provides several examples of the studies that have adopted these data analysis methods/models for research on teleactivities (C) and travel information (I), respectively.

[54] Note that although one may consider DCM also as a SEA, since the DCM function (e.g., utility function) in many studies is *singular*, this overview distinguishes DCM and SEA as different data analysis methods given their different characteristics of dependent variables and the ways of analysis methods.

[55] Note that geographic information system (GIS) is not included as a type of data analysis methods/models in this overview. It has been proposed by some authors as an alternative method to these above-presented traditional methods for study of people's activity-travel behavior in the ICT age (see, e.g. Kwan, 2000; Shaw and Yu, 2009; Yin et al., 2011; Yu, 2006). However, although GIS has been already commonly used to study people's activity-travel behavior in general (see, e.g. Kamruzzaman et al., 2011; Neutens et al., 2012b; Papinski and Scott, 2011), it has not yet been commonly used for studies related to ICT. No travel information-related study in the literature, to the best of the author's knowledge, has used GIS. While it has been proposed by these cited studies as a data analysis method for research on teleactivities, the data used in these studies for illustration of the approach are hypothetical, or ICT-irrelevant.

Table 2-8: Data analysis methods/models and examples of studies

Method/model	C/I	Examples of studies[56]	
Discrete Choice Models (DCM)	C	Mannering and Mokhtarian (1995)	a multinomial logit model of individuals' choice of telecommuting frequency
		Mokhtarian and Salomon (1996b)	a binary logit model of teleworking adoption
		Bagley and Mokhtarian (1997)	three discrete choice models of individual's preference for home- and center-based teleworking (two binary logit models and one nested logit model)
		de Graaff and Rietveld (2004)	a short-run and a long-run utility-based choice model of teleworking with consideration of money budget and time budget
		Yeraguntla and Bhat (2005)	a joint model of the choice of whether or not to do telework and the frequency of teleworking
		Páez and Scott (2007)	a discrete choice model with elements of social contacts included, in addition to conventional factors such as the attributes of alternatives and the characteristics of decision-makers, for a study of individual's choice of teleworking
		Vana et al. (2008)	a joint choice model to analyze work-hour arrangement, teleworking location and frequency of teleworking
		Haddad et al. (2009)	ordered probit regression analysis for analysis of determinants of the desire for and frequency of part-day and whole-day teleworking
		Zhang and Timmermans (2010)	a scobit model to examine the probability for activity participation along the axis of travel time for multitasking behavior of public transport users

[56] Note that studies that used more than one type of data analysis methods (e.g., used both SEA and DCM) are mapped according to the main data analysis method they used.

		Rotem-Mindali (2010)	a discrete choice model where consumer's choice of mode of purchase (in-store shopping or teleshopping) is a function of, *inter alia*, the consumer's information gathering behavior via different ways (e.g., Internet, phone, stores, media advertisements, friends)
	I	Jha et al. (1998)	nested logit model for traveler's departure time choice and route choice with information provision; traveler's perception updating of travel time in light of travel information is included
		Hato et al. (1999)	probit choice models for information acquisition, information reference, and route choice
		Mahmassani and Liu (1999)	a multinomial probit model for commuters' departure time and route switching decisions in response to travel information: the probit model framework is adopted to capture the serial correlation arising from repeated decisions made by the same respondent in a laboratory simulator experiment
		Khattak et al. (2008)	two binary logit models for study of effects of travel information – whether travelers change travel decision and whether travelers divert from their travel route are used as dependent variables, respectively
		Ben-Elia et al. (2013a)	a panel-based mixed logit model for travelers' route choice under the provision of travel information with different level of accuracy
		Chorus et al. (2013)	an integrative discrete-choice model of traveler response to pre-trip information sequential acquisition
Structural Equation Models (SEM)	C	Gould et al. (1998)	a structural equation model to analyze the data of an activity-travel diary survey about the relationships between work activities, maintenance activities, discretionary activities, and shopping activity time and shopping travel time
		Mokhtarian and Meenakshisundaram (1999)	a disaggregate longitudinal structural equations modeling of a panel data of communication activities and travels for the relationship between the number of instances of communication activities at time 1 and time 2, the elapsed time between measurements, and exogenous socio-demographic variables

		Senbil and Kitamura (2003)	a structural equation model for a survey study about the relationships between telecommunications and travels; the considered factors include durations of activities by type, number of visits made to pursue activities by type, travel times, etc.
		Farag et al. (2007)	a structural equation model for a study of the relationships between e-shopping and in-store shopping; the factors in the model include shopping attitudes, shopping behavior, Internet behavior, lifestyle/personality, land-use features, and socio-demographics;
		Wang and Law (2007)	a structural equation model for a survey study of the impacts of ICT usage (using email, Internet service, video-conferencing and videophone for either business or personal purposes) on time use for activities and travel behavior (travel time spent and number of trips)
		Choo and Mokhtarian (2007)	a structural equation model to analyze the national time series data spanning 1950-2000 in the US to explore the aggregate relationships between telecommunications (number of telephone calls) and travel (passenger vehicle-miles traveled)
		Cao et al. (2012)	a structural equation model, based on the data from a shopping survey, to investigate the interactions among online purchases, in-store shopping, and product search via internet; other considered factors include shopping accessibility, shopping responsibility, shopping attitudes, demographics, and Internet experience
	I	Hato et al. (1999)	a structural equation model to extract information processing capability and cognitive involvement as latent psychological factors that influence driver behavior with respect to the acquisition and use of travel information
		Farag and Lyons (2010)	a structural equation model to study the attitudes towards (non-)use of public transport information; the model is based on attitude theory and include factors of attitudes, past behavior and subjective norms
		Farag and Lyons (2012)	a structural equation model to study the use of pre-trip public transport information for business and leisure trips
Singular Equation Approaches (SEA)	C	Mokhtarian and Salomon (2001)	basic statistical analysis for a study of commuters' attitude towards travel and affinity for travel
		Hjorthol (2002)	correlation analysis and linear regression analysis for a study of relations between daily travel and use of home computer

		Gould and Golob (2002)	a logistics regression model for a study of how socio-demographics of households affect the households' choices of teleshopping
		Van Slyke et al. (2004)	factor analysis and multiple regression analysis to identify the factors that may influence the adoption of teleshopping
		Farag et al. (2006)	multivariate analysis, including regression analysis and logistics regression analysis, to study the relations between spatial factors (e.g., urban versus rural, accessibility to shops) and teleshopping
		Bonsall and Shires (2006)	linear regression models to analyze business-related meetings among European firms from an employer perspective
		Lyons et al. (2007)	basic statistical analysis for a study of travel time use for business, commuting and leisure travel
		Lu and Peeta (2009)	Poisson regression for the set of non-adopters and negative binomial model for the set of adopters of teleconferencing of the 116 firms where they conducted a survey
		Waerden et al. (2009)	a logistics regression model to study the multitasking behavior of rail passengers observed on a railroad line between two cities in the south of the Netherlands (Tilburg and Deurne)
		Alexander et al. (2010a)	a logistics regression model to identify the factors that most affect the propensity to have a flexible work schedule and a stochastic frontier model to estimate the earliest possible start time and the latest possible end time of work
		Denstadli et al. (2012)	a logistics regression model for analysis of the relations between face-to-face meetings and the access to telemeeting facilities and usage of telemeeting
		Denstadli et al. (2013)	a series of statistical analysis (e.g., cluster analysis, logistics regression, MANOVA) for analysis of the relations between face-to-face meetings and business travels and the access to telemeeting facilities and usage of telemeeting
		Julsrud et al. (2012)	basic statistical analysis (e.g., basic descriptive analysis and chi-square test) and logistics regression analysis to analyze the difference between room-based VC (video conferencing) and internet-based VC
		Gripsrud and Hjorthol	singular equation approaches (bivariate analysis and binary logistics regression analysis)

		(2012)	for data analysis of travel time use and ICT use during travel
	I	Zhang et al. (2008)	two fixed-effects models to analyze the relation between the use of real-time bus arrival information and two variables related to the number of bus trips; five ordered probit models for analysis of the relation between the use of real-time bus arrival information and five psychological indicators
		Wang and Khattak (2011)	Geographically Weighted Regression (GWR) – a logistics regression model estimated on a local basis (e.g., household), where frequency of travel information acquisition and the change of travel decision (e.g., departure time, model, route) because of information are used as dependent variables, respectively
		Zito et al. (2011)	an ordered probit demand model to determine the potential additional public transport demand attracted by the adoption of Advanced Traveler Information Systems
		Watkins et al. (2011)	a series of paired differences of means t-tests for testing the difference between the mean measured wait time and the mean perceived wait time in a study of the impact of mobile real-time information on the perceived and actual wait time of transit riders & a regression model for the prediction of perceived wait time based on the actual wait time, the use of real-time information, and other factors about the rider or the bus
		Joh et al. (2011)	CHAID analysis (a statistical method that uses a recursive process of splitting sample based on predictor variables into partitions according to Chi-square test) to analyze the roles of contextual variables in explaining information acquisition behavior

In sum, it can be concluded from the presented overview that the three types of methods/models have been widely used for data analysis for study of travelers' choices of ICT and the effect of ICT on travel behavior. However, it is important to note the different characteristics and applicability of these data analysis methods/models, which are discussed as follows from a general perspective (rather than a perspective of relevance of these methods to this research only).

Singular equation approaches (SEA)

Although the methods such as descriptive statistics analysis, correlational analysis, factor analysis, ANOVA/MANOVA and regression analysis are all categorized as SEA in this overview, it should be noted that there are substantial differences between all these methods (see, e.g. Hair et al., 2010; McClave et al., 1998 for more details of these methods). To name a few, the strength of descriptive statistical analysis is that it is relatively easy to conduct. Descriptive statistical analysis is also an important step to show a general overview of the data – for example, the characteristics of samples, or the pattern of the observed travel behavior or ICT-use of a sample in terms of frequency, market share, etc. However, descriptive studies convey rather little information of the data in addition to a general overview (Cao and Mokhtarian, 2005). Correlational analysis, which is also easy to conduct, is useful to explore the relationships between different variables. But considering that travel behavior and ICT-use often involve multiple explanatory variables, correlation analysis becomes insufficient. Hence, studies often use correlational analysis to prepare for more advanced data analysis. Factor analysis, which is useful to identify common underlying dimensions of variables (de Sá, 2003), however, cannot be used to study dependence of factors (e.g., the relationship between choice of teleworking and factors such as environment, commuting condition, etc.). ANOVA/MANOVA are useful to judge whether observed effects are due to non-metric variables (Dekking et al., 2005) and hence can be used to study and compare, for example, the choices of teleworking (e.g., frequencies, attitudes, etc.) between different groups in categories of ages, gender, occupation, etc. But they cannot be used as data analysis methods when the study relation involves metric variables such as commuting time. For the studies aiming to study relations between travel behavior or ICT use and other explanatory factors, regression analysis can be used. But it is only suitable when single relation (single dependent variable) is concerned and the dependent variable is not discrete.

Discrete choice models (DCM)

Because of the advantage in quantitatively modeling complex behavioral choices, discrete choice models have been, to a dominant extent, used in modeling travelers' behaviors and decision-making (including study related to ICT) (see, e.g. Chorus et al., 2013; McFadden, 2001). The well-developed multinomial logit model, nested logit model, probit model, and more flexible mixed logit model prove to be powerful to model travelers' behavioral choices (see, e.g. Ben-Akiva and Lerman, 1985; McFadden, 1974; Train, 2003). The flexibility of specifying different DCM (e.g., different error component structure, different included variables) according to particular study aim also enhances the effectiveness of using DCM for data analysis. Compared to SEA, especially descriptive statistics analysis, correlational analysis, DCM can produce more in-depth information (e.g., people's valuation towards variables). In addition, there are fewer complications with data collection and data requirement for DCM than for SEM or GIS (see discussion below). The most important requirement is that DCM deal with only categorical dependent variables – that is, discrete choice data, such as binary choice data (e.g., whether or not do teleshopping) or multiple categorical data (e.g., different types of information).

Structural equation models (SEM)

Unlike regression analysis or DCM, SEM allow for multiple simultaneous directions of causality, and distinguish direct effects and indirect effects as well as the total effects of explanatory variables on dependent variables. SEM is hence useful when study aims to explore the relationships between multiple dependent and independent variables (see, Golob, 2003 for a detailed literature review of SEM for travel behavior research). Another advantage of SEM is that they can take measurement errors into account, which results in less bias in the estimated coefficients and potentially larger portions of explained variance (Bollen, 1989). In addition, SEM can incorporate latent variables, which increases the exploratory power of using SEM for data analysis[57]. Hence, given the complexity of relations between activity participation, ICT-use and travels in reality, SEM are suggested as a useful method for analyzing multi-directional relationships between people's choices of teleactivities, travels, and other factors that might be of influence (Mokhtarian and Meenakshisundaram, 1999). However, the rather strict requirements with regard to model development, data, and model validity make the implementation of SEM rather difficult. For example, SEM is a *confirmatory* approach, rather than an *exploratory* approach (Bollen, 1989). That is, SEM can only be used when there is a well-developed theoretical model with hypothetical but theory-driven relationships. It is not appropriate to use SEM to explore a raw dataset without pre-defining a theoretical framework. Using SEM also has high requirements with regard to data sample size, data normality, etc. (Bryne, 2001). In addition, the validity of the results from SEM analysis is dependent on a range of criteria such as overall model fit, construct validity, etc. (see, e.g. Hair et al., 2010 for a detailed discussion of these issues). Hence, compared to other methods, SEM is relatively more difficult to implement.

To conclude, all these data analysis methods/models have their own advantages and limitations. Selection of appropriate methods/models for data analysis is also better to be made according to particular study aim. The relevance of this overview to the data analysis in the research described in this thesis is detailed in following section 2.5.6.

2.5.6 Summary and relevance to the research described in this thesis

This section 2.5 provides an overview of the models and methods that have been used in the literature for the study of travelers' choice of ICT and ICT's effects on travel behavior, including: a) the *theories/conceptual models* (section 2.5.2 and section 2.5.3), b) the *data collection methods* (section 2.5.4), and c) the *data analysis methods/models* (section 2.5.5). The aim of the overview is first to derive knowledge of research methods from previous studies and as such to provide inspiration for the research presented in this thesis, and secondly to provide references that are expected to be of relevance to future related research.

[57] Note that DCM can also incorporate latent variables, resulting in the so-called hybrid discrete-choice latent variable models (see, e.g. Ben-Akiva and Boccara, 1995; Ben-Akiva et al., 2002; Chorus, 2012d; Walker, 2001 for more details).

Summary

First, this section provides an overview of *the theories and the conceptual models* for study of travelers' choices of ICT and ICT's effects on travel behavior (see section 2.5.2 and section 2.5.3 for related references):

a) Theories/conceptual models for study of user acceptance and use of ICT:

Several key relevant theories can be found in the literature that is not related to travel behavior but is about user acceptance and use of ICT, including: *Theory of Reasoned Action (TRA); Theory of Planned Behavior (TPB); Thiandis' Theory of Interpersonal Behavior (TIB); Innovation Diffusion Theory (IDT); Motivation Theory (MT)*; and *Social Cognitive Theory (SCT)*. These theories have been often applied to study user acceptance and use of ICT. Some of these theories are also used as basis for development of other models of user acceptance and use of ICT, for example, *Technology Acceptance Model (TAM)* and its variants (TAM2, the model of determinants of perceived ease of use, and TAM3), and the *Unified Theory of Acceptance and Use of Technologies*. These models, although they are applied or developed for studies not related to travel behavior, could also be (potentially) applied for study of travelers' choices of ICT and ICT's effects on travel behavior.

b) Theories/conceptual models for study related to teleactivities and travels:

The earliest and probably the most prominent model framework for study of the relationships between teleactivities and travels is the *SCMN (substitution, complementarity, modification or neutrality)* framework. This model framework forms a fundamental basis for many studies of people's choices of teleactivities and their effects on travel behavior – a substantial number of following studies on teleactivities (e.g., teleworking, telemeeting, teleshopping, teleleisure) are based on this model framework. The transport community has later extended the interests into how ICT fundamentally changes the ways of people conducting activities rather than only the uni-dimensional SCMN relationship, resulting in models focusing on aspects such as *fragmentation* and *multitasking*.

c) Theories/conceptual models for study related to travel information and travels:

First, three main categories of models for study related to travel information are discussed in the overview, including: a) *utility-based models* that are developed based on expected utility theory or random utility theory; b) *(cumulative) prospect theory-based models* that are developed based on (cumulative) prospect theory; and c) *random regret minimization models* that are developed based on random regret minimization theory.

Secondly, this section provides an overview of the *data collection methods* that are used in empirical studies in the literature, and discusses the advantages and limitations of these methods from a general perspective (rather than a perspective of relevance of these methods to this research). The addressed data collection methods include: a) *interview*; b) *activity-travel diary*; c) *questionnaire survey*; d) *simulator experiment*; and e) *field observation*.

Finally, this section provides an overview of the *data analysis methods/models* used in the literature, and discusses the characteristics and applicability of these data analysis methods/models from a general perspective. The addressed data analysis methods/models include: a) *discrete choice models (DCM)*; b) *structural equation models (SEM)*; and c) *singular equation approaches (SEA)*.

Relevance to the research described in this thesis

This overview is expected to be of relevance to future studies of travelers' choice of ICT and ICT's effects on travel behavior in general. But in particular, this overview is of relevance to the research described in this thesis, as it provides knowledge for the following research of model development, data collection, and data analysis.

First, the literature overview of the theories and the conceptual models for the study of travelers' choice of ICT and ICT's effects on travel behavior provides knowledge for the model development in this research. As introduced in *Chapter 1* and will be detailed in the following chapters of this thesis, the research first develops a structure equation model for the interactions between travelers' use of travel information and telecommunication facilities and their relationships with other possible factors (*Chapter 3*). The research further develops a theoretical model that measures the effects of travel information and teleactivities on accessibility (*Chapter 4*). The model is developed within the utility paradigm and explicitly considers travelers' choices of travel information and teleactivities, including their potential interactions, in measuring the effects of ICT on accessibility. The accessibility model is further translated into a RUM-based discrete-choice behavioral model (*Chapter 5*) that models traveler's choices of ICT under conditions of risks and constraints for data analysis (see the third point below).

Secondly, the literature overview of the data collection methods for the study of travelers' choice of ICT and ICT's effects on travel behavior and the discussion of their advantages and limitations provide knowledge for the data collection that is conducted in this thesis. More specifically, in this research applies the data collection methods of a web-survey and a simulator experiment. As will be detailed later in *Chapter 3*, a web-survey is conducted to collect information about respondents' real-life behavior of using travel information and teleworking (RP-data) and their potential behavior under hypothetical circumstances (SP-data). The collected data is used to analyze the developed structure equation model for investigation of the interactions with regard to travelers' use of travel information and teleworking, and their relations with considered factors. A travel simulator experiment, which is presented in *Chapter 5* of this thesis, is conducted to collect subjects' choices of travel information, teleworking and routes in a set of hypothetical commuting environments. The collected data is used to estimate the discrete-choice behavioral model translated from the theoretical model for measuring ICT's effects on accessibility.

Finally, the overview of the data analysis methods/models that have been used in the literature for the study of travelers' choice of ICT and ICT's effects on travel behavior, including the discussion of their characteristics and applicability, provides knowledge for the data analysis in this thesis. In particular, a structural equation model (SEM) and a discrete choice model (DCM) are adopted as the main data analysis methods/models in this research. SEM is adopted to analyze the above-introduced conceptual model based on the web-survey data, given the multiple relationships included in the model (*Chapter 3*). In light of the advantages of DCM in data analysis and the adopted utility paradigm for the model development, DCM is adopted to estimate the RUM-based behavioral model based on the data collected via the travel simulator experiment (*Chapter 5*).

2.6 Summary of the chapter

This chapter provides an overview of the studies in the literature related to ICT and accessibility. The overview aims to form theoretical and knowledge basis for the research presented in this thesis as well as to derive knowledge that is expected to be of relevance to future related research.

Three literature overviews, including the relevance of these overviews to the research in this thesis, are presented:

1. A literature overview of the accessibility measures *(section 2.3)*

This overview aims to provide inputs from the area of accessibility measures, for the development of the accessibility model in this research (see C*hapter 4*) and for future related studies. The overview first presents an overview of four categories of physical accessibility measures that do not consider any ICT-related factors, including a) *proximity-based*, b) *space/time-based*, c) *activity-based*, and d) *utility-based* accessibility measures. The advantages and limitations of these measures are also discussed from a general perspective. Given the research interest, the overview further provides an overview of the models that have been developed in the literature to measure ICT's effects on accessibility.

Concluded from this overview, it seems that to date few models that are able to measure ICT's effects on accessibility yet exist, and no model explicitly takes into consideration both travel information and teleactivities. However, in light of the expected interaction with regard to travelers' use of travel information and teleactivities, there is a need for a generic, integrative and quantitative model that is able to measure the effects of different forms of ICT – information-related technologies for travel information and telecommunication-related technologies for teleactivities, including their potential interactions – on accessibility. This forms the primary aim of this research. In addition, a random utility theoretical framework is adopted in the accessibility model development in this thesis (*Chapter 4*), for two reasons: a) it is critical to take into consideration travel behavior in the development of a model for measuring ICT's effects on accessibility; and b) random utility-measures are advantageous in terms of theoretical soundness, behavioral realism, operationalization, and usability for economic evaluation.

2. A literature overview of ICT's (potential) effects on accessibility *(section 2.4)*

This overview aims to provide insights into ICT's (potential) effects on accessibility that are expected to be both of scientific relevance and practical implications. First, the overview provides an overview of the effects of teleactivities on travel behavior, including a) the effects of teleactivities on people's travels – whether or not teleactivities substitute, generate, or modify travels; b) the effects of ICT on the way people conduct activities, and in turn on people's travel behavior; and c) the effects of teleactivities on disutilities of physical travels and space-time constraints. Secondly, the overview presents an overview of the effects of travel information on travel behavior. Thirdly, this overview also discusses several important factors that are of relevance to ICT use and ICT's effects on travel behavior. Finally, the overview also presents an overview of ICT's effects on accessibility.

Concluded from the overview, it seems that in comparison to the ample studies into ICT's effects on travel behavior, studies into ICT's effects on accessibility are still sparse. The understanding of the effects of ICT on accessibility is still very limited because of the lack of analytical frameworks and methodologies. There is still a need for new models to measure the potential effects of ICT on accessibility. In particular, travel behavior, given its importance, should be taken into consideration. A model for accessibility measurement without considering travelers' choice and preference would overlook some important (potential) effects of ICT on accessibility, resulting in biased measurement of accessibility. However, given the complexity of the topic, it seems impossible to include all types of ICT's effects into one model, while still keeping the tractability of the developed model at an acceptable level. Given these arguments, a rather general perspective is adopted in the model development in this thesis (see *Chapters 4*, and *5*). The model for accessibility measurement developed in this thesis neither aims to include all types of ICT's effects, nor aims to particularly focus on one type of ICT's effects. Rather, the focus of the model for accessibility measurement in this thesis will be on the consideration of both teleactivities and travel information, including their potential interactions, and several key effects of ICT.

3. A literature overview of the models and methods for the study of ICT choice and ICT's effects on travel behavior *(section 2.5)*

This overview aims to derive knowledge of research methods from previous studies and as such to provide inspiration for this research, and also aims to provide references that are expected to be of relevance for future related research. First, this section provides an overview of *the theories and the conceptual models* used to study travelers' choices of ICT and the effects of ICT-use on travel behavior, including a) the theories/conceptual models to study *user acceptance and use of ICT*; b) the theories/conceptual models to study traveler's choices of *teleactivities* and the related effects on travels; and c) the theories/conceptual models to study the use of *travel information* and the related effects on travels. Secondly, the overview provides an overview of the *data collection methods* that have been used for data collection in empirical studies, and discusses the advantages and limitations of these methods from a general perspective. The addressed data collection methods include: a) *interview*; b) *activity-travel diary*; c) *questionnaire survey*; d) *simulator experiment*; and e) *field observation*. Thirdly, the section presents an overview of the *data analysis methods/models* that have been used in the literature for data analysis, and discusses the characteristics and applicability of these data analysis methods/models from a general perspective. The addressed data analysis methods/models include: a) *discrete choice models* (DCM); b) *structural equation models* (SEM); and c) *singular equation approaches* (SEA).

This overview provides knowledge for the conducted research presented in this thesis. First, the literature overview of the theories and the conceptual models for the study of travelers' choice of ICT and ICT's effects on travel behavior provides knowledge for the model development that are presented in the following chapters of this thesis, including a) a structural equation model for the interactions between travelers' use of travel information and telecommunication facilities and their relationships with other possible factors (*Chapter 3*); b) a utility-based accessibility model that measures the effects of travel information and teleactivities, including their potential interactions, on accessibility (*Chapter 4*); and c) a RUM-based discrete-choice behavioral model that is translated from the developed accessibility model for traveler's choices of ICT under conditions of risks and constraints for data analysis (*Chapter 5*). Secondly, the literature overview of the data collection methods for the study of travelers' choice of ICT and ICT's effects on travel behavior and the discussion of their advantages and limitations provide knowledge for the data collection in this thesis. More specifically, based on the insights derived from this part of the overview, the methods of web-survey and simulator experiment are adopted as the data collection methods in this research. Thirdly, the overview of the data analysis methods/models that have been used in the literature to study travelers' choices for ICT use and their effects on travel behavior, including the discussion of their characteristics and applicability, provides knowledge for the data analysis in this thesis. In particular, based on the discussion of each method's characteristics and applicability, this thesis adopts structural equation model (SEM) and discrete choice model (DCM) as the main data analysis methods/models.

3 Travelers' preferences for travel information and teleworking services: results from a web survey

Abstract

To understand the impact of ICTs on accessibility, one needs to understand the impact of ICTs on traveler behavior. A necessary condition for ICTs to influence traveler behavior is that travelers actually use ICTs that are available to them. Understanding travelers' decisions whether or not to use ICTs is therefore a crucial element of any model that aims to understand the impact of ICTs on accessibility. Given that travelers are generally not forced to use ICTs, their decisions to (not) use ICTs can be safely assumed to be the result of their underlying preferences; this Chapter empirically studies these preferences of travelers for ICTs.

As argued in *Chapter 1*, it appears more than reasonable to expect that travelers' preferences for travel information (the "I" in ICT) and teleworking and telecommunication facilities (the "C" in ICT) could be interrelated. However, whether or not the expectation is realistic is still not clear. As such, it is unclear to what extent these interactions should be considered in research concerning travelers' choices of travel information and telecommunication facilities. It hence becomes important to obtain empirical insights into the possibly interrelated nature of preferences for travel information and telecommunication functionalities of ICT, in advance of further behavioral model development.

In accordance with this aim, this chapter presents a preliminary empirical study based on a web-survey that was conducted among Dutch commuters; it uses structural equation modeling (SEM) analysis to answer the following research questions – a) whether (and to what extent) a

correlation exists between travelers' preferences for teleworking[58] and travel information as expected, and b) what are the relations between travelers' preferences for teleworking and travel information and other factors that could be of influence, such as travelers' perception of the reliability of commuting time, the availability and reliability of travel information, the availability of teleworking and the quality of teleworking environment and facilities. The analysis results confirm the expectation that travelers' preferences for travel information and teleworking are, to a certain extent, interrelated. A positive correlation is found between travelers' preferences for travel information and teleworking, implying that common underlying factors or personality traits exist that influence both travelers' preferences for travel information and teleworking. This also implies that travelers who prefer to use travel information seem to also prefer teleworking and vice versa (as both are driven by the common underlying factors or personality traits). In addition, the study shows significant effects, on preferences, of other factors, including perceived availability of teleworking, perceived quality of teleworking environment and facilities, perceived reliability of commuting time, and perceived availability of travel information. However, it appears that for the sample used in this study, there are no cross effects between i) on the one hand the perceived availability of teleworking and the perceived quality of the teleworking environment and facilities and on the other hand their preferences for travel information, and ii) on the one hand the perceived availability and reliability of travel information and on the other hand preferences for teleworking.

3.1 Introduction

As argued before in *Chapter 1*, understanding travelers' preferences for travel information (the "I" in ICT) and preferences for teleworking and telecommunication facilities (the "C" in ICT), and their possible interrelations, is important when analyzing ICT's effects on travel behavior and in turn on accessibility. From a traveler's behavioral perspective, it appears more than reasonable to expect that interactions may exist between the "I" and "C" in ICT. First, it is increasingly the case that travel information- and telecommunication-related facilities are integrated within the same device (e.g., a tablet that can be used to check travel information and can also be used to do teleworking). Secondly, it seems likely that traveler's use of travel information and telecommunication facilities may be (partly) driven by same set of factors, such as an unreliable commuting time due to peak-hour congestions. Commuters may choose to acquire travel information to assess the commuting time or choose to telework from home in order to avoid congestion in this case. Thirdly, the traveler's use of travel information and telecommunication facilities could be mutually influenced. For example, a commuter may choose to work from home after she has learnt from travel information that her commuting route from home to work is severely congested. Or consider an example that a commuter who likes working from home may more prefer acquiring travel information in the morning, given that she would like to make the decision whether or not to telework from home based on the received travel information.

Although these arguments seem to be rather reasonable, whether or not the expectation is realistic is not yet clear. As identified in the literature overview in *Chapter 2*, fruitful insights

[58] Note that the study is particularly confined to one type of teleactivities – teleworking, rather than other teleactivities (e.g., teleshopping), which is in line with the generic research interest of this PhD-research.

can be found in the literature with regard to the factors that may affect travelers' choices of travel information or teleactivities. However, no empirical study explicitly explores whether there are common factors and to which extent these factors may jointly affect travelers' choices of travel information and teleactivities. As such, it is unclear to what extent these interactions should be considered in research concerning travelers' choices of travel information and telecommunication facilities. It hence becomes important to obtain empirical insights into the possibly interrelated nature of preferences for travel information and telecommunication functionalities of ICT, in advance of any further behavioral model development.

Given this background, this chapter presents a preliminary empirical study that aims to provide inputs for the following model development in this thesis and also provide related insights that are expected to be of practical interests. In particular, this preliminary study aims to explore a) whether (and to what extent) any correlation exist between travelers' preferences for teleworking and travel information as expected, and b) what are the relations between travelers' preferences for teleworking and travel information and other factors that could be of influence, such as travelers' perception of the reliability of commuting time, the availability and reliability of travel information, the availability of teleworking and the quality of the teleworking environment and facilities.

The study is based on a web-survey among 261 Dutch commuters[59] about their daily life behavior in terms of using travel information and teleworking, and their potential behavior in terms of using travel information and teleworking under hypothetical conditions. In addition, the survey also collected data about commuters' actual use of ICT for teleworking, and commuters' perception of relevant characteristics of travel information, teleworking, commuting and work. The study subsequently develops a structural model and uses structural equation modeling (SEM) to analyze the collected data, in order to explore the possible interactions between the commuters' preferences for travel information and teleworking, and their relationships with the other considered factors.

The results are expected to be of relevance to the following research in this thesis and are also expected to be of practical relevance. First, as will be detailed in *Chapters 4* and *5*, insights into whether there are common underlying factors influencing travelers' choices of travel information and teleworking may serve as inputs for the model development phase. Secondly, these derived insights are also expected to be relevant to practitioners and policy makers in light of, on the one hand, the anticipated benefits of using ICT to improve accessibility, and, on the other hand, the increasing penetration of both travel information services and teleworking opportunities into people's daily lives.

The following scope of study is adopted: first, the study focuses on travel information in general, rather than specific types of travel information (e.g., a particular type of information concerning a train schedule). Secondly, the study is confined to teleworking, rather than other teleactivities such as teleshopping, which is in line with the generic research interest underlying this thesis. Thirdly, the study focuses on commuters' preferences for pre-trip travel

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[59] Note that the survey respondents include both commuters to work and people traveling for education purposes (students). Normally traveling for education purposes is not considered as commuting; however, the term "commuters" is used for both categories from now on in this chapter, for the ease of communication.

information and teleworking from home before their morning commute. It implies that the data collection does not include other situations where, for example, a traveler teleworks during travels (e.g., working on the train from home to work) or acquires en-route travel information when driving from home to work. In addition, the recruited sample for the data collection is confined to Dutch commuters who go to work or study by car regularly or at least have the experience ever of doing so. Furthermore, note that the main interest of the study is to test the hypothesized relations between the above mentioned factors towards travelers' preferences for teleworking and travel information. This study as such does not aim to (fully) explain travelers' preferences for teleworking and travel information and to exhaust all possibly relevant factors. Finally, the study does not aim to forecast market shares for ICTs given certain contextual conditions, but rather wishes to study determinants of preferences for these ICTs.

The remainder of this chapter is structured as follows. Section 3.2 presents the conceptual model for the study. Section 3.3 introduces the data collection – how the conceptual model is operationalized into data needs and related survey questions – and presents the survey respondents. The data analysis and results are presented in section 3.4. Section 3.5 concludes this chapter.

3.2 A conceptual model

This section introduces the conceptual model developed for the study[60]. Figure 3-1 presents the structured conceptual model, where the ellipses indicate the latent constructs (variables) and the arrows indicate the hypothesized effect (one-sided arrow) or correlation (two-sided arrow) between constructs. The latent constructs are also distinguished into latent exogenous constructs (independent variables) and latent endogenous constructs (dependent variables). Note that the conceptual model is developed from a more general perspective than the model that will subsequently be operationalized and used for data collection and data analysis. As will become clear later on, the variables that are included in this conceptual model are defined with a broader scope, while the operationalized model focuses on a range of specific variables that are defined with a narrower scope.

[60] One may argue that the model is not completely theory driven and as such is not appropriate for SEM analysis, since SEM is a *confirmatory* approach, rather than an *exploratory* approach – i.e., a SEM model should be developed with sufficient theoretical justification (Bollen, 1989; Hair et al., 2010). However, it is believed that the anticipated behavioral realism that is used to develop the model provides compelling rationale to support the relations to be investigated and sufficiently justifies the use of SEM analysis. In addition, to *explore* travelers' behavior with regard to teleworking and travel information in reality can be considered as to *confirm* whether or not the anticipated relations exist in reality. Also note that the *theory-driven* condition for developing SEM model is actually often deviated or violated in practice (Asparouhov and Muthén, 2009). Researchers often sequentially modify models in practice according to the results estimated from real data in order to achieve better model fit. The procedure then actually becomes exploratory rather than confirmatory.

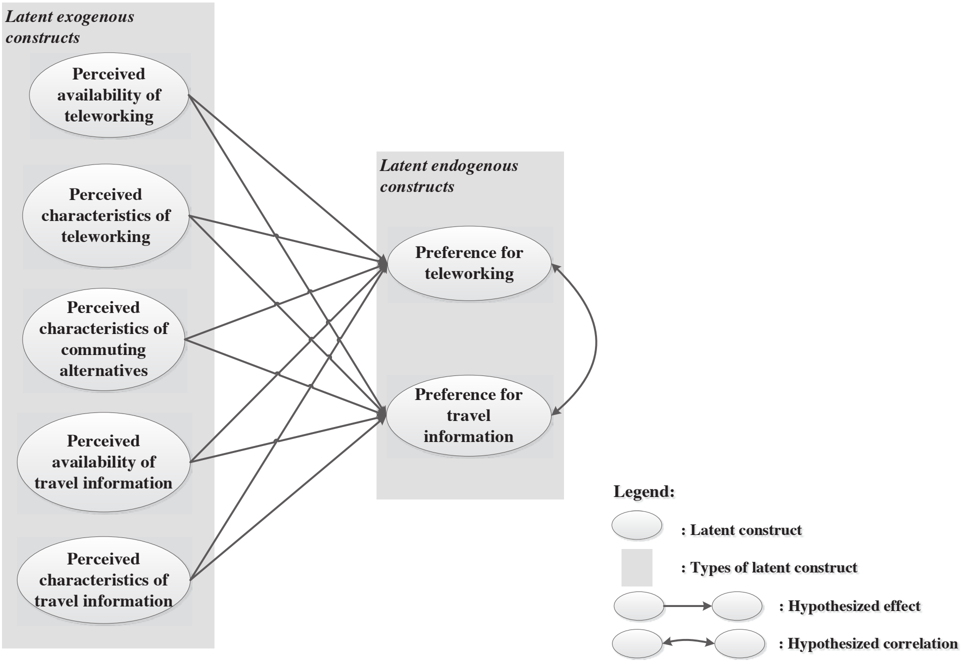

Figure 3-1: Conceptual model of travelers' preference for teleworking and travel information

Latent constructs (endogenous constructs and exogenous constructs) in the conceptual model

Two endogenous constructs are included in the conceptual model – "*preference for teleworking*", and "*preference for travel information*". The constructs can be used to represent a) travelers' *revealed preference*, such as inferred from traveler's actual use of travel information and actual use of teleworking, b) travelers' *stated preference*, such as inferred from travelers' stated extent to which they would like to acquire travel information or telework, or c) inferred from both revealed use and stated intentions for using teleworking/travel information. The reason to conceptualize the two dependent variables in such a general way is that it results in flexibility in operationalization – the dependent variables can be specified and operationalized according to the particular research needs and available data. It should be noted, however, that in the process of operationalization (i.e., the process of defining specific measurement variables and collecting data to measure constructs[61]), it is important to ensure the reliability of the measurement variables for the constructs – i.e., the degree of consistency between multiple measurements. Take an example of a traveler who does not often telework because of a lack of teleworking facilities but would like to telework more – this would result in a low score in terms of revealed preference but a high score in terms of stated preference. In this case, the reliability of the two measurements is low and it is hence not appropriate to use the combined revealed preference data and the stated preference data as a generic measurement of a "preference for teleworking". In particular, note that although conceptual consistency – whether measurements are conceptually related – can be used as a criterion, the reliability of the latent construct is more an empirical issue. To the extent that the data allows researchers to define the construct as a combination of revealed preference and stated preference (and if researchers can interpret the results), researchers can define it as such. This argument holds for the other constructs used in this study as well.

Five exogenous constructs are included in the conceptual model. In order to keep the study at a tractable level, rather than to include all the factors[62] that have been identified in the literature as being potentially relevant to travelers' preferences for travel information and teleworking respectively, the model focuses on these five constructs that are believed to be of the most importance and might jointly affect travelers' preferences for travel information and teleworking. The five constructs are: a) *"perceived availability of teleworking"* – travelers' perception of the extent to which it is possible for them to telework, which may be determined by aspects such as the type of the traveler's work (e.g., whether or not the work can be performed by teleworking) and the culture of the work environment (e.g., whether teleworking is acceptable and common at the traveler's employer); b) *"perceived characteristics of teleworking"* – travelers' perception of the characteristics of teleworking, such as the quality of the teleworking environment and teleworking facilities; c) *"perceived characteristics of commuting alternatives"* – travelers' perception of the characteristics of commuting alternatives, such as the reliability of commuting time; d) *"perceived availability of travel information"* – travelers' perception of the extent to which travel information is available to travelers, which may reflect, for example, whether someone finds it difficult to find travel information; and e) *"perceived characteristics of travel information"* – travelers' perception of the characteristics of travel information, such as the reliability of travel information. It should be noted that in operationalization and analysis based on real data, one or more of these constructs may turn out to be correlated (implying collinearity/multicollinearity between constructs). Beforehand, it can be already argued that the constructs "perceived availability of teleworking" and "perceived quality of teleworking" might be related, just as the constructs "perceived availability of travel information" and

[61] Note the distinction between *measurement variables* and *constructs*. Take the endogenous constructs in this conceptual model for example; the constructs here refer to "*preference for teleworking*", and "*preference for travel information*", while measurement variables refer to the specific variables that are asked via questions in surveys in order to measure the constructs. Examples of measurement variables for the dependent variables could be *how often a traveler acquires information/teleworking per week*, *the extent to which a traveler likes to acquire travel information/teleworking*, or *the extent to which travel information/teleworking is stated to be important to a traveler.*

[62] Literature has identified a range of factors that may play roles in determining travelers' preferences for travel information and for teleworking, respectively. See the literature overview in *Chapter 2* for the factors being potentially related to travel information and teleworking, respectively.

"perceived quality of travel information". This does not necessarily suggest that researchers must always define mutually-exclusive measurement variables for these constructs in order to exclude correlations[63]. However, care should be exercised in interpretation of the effects sizes of the paths between these constructs and the endogenous constructs. These potential correlations between constructs should be taken into consideration to avoid misinterpretation.

Relations between constructs

Based on the anticipation of travelers' behavior in reality, the following *relations* are hypothesized for later exploration between the exogenous and the endogenous constructs.

- *"Perceived availability of teleworking"* is expected to be related to travelers' *"preference for teleworking"*. However, it should be noted that the relevance may be different in terms of the way in which "preferences for teleworking" is operationalized. For example, a positive relation can be expected between these two constructs when revealed-preference data is used to measure the "preference for teleworking" – the more available teleworking is to a traveler, the more often he/she may telework. It may be not the case when the endogenous construct is operationalized as travelers' need for teleworking.

- *"Perceived availability of teleworking"* is also expected to play a role in affecting travelers' *"preference for travel information"*. Consider an example where the mere fact that a telework-option is available to a traveler makes that he/she is more inclined to acquire travel information in the morning (given that he/she knows that depending on the received information, he/she has the option to decide to work from home). In this example, a positive relation exists between the endogenous construct "perceived availability of teleworking" and the exogenous construct "preference for travel information" (which is operationalized as revealed-preference or stated-preference).

- *"Perceived characteristics of teleworking"* is expected to be related to travelers' *"preference for teleworking"*. In an example where the quality of teleworking environment and facilities is used as an exogenous variable and the endogenous construct is operationalized as revealed-preference or stated-preference (but probably not as *need for teleworking*), a positive relation can be anticipated. It is a behaviorally reasonable expectation that the better the quality of teleworking environment and facilities is, the more preferable teleworking option would be to travelers.

- *"Perceived characteristics of teleworking"* is expected also to be related to travelers' *"preference for travel information"*, following a similar argument as the one for the

[63] Note that by saying this here, the author does not mean to say that researchers should not pay attention to this issue in the first place. In general, multicollinearity in SEM does not reduce the reliability of the model as a whole, and multicollinearity is acceptable under certain conditions. In addition, correlations between constructs in behavioral models are often unavoidable in practice, since many of constructs are often naturally correlated. However, multicollinearity may pose problems in SEM under some conditions. Multicollinearity is difficult to manage after the fact. Hence, it is still advisable for researchers to manage the constructs to mitigate multicollinearity in the first place. In addition, as argued, after the fact happened, great care should be excised in result interpretation of the relations of the constructs that are involved with multicollinearity towards the other constructs. See, for example, Kaplan (1994), Marsh et al. (2004), and Grewal et al. (2004) for more elaborated discussions of multicollinearity in SEM.

possible relations between "perceived availability of teleworking" and "preference for travel information".

- Just as the expected relation between "perceived availability of teleworking" and "preference for teleworking", *"perceived availability of travel information"* is expected to be related to *"preference for travel information"* when, for example, revealed-preference data such as frequency of acquiring travel information is used to operationalize travelers' "preference for travel information".

- *"Perceived availability of travel information"* is expected to be related to travelers' *"preference for teleworking"*. For example, as argued before, a traveler may like teleworking because he/she has plenty of resourceful travel information available to him/her and thinks that he/she can acquire information in advance of making decision whether or not to telework in order to avoid morning congestion. Hence, a positive relation may exist in this case.

- *"Perceived characteristics of travel information"* is expected to be related to travelers' *"preference for travel information"*. As has been well established in the literature (see, e.g. Chorus et al., 2006b; Emmerink et al., 1995; Hato et al., 1999), characteristics of travel information such as the reliability of travel information affect travelers' preference for travel information.

- Following the line of argumentation for the other addressed relations, *"perceived characteristics of travel information"* is expected to be related to travelers' *"preference for teleworking"*.

- Finally, *"perceived characteristics of commuting alternatives"* is expected to be related to both travelers' *"preference for teleworking"* as well as their *"preference for travel information"*. The expectation is intuitive: to name one manifest determinant – reliability of commuting time – a traveler whose commuting time is rather unreliable due to morning peak-hour congestion is expected to be more likely to acquire travel information in order to assess his/her commuting time. The traveler may also be more inclined to telework in this example in order to avoid morning peak-hour congestion.

In addition to these expected relations between the exogenous and the endogenous constructs, a *correlation* is also expected between the two endogenous constructs *"preference for teleworking"* and *"preference for travel information"*. This is because other common underlying factors than the considered exogenous constructs may exist in reality, for example, travelers' intrinsic preferences or dislikes for ICT-based services in general. These factors that are not included in the model may affect travelers' preferences for both travel information and teleworking, resulting in correlation between the two constructs.

3.3 Data collection: the web-survey

This section first introduces how the constructs in the conceptual model are operationalized into data needs and related survey questions in this study (section 3.3.1), and secondly presents the characteristics of the survey respondents (section 3.3.2).

3.3.1 The web-survey

Without listing all the questions that were asked in the survey[64], Table 3-1 presents an overview of the questions that were used to collect the data of the measurement variables of relevance to the considered constructs. First, the two endogenous constructs "preference for teleworking" and "preference for travel information" are measured via both revealed-preference and stated-preference questions – that is, the survey asked respondents about their daily life behavior and their potential behavior under hypothetical situations to measure travelers' preferences for teleworking and travel information, respectively. Second, as mentioned before, in order to keep the length of the survey and the model complexity at a tractable level, the conceptual model is operationalized with a rather narrow scope. In particular, in operationalization, the latent construct "perceived characteristics of teleworking" in the conceptual model is confined to "perceived quality of teleworking environment and facilities". The latent construct "perceived characteristics of travel information" in the conceptual model is confined to "perceived reliability of travel information" in the operationalized model. The latent construct "perceived characteristics of commuting alternatives" in the conceptual model is confined to "perceived reliability of commuting time" in the operationalized model.

Table 3-1: Operationalization of the conceptual model into the questions in the web-survey

Latent constructs in operationalized model	Questions for constructs[65]	Measurements
Latent exogenous constructs		
Perceived availability of teleworking	Teleworking is common at my employer.	1= strongly disagree ~ 5=Strongly agree
	Teleworking is in general not an option for me, because of my work type.	1= strongly disagree ~ 5=Strongly agree
	Teleworking is not an option for me, because my employer does not allow it.	1= strongly disagree ~ 5=Strongly agree
	Teleworking is not an option for me, because of my situation at home	1= strongly disagree ~ 5=Strongly agree
	The beginning time of my work is flexible; I do not need to be at the office at a fixed time in the morning.[66]	1= strongly disagree ~ 5=Strongly agree

[64] The questions included in Table 3-1 are translated from the original questions in Dutch in the web-survey.

[65] Note that, as will become clear later in the data analysis, not all the variables collected via the questions are used in the final model.

Perceived quality of teleworking environment and facilities	I have a nice home working environment.	1= strongly disagree ~ 5=Strongly agree
	I have all the ICT equipment (e.g., computer, telephone or smartphone) that is needed for teleworking at home.	1= strongly disagree ~ 5=Strongly agree
	Via internet I can easily access all files and software that are needed for teleworking (e.g., via digital working environment).	1= strongly disagree ~ 5=Strongly agree
Perceived availability of travel information	There is sufficient travel information available for my commuting trip from home to work.	1= strongly disagree ~ 5=Strongly agree
	It costs me little effort to look for relevant travel information for my travel from home to work.	1= strongly disagree ~ 5=Strongly agree
Perceived reliability of travel information	Travel information is generally not reliable.	1= strongly disagree ~ 5=Strongly agree
Perceived reliability of commuting time	How long, on average, does it take you to travel from home to work (one-way) in the morning?	Open question (fill in the travel time in minutes)
	How long does it take you to travel from home to work (one-way) in the morning if there is no traffic jam or delays for public transport?	Open question (fill in the travel time in minutes)
	How often is the travel time from home to work (one-way) in the morning considerably longer than normal (the travel time you incur on a regular basis), for example because of unexpected public transport delays or traffic jams?	1= never ~ 5= (Almost) always
	The travel time of the travel mode and route that I usually take to travel from home to work is reliable.	1= strongly disagree ~ 5=Strongly agree
Latent endogenous constructs		
Preference for teleworking	How many days per month, on average, do you work, part of the day or the whole day, from home?	Open question (fill in the number of days)

[66] Note that one may think that, strictly speaking, this question does not directly measure the availability of teleworking. However, this question that asks respondents whether they need to be at the office at a fixed time in the morning also indirectly reflects whether it is possible for them to work from home, and can be also considered as a measurement of this construct as well, as perceived availability of teleworking reflects travelers' perception of the extent to which it is possible for them to telework in the study.

	Teleworking sometimes is nice.	1= strongly disagree ~ 5=Strongly agree
	Teleworking is a solution for me when there are problems with traffic or with public transport[67].	1= strongly disagree ~ 5=Strongly agree
	It would be nice to telework more than I do now, if my work type, work culture, my employer and my house situation would allow it.	1= strongly disagree ~ 5=Strongly agree
Preference for travel information	For the days you commute to work, how often do you acquire travel information before you depart from home?	1= never ~ 5= (Almost) always
	Travel information is essential for me to plan my schedules in working days.	1= strongly disagree ~ 5=Strongly agree
	I often base my departure time on travel information (e.g., traffic information).	1= strongly disagree ~ 5=Strongly agree

3.3.2 The survey respondents

The web-survey was designed via an online questionnaire tool. The survey took about 30 minutes to fill in, on average. 271 Dutch participants were recruited for the survey via placement of advertisements in newspapers and online platforms. Out of the total 271 participants who were recruited, 261 respondents provided valid answers to the survey[68]. Table 3-2 shows the socio-demographics of the 261 respondents. Car (as a driver) is the major commuting mode in the sample (67.4%), and the majority of the respondents are employees (74.3%). The majority of the respondents live in the Randstad-area (73.9%). In addition, a majority of the respondents hold higher education degrees (65.9%). In terms of age, gender and income (net household income per month), the sample has a fairly high level of heterogeneity. Several notes should be mentioned here before the analysis results are presented in the remainder of this chapter. First, the recruitment advertisement was placed as an open call. The population that the sample subjects represent is unknown. But it was made clear during the recruitment process, although no actual screening was implemented, that

[67] Note that, strictly speaking, this question implies causation between the condition (when there are problems with traffic or with public transport) and the adoption of teleworking as a solution. However, it turns out to be acceptable in the data analysis, as will be elaborated in the section 3.4 of this chapter later.

[68] Of the 10 respondents with invalid answers, eight did not complete the entire questionnaire largely, while two provided same answers to almost all the questions. The answers of these respondents are completely deleted from the data analysis.

participants were expected to have experience with commuting to work or study[69] by car, for the sake of better understanding and identifying with the survey. Second, the sample representativeness of the entire population is not particularly tested. In light of the study aim to test the relations rather than to forecast market shares, the sample representativeness of the entire population is believed to be not a primary concern. No substantial differences in terms of the relations to be investigated are a priori expected if different samples are used for study. Characteristics such as age, gender, and education may be of relevance to travelers' preferences for teleworking and travel information, as established in the literature (see *Chapter 2* of this thesis for related literature overview). However, the relevance of these characteristics to the interrelation between travelers' preferences for travel information and teleworking is considered beyond our research scope. In addition, sufficient sub-sample sizes should be ensured in order to investigate any differences between travelers in terms of different socio-demographic characteristics. Hence these characteristics are not included in the model. But including them may be an interesting aspect for future research.

Table 3-2: Characteristics of survey respondents (N=261)

Variable	Total (N=261)	
	Frequency	**Percentage**
Age		
15-24	43	16.5
25-34	106	40.6
35-44	67	25.7
45-54	31	11.9
55-64	12	4.6
65 or older	2	0.8
Total	261	100.0
Occupation		
Employee	194	74.3
Volunteer	9	3.4
Student	54	20.7
Others	4	1.5
Total	261	100.0
Gender		
Male	148	56.7
Female	113	43.3
Total	261	100.0

[69] Students were asked to consider their *education* as *work* in the survey.

Location of household		
Randstad	193	73.9
Non-Randstad	68	26.1
Total	261	100.0
Highest completed education[70]		
Elementary school	1	0.4
Secondary school	43	16.5
Vocational education	43	16.5
Higher education	172	65.9
Others	2	0.8
Total	261	100.0
Net household income per month (euro)[71]		
No income	8	3.1
<1000	36	13.8
1000-2000	46	17.6
2000-3000	49	18.8
3000-4000	36	13.8
4000-5000	23	8.8
>5000	13	5.0
I do not want to answer or I do not know	50	19.2
Total	261	100.0
Main commuting mode		
Car (as a driver)	176	67.4
Car (as a passenger)	6	2.3
Public Transport	48	18.4
Motorcycle/Moped	5	1.9
Bicycle	26	10.0
By foot	0	0.0
Others	0	0.0
Total	261	100.0

[70] The categories of education are classified based on Dutch education system, which were used to in the survey: a) Elementary school includes *Basisonderwijs*, b) Secondary school includes *VMBO, MAVO, HAVO, VWO/Gymnasium*, and *VAVO*, c) Vocational education includes *MBO*, and d) Higher education includes *HBO* and *WO*.

[71] The income only includes the income of the respondent and his/her partner, if any.

3.4 Data analysis and results: structural equation modeling analysis

This section presents the data analysis procedure (section 3.4.1) and the analysis results (section 3.4.2). Structural equation modeling (SEM)[72] is applied in the study for data analysis since the operationalized model includes not only effects but also correlations between constructs, and since latent constructs have been measured along multiple dimensions. SEM is particularly useful in testing this sort of complex and multiple dependence relationships and it takes measurement errors into account, which results in less bias in estimation and potentially larger portions of explained variances (Bollen, 1989; Jöreskog, 1993).

3.4.1 Analysis procedure

Before presenting the estimation procedure for the structural equation model, this paragraph first briefly discusses the data requirements for a successful SEM analysis and whether the sample data in this study meets these requirements. First of all, SEM is in some ways more sensitive to sample size than other multivariate approaches. Given the model complexity and the measurement model characteristics in this study, which are elaborated below, the survey sample size[73] (N=261) can be considered modest, but sufficient to serve the study aim (see, Hair et al., 2010 for a detailed discussion of the issue about sample size)[74]. Secondly, since the survey sample data deviates from multivariate normality, the estimation uses the MLM method (maximum likelihood estimation with robust standard errors and a Satorra-Bentler scaled test statistics), which is robust to non-normality and often used in SEM studies to deal with non-normality (Satorra and Bentler, 1988, 1994). Depending on the complexity of study model and the severity of non-normality problem, sample sizes of 200-500 are sufficient for good estimates with the MLM estimation method (Curran et al., 1996; Hu et al., 1992; Rosseel, 2012). Thirdly, like to other multivariate analysis, missing data could be a cause of problem to SEM analysis in estimation or interpretation, and the issue needs remedies if the missing data is substantial and nonrandom. Various procedures can be utilized to remedy missing data; however, each approach has its own advantages and disadvantages, and there is no golden rule in determining which approach is superior to others (see, Hair et al., 2010 for a

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[72] See *Chapter 2* for a literature overview of the studies that have used SEM for data analysis for study of travelers' choices of ICT and ICT's effects on travel behavior.

[73] A larger sample is believed to be able to reduce effects from deviation from normality and multicollinearity in model estimation and to produce more stable solutions that are more likely to be replicable (Hair et al., 2010). However, to obtain a larger sample is constrained in this study because of the available budget for the data collection.

[74] The suggested sample size according to Hair et al. is as follows:

- Minimum sample size-100: models containing five or fewer constructs, each with more than three items (observed variables) and with high item communalities (.6 or higher).
- Minimum sample size-150: models with seven constructs or less, modest communalities (.5), and no under-identified constructs.
- Minimum sample size-300: models with seven or fewer constructs, lower communalities (below .45), and/or multiple under-identified (fewer than three) constructs.
- Minimum sample size-500: models with large numbers of constructs, some with lower communalities, and/or having fewer than three measured items.

detailed comparison of these different approaches). In this study, pre-tests[75] show that missing data is not a serious issue in the collected data. For the missing data, model-based EM imputation approach was used to remedy the missing data.

In addition to these tests and remedies conducted to meet the data requirements for a successful SEM analysis, the entire estimation process also involves a series of preparation and other types of analysis before reaching the final model that is theoretically meaningful and statistically well fitting (to be presented later in section 3.4.2). The estimation procedure is described as follows.

First, the basic statistics of all the variables are calculated, and the bivariate correlations between the variables are calculated in order to obtain a whole picture of all the variables and relations between these variables.

Second, an explorative factor analysis (EFA) is conducted in the statistical software package SPSS to explore the patterns of the measurement variables – whether the a-priori expectation that is used to define the measurement variables for the latent constructs in the operationalized model is consistent with the patterns concluded from the analysis based on the empirical data[76]. EFA is a technique particularly suitable for examining the underlying patterns or relationships for a large number of variables and it can be utilized to determine whether large number of variables can be summarized in a smaller set of factors or components (Hair et al., 2010). The explorative factor analysis shows that a majority of the variables demonstrate underlying patterns that are in line with the a-priori conceptualization, except for the variable *"frequency of teleworking – how many days per month, on average, do you telework part of the day or the whole day at home"* and the variable *"Teleworking is an option for me, because of my house situation"*, which are loaded on factors different from what was expected. These two variables are hence considered to be excluded in the SEM analysis later.

A confirmatory factor analysis (CFA) is conducted next to estimate the measurement model in software Mplus 6 (Muthén and Muthén, 1998-2012) – that is, to estimate the loadings of all the measured variables for the latent constructs in the operationalized model, and to estimate the mutual correlations, rather than the hypothesized paths, between all the constructs. Achieving a statistically well-fitting measurement model is an essential step to take before conducting a SEM analysis (Bryne, 2001; Jöreskog and Sorbom, 1996). Several tests are

[75] The pre-test involves the following processes: a) determine the type of missing data – whether or not the missing data is ignorable; b) determine the extent of missing data – whether the extent of missing data is low enough to not affect the results; c) diagnose the randomness of the missing data process – are the missing data missing at random or missing completely at random; and d) select the imputation method for missing data. See Hair et al. (2010) for more details of these processes.

[76] As SEM should always be attempted with a strong theoretical basis for model specification, it does not require explorative factor analysis to explore the underlying patterns of measurement variables in advance. Rather, confirmatory factor analysis, which will be introduced later, should be used to estimate the measurement model (Bryne, 2001). However, as introduced, the conceptual model in this study is developed based on the anticipation of travelers' behavior and preference in realism, rather than some underlying theory or established insights in the literature. Hence, the explorative factor analysis is conducted to test statistically whether the underlying patterns of the measurement variables are in line with the a-priori expectation in order to form a reasonable measurement model for SEM analysis.

conducted based on different specifications. The variables with factor loading on construct smaller than 0.5 or insignificant are deleted (Hair et al., 2010) and the model is re-estimated. The results of the measurement model with best model fit are used for the following SEM analysis. The details are elaborated in section 3.4.2.

After obtaining the measurement model with best model fit, the structural model is constructed to include the hypothesized paths between the latent constructs into model estimation. The model test and parameter estimates are based on the covariance matrix and estimated using MLM estimation method in Mplus 6. After estimation of the full model wherein all hypothesized paths are included, insignificant[77] paths (but not insignificant correlations), which can be considered irrelevant to the model, are deleted and the model is re-estimated. In addition, modification indices (MI) are used to assess whether the paths that were not theoretically expected should be included into the model. Modification indices indicate the decrease in the chi-square value (i.e., model fit improvement) if an extra path is added for estimation (Bryne, 2001). The estimation results of different model specifications are compared, and the final model is chosen based on the criteria of model fit to the data and theoretical plausibility. Some test results are reported in the appendix of this chapter, and the final model is presented in section 3.4.2.

3.4.2 Analysis results

Figure 3-2 presents the estimation results of the final model[78].

[77] Significance level α=0.05 is adopted in this study.

[78] Abbreviated indicators correspond to (answers to) survey questions; see Table 3-4 for details. Values between brackets are p-values; values in the middle of arrows are factor loadings.

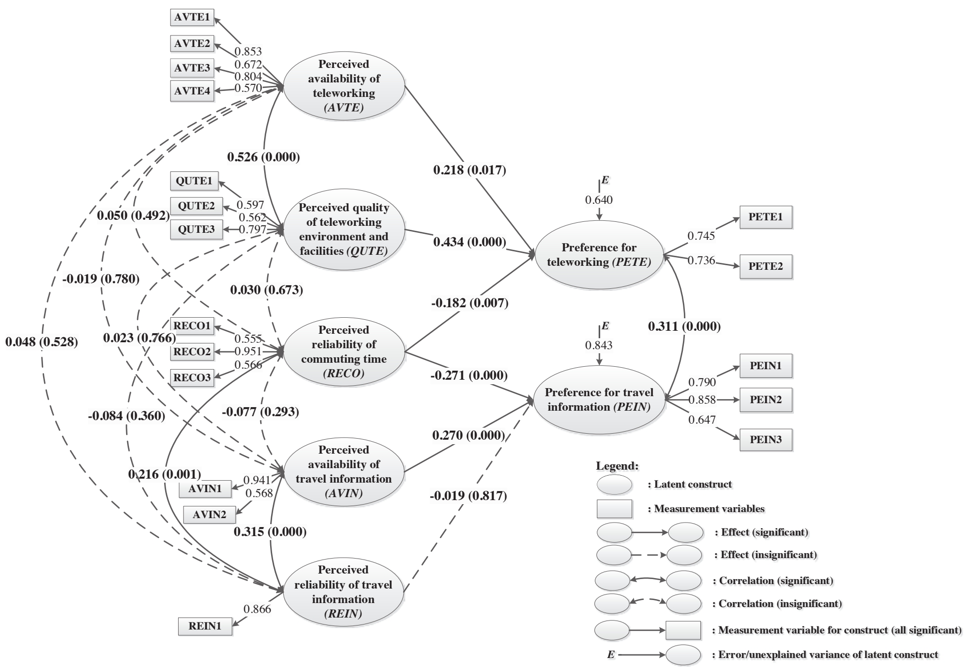

Figure 3-2: The estimated final structural model of travelers' preferences for teleworking and travel information[79]

This section first discusses the model fit of the final model. It should be noted that there are many indicators to evaluate SEM fit, and SEM cannot be assessed only based on one single model fit indicator. The rule of thumb is to use multiple indicators, preferably a) chi-square value and degree of freedom (d.f.), b) one absolute fit index (e.g., RMSEA or SRMR), c) one incremental fit index (e.g. CFI), d) one goodness-of-fit index (e.g., CFI), and e) badness-of-fit index (e.g. RMSEA, SRMR) (Hair et al., 2010). Table 3-3 presents the key indicators for the model fit. The indices show that the final model has a good model fit. First, the SEM model estimation meets the order and rank conditions for successful identification of a SEM model – that is, the degree of freedom (d.f.) is larger than 0 and each individual parameter is uniquely algebraically defined (i.e., no cross-loadings). Secondly, although the chi-square value is statistically significant (chi-square=146.064. p=0.0466), which means that the observed covariance matrix does not match the estimated covariance within sampling variance, the p-value is rather close to the significance level 0.05. Also note that exclusive reliance on this

[79] For the sake of readability, labels are used to represent the measurement variables, and the error terms (i.e., unexplained variances) of the measurement variables are not illustrated in the figure. The meanings of the labels are given in Table 3-4 later. The error terms of the measurement variables can be computed as: $\text{error} = 1 - (\text{standardized factor loading})^2$. The standardized path estimates are shown. The values in the parentheses represent the t-values of the estimates. The standardized factor loadings of the measurement variables for the constructs are shown and they are all significant (p<0.05).

index to judge model fit is unacceptable, since this index is very sensitive to sample size (Bryne, 2001; Hox and Bechger, 1998). Therefore, it is recommended to review other fit indices. The value of the comparative fit index (CFI) and the value of the Tucker Lewis Index (TLI), as the most widely used indices, are well above the recommended lower limit of 0.90, implying a good model fit (Hu and Bentler, 1999). The value of the root mean square error of approximation (RMSEA), which is a badness-of-fit index, has a value below the recommended upper limit of 0.05, again suggesting a good model fit (Browne and Cudeck, 1993). The 90% confidence interval of RMSEA within 0.004~0.045, and the high probability (0.990) of RMSEA smaller than 0.05 also suggest a good model fit (Jöreskog and Sorbom, 1996). The value of the standardized root mean residual (SRMR), which has a value below the recommended upper limit of 0.08, again suggests a good model fit (Hu and Bentler, 1999). In sum, it can be concluded that the final model has a good model fit.

Table 3-3: Model fit of the final model

N	Chi-square	d.f.	P-value	CFI	TLI	RMSEA	SRMR
261	146.064	119	0.0466	0.978	0.971	0.030*	0.046

**: Estimate: 0.030; 90 Percent C.I.: 0.004 ~0.045; Probability RMSEA ≤ 0.05: 0.990*

The measurement variables for the constructs in the final model are presented in Table 3-4. The construct validity (i.e., the extent to which measurement variables actually reflect the latent constructs that the measurement variables are designed for) in the final model is discussed as follows[80]. First, the measurement variables that are concluded with standardized factor loadings on the latent constructs smaller than 0.5 in the model test are excluded in the final model. Standardized factor loading represents how much variation in a measurement variable is explained by latent construct. A good rule of thumb is that standardized loading estimates should be 0.5 or higher, and ideally 0.7 or higher. Secondly, construct reliability[81] (CR) values are calculated to check the reliability of the constructs (i.e., the degree of the consistency between multiple measurement variables of a construct). A value of CR of 0.7 or higher suggests good reliability. Reliability between 0.6 and 0.7 may be acceptable, provided that the reliabilities of other constructs in a model are good. The calculated values of CR in the final model indicate that internal consistency exists, meaning that the measurement variables for each latent construct consistently represent the construct. Thirdly, the values of average variance extracted (AVE) of all the constructs, except the construct *"quality of teleworking environment and facilities"*, are higher than the recommended lower limit of 50%. These general positive results suggest the convergent validity of the model (i.e., less error remains in the item than the variance explained by the latent construct imposed on the measure). Fourthly, the values of the square of the correlations between any two constructs

[80] The handbook *Multivariate data analysis: a global perspective* of Hair et al. (2010) is used as reference for the following discussion. Interested readers may refer to the book for more details (e.g., the equations to calculate values; the rule of thumb for judging the construct validity).

[81] Note that this study uses construct reliability (CR) instead of Cronbach's alpha to evaluate the construct validity. Although Cronbach's alpha is still often adopted in studies, some literature argues that it is not advisable to use Cronbach's alpha to check construct reliability in SEM, since it may understate reliability (see, e.g. Raykov, 1998; Zimmerman et al., 1993).

(Table 3-5) are smaller than the AVE values of these two constructs. This implies that each latent construct explains more of the variances in its measurement variables than that shared with the other constructs. It provides good evidence of discriminant validity (i.e., the extent to which a construct is truly distinct from other constructs). Overall, it can be concluded that the final model has good construct validity. However, two additional notes with regard to the constructs and the measurement variables in the final model should be mentioned. First, this study uses one single measurement variable for the construct *"perceived reliability of travel information"* (single-indicator construct). It is acceptable to use one measurement variable for a construct when the construct concept can be adequately represented with a single item, but a minimum of three variables per construct is preferable in order to provide adequate identification for the construct (Hair et al., 2010). In this study, although the construct *"perceived reliability of travel information"* is believed to be adequately represented with the measurement variable "Travel information is in most cases reliable.", this practice results in an unexpected result, which will be elaborated later. Second, as argued before, the way in which constructs are operationalized and as such how they can be conceptually interpreted is important in interpretation of inter-construct relations. Hence, although the measurement variables statistically show sufficient construct validity in this study, it is still important to take into account the conceptual interpretation of the constructs in terms of the measurement variables when later interpreting the relations concluded in the final model. For example, as can be seen from the measurement variables for the two endogenous constructs, revealed-preference (e.g., the actual frequency of usage) and/or stated-preference (e.g., the likes or dislikes stated by respondents) variables are used. Hence, they are not appropriate to be interpreted as travelers' *needs* for teleworking/travel information.

Table 3-4: Overview of the measurement variables for the constructs in the final model

Latent construct and label	AVE	CR	Measurement variables	Label	Range	Standardized factor loading[82]
Latent exogenous constructs						
Perceived availability of teleworking *(AVTE)*	53.76%	0.82	Teleworking is common at my employer.	AVTE1	1= strongly disagree ~ 5=Strongly agree	0.853
			Teleworking is in general an option for me, because of my work type.[83]	AVTE2	1= strongly disagree ~ 5=Strongly agree	0.672
			Teleworking is an option for me,	AVTE3	1= strongly disagree ~	0.804

[82] standardized factor loading using the variances of the latent variables as well as the variances of the background and outcome variables for standardization (Muthén and Muthén, 1998-2012)

[83] This variable is reversed from the original data to make the range consistent with the other measurement variables for the same construct.

			because my employer does allow it.[84]		5=Strongly agree	
			The beginning time of my work is flexible; I do not need to be at the office at a fixed time in the morning.	AVTE4	1= strongly disagree ~ 5=Strongly agree	0.570
Perceived quality of teleworking environment and facilities *(QUTE)*	43.58%	0.69	I have a nice home working environment.	QUTE1	1= strongly disagree ~ 5=Strongly agree	0.597
			I have all the ICT equipment (e.g., computer, telephone or smartphone) that is needed for teleworking at home.	QUTE2	1= strongly disagree ~ 5=Strongly agree	0.562
			Via internet I can easily access all files and software that are needed for teleworking (e.g., via digital working environment).	QUTE3	1= strongly disagree ~ 5=Strongly agree	0.797
Perceived reliability of commuting time *(RECO)*	51.09%	0.75	Similarity between the average commuting time and the shortest possible commuting time[85]	RECO1	1= significantly different ~ 5=exactly same	0.555

[84] This variable is reversed from the original data to make the range consistent with the other measurement variables for the same construct.

[85] This variable is computed from two variables that are included in the questionnaire – *"the average commuting time (How long, on average, does it take you to travel from home to work (one-way) in the morning?)"* and *"the shortest commuting time (How long does it take you to travel from home to work (one-way) in the morning if there is no traffic jam or delays for public transport?)"*. This variable reflects the extent to which traffic jams or delays for public transport, if any, cause the increase of commuting time for travelers.

			How often is the travel time from home to work (one-way) in the morning considerably longer than normal (the travel time you incur on a regular basis), for example because of unexpected public transport delays or traffic jams?[86]	RECO2	1=(Almost) always ~ 5= never	0.951
			The travel time of the travel mode and route that I usually take to travel from home to work is reliable.	RECO3	1= strongly disagree ~ 5=Strongly agree	0.566
Perceived availability of travel information *(AVIN)*	60.41%	0.74	There is sufficient travel information available for my commuting trip from home to work.	AVIN1	1= strongly disagree ~ 5=Strongly agree	0.941
			It costs me little effort to look for relevant travel information for my travel from home to work.	AVIN2	1= strongly disagree ~ 5=Strongly agree	0.568
Perceived Reliability of travel information[87]	75.00%	0.75	Travel information is generally reliable.[88]	REIN1	1= strongly disagree ~ 5=Strongly agree	0.866

[86] This variable is reversed from the original data to make the range consistent with the other measurement variables for the same construct.

[87] For this single-indicator construct *REIN*, the residual variance of the measurement variable *REIN1* is fixed as 0.25 [residual variance = (1 – the mean of the CR of all the other constructs) * sample variances of the variable] in the model estimation as a common practice for single-indicator constructs (Muthén and Muthén, 1998-2012).

(REIN)						
Latent endogenous constructs						
Preference for teleworking *(PETE)*	54.84%	0.71	Teleworking sometimes is nice.	PETE1	1= strongly disagree ~ 5=Strongly agree	0.745
			Teleworking is a solution for me when there are problems with traffic or with public transport[89].	PETE2	1= strongly disagree ~ 5=Strongly agree	0.736
Preference for travel information *(PEIN)*	59.30%	0.81	For the days you commute to work, how often do you acquire travel information before you depart from home?	PEIN1	1=never ~ 5=almost always	0.790
			Travel information is essential for me to plan my schedules in working days.	PEIN2	1= strongly disagree ~ 5=Strongly agree	0.858
			I often base my departure time on travel information (e.g., traffic information).	PEIN3	1= strongly disagree ~ 5=Strongly agree	0.647

[88] This variable is reversed from the original data to make the range consistent with the other measurement variables for the same construct.

[89] As mentioned, strictly speaking, this variable implies causation. However, it is still included in the final model based on the following reasons: a) the factor loading of this variable on the latent construct is rather high (>0.7); b) the resulted AVE and CR of the latent construct suggest the construct reliability; and c) deleting this variable would result in a single indictor for the construct, which is not favorable in SEM analysis.

Table 3-5: Estimated correlation matrix for the latent constructs*

Constructs	AVTE	QUTE	RECO	AVIN	REIN	PETE	PEIN
AVTE	1	27.67%	0.25%	0.04%	0.23%	19.10%	0.04%
QUTE	0.526	1	0.09%	0.05%	0.71%	29.48%	0.00%
RECO	0.05	0.03	1	0.59%	4.67%	2.50%	8.70%
AVIN	-0.019	0.023	-0.077	1	9.92%	0.04%	8.12%
REIN	0.048	-0.084	0.216	0.315	1	0.42%	0.01%
PETE	0.437	0.543	-0.158	0.02	-0.065	1	7.73%
PEIN	-0.019	0	-0.295	0.285	0.008	0.278	1

(: Below the diagonal: estimates of correlations; Upper the diagonal: square of correlations)*

In light of the evidence of good model fit and construct validity, the remainder of the section discusses the relations between the constructs (Figure 3-2). The estimation results show that some hypothesized relations are significant, while insignificant relations are also found between some constructs. These insignificant relations are deleted in the model estimation (and hence not illustrated in the final model in Figure 3-2), except for the path estimate between the two constructs *"perceived reliability of travel information"* and *"preference for travel information"* (the reasons for including this path in the final model will be elaborated later). Significant correlation, as expected, is found between the two endogenous constructs *"preference for teleworking"* and *"preference for travel information"*. The correlations between the exogenous constructs are all included in the model estimation and illustrated in the final model in Figure 3-2. Note, again, that the discussion below should be interpreted while taking into account what measurement variables are used for constructs.

First, the perceived extent to which travelers are allowed to telework (*"perceived availability of teleworking"*) is found to be positively related to travelers' *"preference for teleworking"* (estimate=0.218, p=0.017). The *"perceived quality of teleworking environment and facilities"* also has a significant positive relation with travelers' *"preference for teleworking"* (estimate=0.434, p=0.000), suggesting that the better the quality of teleworking environment and facilities is, the more travelers prefer teleworking. However, note that a significant correlation is found between the two exogenous constructs *"perceived availability of teleworking"* and *"perceived quality of teleworking environment and facilities"* (estimate=0.526, p=0.000). It is not surprising that these two constructs turn out to be empirically correlated. However, as argued before, this correlation should be taken into consideration when interpreting the paths – the signs and, in particular, the effects sizes of the paths – between these two exogenous constructs and the endogenous construct *"preference* *for teleworking"*. According to the rules[90] of Grewal et al. (2004) for assessing the extent to which the different level of multicollinearity poses problem in theory testing (in terms of ascertaining the direction (positive or negative) and the significance of the estimates), the effects of the collinearity between the two exogenous constructs on the results in this study can be considered negligible, given that a) these two constructs satisfy discriminant validity (argued before), b) the construct reliabilities are sufficiently high (argued before), and c) the R^2 value of the endogenous construct is greater than 0.25 (elaborated later). Hence, despite the correlation between these two exogenous constructs, the estimates and the inference of the relations according to the signs and the significance of the estimates can be considered as valid. It can be concluded that both *"perceived availability of teleworking"* and *"perceived quality of teleworking environment and facilities"* are positively associated with travelers' *"preference for teleworking"*. Note, however, that given the correlation between the two constructs, it is not appropriate to compare the estimates of the two relations, and infer which effect is greater than the other.

Secondly, the estimation results show a significant negative relation of the *"perceived reliability of commuting time"* on travelers' *"preference for teleworking"* (estimate=-0.182, p=0.007). It appears that the less reliable travelers' commuting time is, the more travelers prefer to telework. As expected, a similar relation is also found of the construct *"perceived reliability of commuting time"* on travelers' *"preference for travel information"* (estimate=-0.271, p=0.000), suggesting that the less reliable travelers' commuting time is, the more travelers like to acquire travel information. But it is noteworthy that the absolute effect size of *"perceived reliability of commuting time"* on travelers' *"preference travel information"* (-0.271) turns out to be greater than that on travelers' *"preference for teleworking"* (-0.182). This result implies that the reliability of commuting time perceived by travelers appears to have a larger impact on their preference for travel information than on their preference for teleworking, ceteris paribus.

Thirdly, a significant positive relation is found of the construct *"perceived availability of travel information"* on travelers' *"preference for travel information"* (estimate=0.270, p=0.000). It reflects that the more available travel information is (e.g., the travel information is provided and the easier it is for travelers to find travel information), the more travelers acquire travel information. However, not in line with expectations, the hypothesized relation of *"perceived reliability of travel information"* on travelers' *"preference for travel information"* is found to be insignificant (estimate=-0.019, p=0.817). This suggests that the reliability of travel information does not affect the sample respondents' preference for travel

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[90] The rules for judging the level of problem [Type II error (i.e., failure to detect a significant effect)] under different extent of multicollinearity are: a) when multicollinearity is extreme (around 0.95), Type II error rates are generally unacceptably high (over 80%); b) when multicollinearity is between 0.6 and 0.8, Type II error rates can be substantial (greater than 50% and frequently above 80%) when composite reliability is weak (0.7 or lower), R^2 is low (0.25), and sample size is relatively small (ratio of 3:1). However, as reliability improves (0.80 or higher), R^2 reaches 0.75, and sample becomes relatively large (ratio of 6:1), Type II error rates become negligible (below 5%); c) when multicollinearity is between 0.4 and 0.5, Type II error rates tend to be quite small, except when reliability is weak (0.7 or below), R^2 is low (0.25), and sample size is small (ratio of 3:1), in which case error rates can still be high (greater than 50%); and d) when discriminative validity is satisfied, an inference error is unlikely. However, when the criterion is not satisfied, it does not necessarily mean that the chance of committing a Type II error is high.

information, while literature has well established that the reliability of travel information would affect travelers' choice of travel information (see section 2.4.2.2 in *Chapter 2* for related literature). It may indeed be the case among the sample respondents in this study that whether, and the extent to which, travel information is perceived reliable does not affect their actual acquisition and usage of travel information and their perception of the importance of travel information for them to plan their daily schedules in daily life (see Table 3-4 for these measurement variables for the construct *"preference for travel information"*). However, the inference should be treated with caution. It is yet uncertain whether it is indeed general in reality or it is caused by other factors specific to this sample, or by the practice of using one single measurement variable for the construct *"perceived reliability of travel information"* in this study. Based on the available collected data in this study, it seems impossible to identify the exact reason. The additional bivariate correlation test shows that the variable *"reliability of travel information"* [91] does not have significant bivariate correlations with the three measurement variables for the construct *"preference for travel information"*. The variable *"reliability of travel information"* also shows sufficient variation (mean=3.26; standard deviation=0.85), excluding the possibility of insufficient data variation resulting in the insignificant correlations. The practice of using a single-indicator construct may have effects on the estimates (both the relation with the endogenous construct and the correlations with other exogenous constructs). But whether or not this is the reason can only be identified if the current estimates are compared to the results from a model where extra measurement variables are added for the construct *"perceived reliability of travel information"*. Further study[92] is needed before any sound conclusion is made. However, it should be noted that this result does not affect the other results because the estimation of the model with this path deleted also generates the same conclusions as what has been concluded from the estimation results of the model with this path included[93]. Also note that, as introduced before, the main research interest of this study is to explore the interrelations between travelers' preference for travel information and teleworking, rather than to explore the effect of the reliability of travel information on travelers' preference for travel information. The latter has been well studied in the literature. Given these arguments, this result should be considered as a particular outcome rather than a general and significant conclusion that affects the validity of the entire model.

In addition, as expected, a significant correlation is found between the two endogenous constructs *"preference for teleworking"* and *"preference for travel information"* (estimate=0.311, p=0.000). This suggests that other than the exogenous constructs included in the final model, other common underlying factors or personal traits are relevant to travelers' preferences for both teleworking and travel information. It also implies that travelers who prefer to use travel information seem to also prefer teleworking and vice versa (as both are driven by the common underlying factors or personality traits).

Furthermore, the R^2 values (explained variance) for the two endogenous constructs are not high, especially the value of the construct *"preference for travel information"* (Table 3-6).

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[91] measured via the statement "Travel information is generally reliable." on a 1~5 Likert scale in the survey

[92] Given the limited budget and time, this research does not further investigate this issue.

[93] To the author's belief, this above-addressed result is a noteworthy issue. As a result, this chapter presents the final model with this path included. However, the estimation results of the model with this path deleted are also reported in the appendix of this chapter.

The R^2 values indicate the amount of variations in endogenous constructs accounted for by the related exogenous constructs (Kline, 2010). The results imply that the exogenous constructs included in the model explain only a small amount of variation of the two endogenous constructs. Apparently, there are other determinants, which are not considered in the study, but are relevant to travelers' preferences for teleworking and travel information. Note, as introduced before, that the main aim of the study is to test the hypothesized relations, rather than to exhaust all possibly relevant factors and to (fully) explain travelers' preferences for travel information and teleworking. The relatively low R^2 values, in particular the one for the construct *"preference for travel information",* are not surprising, since the study considers a very limited number of factors among the many factors that have been well identified in the literature of relevance to travelers' preference for travel information and travelers' preference for teleworking, respectively (see *Chapter 2* for a literature overview of the related factors).

Table 3-6: R^2 value of the two endogenous constructs

Endogenous construct	R^2
Preference for teleworking (PETE)	36.0%
Preference for travel information (PEIN)	15.7%

Finally, it turns out that for the sample respondents in the study, the perceived availability of teleworking and the perceived quality of teleworking environment and facilities do not affect their preference for travel information, while the perceived availability and reliability of travel information do not affect their preference for teleworking. No significant paths are found between the corresponding constructs in the model estimation. Although these hypothesized effects appear to be reasonable, at least the sample respondents in this study do not show such subtle interactions. However, further study[94] is needed before judging whether this is a general conclusion for the entire population – for example, to test on another sample or to use different measurement variables to operationalize the constructs.

3.5 Conclusions

On the one hand, travelers' preferences for travel information (the "I" in ICT) and teleworking and telecommunication facilities (the "C" in ICT) are expected to be interrelated, and, on the other hand, empirical evidence is lacking to prove this expectation. This chapter presents a preliminary empirical study that aims to provide inputs for the following model development in this thesis and also aims to provide related insights that are expected to be of practical relevance. The study is based on a web-survey conducted among 261 Dutch commuters about their daily life behavior in terms of using travel information and teleworking, and their potential behavior in terms of using travel information and teleworking under hypothetical conditions. This study develops a structural model and uses structural equation modeling (SEM) to analyze the collected data, and explores a) whether (and to what extent) a correlation exists between travelers' preferences for teleworking and travel information as expected, and b) what are the relations between travelers' preferences for teleworking and

[94] Given the limited budget and time, this research does not further investigate this issue.

travel information and other factors that could be of influence, such as travelers' perception of the reliability of commuting time, the availability and reliability of travel information, the availability of teleworking and the quality of the teleworking environment and facilities.

The final model provides good model fit and construct validity, and the following findings are derived from the SEM analysis of the 261 sample respondents:

- The perceived extent to which travelers are allowed to telework is positively related to travelers' preference for teleworking;
- The quality of the teleworking environment and facilities is positively related to travelers' preference for teleworking;
- The perceived availability of travel information to travelers is positively related to travelers' preference for travel information;
- The hypothesized relation of "the perceived reliability of travel information" on travelers' "preference for travel information" is found insignificant in this study, suggesting that, among the sample respondents, the reliability of travel information does not affect their preference for travel information. However, this inference should be treated with caution;
- The perceived reliability of commuting time is found to be negatively related to both travelers' preference for teleworking and travelers' preference for travel information – the less reliable travelers' commuting time is, the more travelers prefer to telework or acquire travel information;
- It appears that the reliability of commuting time perceived by travelers has a larger impact on their preference for travel information than on their preference for teleworking, ceteris paribus;
- A significant correlation is found between travelers' preference for teleworking and preference for travel information, suggesting that other common underlying factors or personal traits than what are considered in the study are relevant to travelers' preferences for both teleworking and travel information. This also implies that travelers who prefer to use travel information seem to also prefer teleworking and vice versa (as both are driven by the common underlying factors or personality traits);
- Other factors than the ones that are considered in the model exist of effects on travelers' preference for teleworking and preference for travel information;
- It appears that for the sample respondents in the study, the perceived availability of teleworking and the perceived quality of teleworking environment and facilities do not affect their preference for travel information, while the perceived availability and reliability of travel information do not affect their preference for teleworking.

These aforementioned results are expected to be of relevance to this research and are also expected to be of practical relevance. In particular, this study is of relevance to the following model development in this thesis. The study provides empirical insights, and also empirical evidence to support the rationale, for the model development to consider the interrelations between the "I" and the "C" in ICT. The details of the model will be elaborated in the following chapters of this thesis (*Chapters 4* and *5*). The derived insights will be also used for derivation of practical and policy implications in *Chapter 6*.

However, it should be noted that, as what has been addressed in detail in the previous sections in this chapter, aspects including the aim and scope of the study, the way in which the model is operationalized, the resulted unexpected relations subject to the given sample data, etc. should be taken into consideration in the interpretation of these findings. Further study is also advised for some of these issues (e.g., insignificant relations of certain factors on travelers' preferences for teleworking and travel information) before making general conclusions.

Appendix

Results of other tested structural models

The full-fledged structural model with all hypothesized paths included

Table 3-7: Model fit of the full-fledged structural model with all hypothesized paths included

N	Chi-square	d.f.	P-value	CFI	TLI	RMSEA	SRMR
261	145.355	115	0.0293	0.975	0.967	0.032*	0.045

**: Estimate: 0.032; 90 Percent C.I.: 0.011 ~0.047; Probability RMSEA ≤ 0.05: 0.980*

Figure 3-3 presents the full-fledged estimated model, wherein all the paths defined in the conceptual model are estimated.

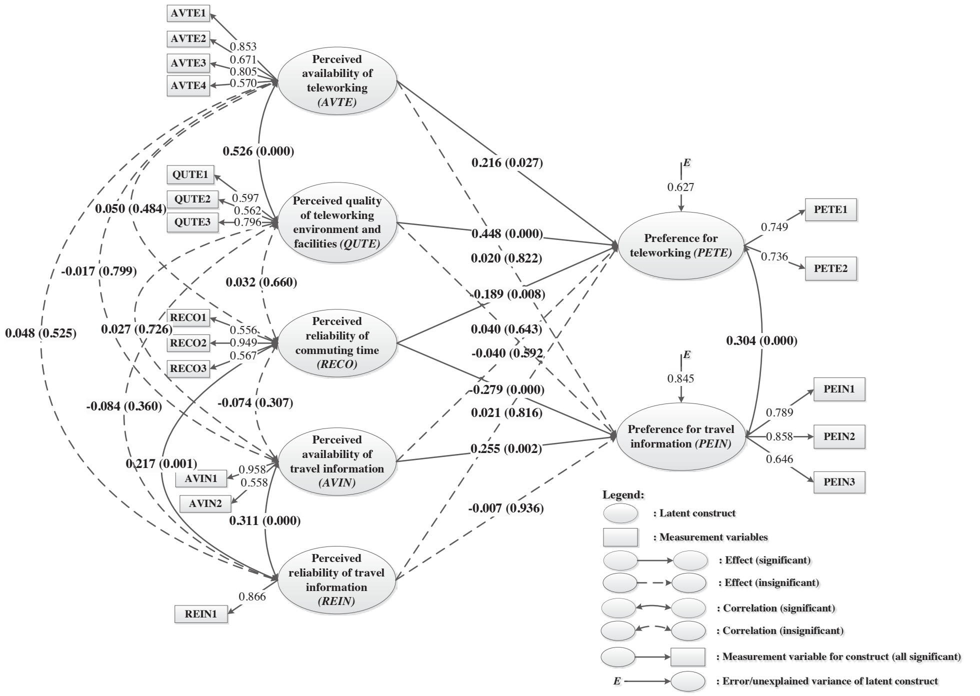

Figure 3-3: The estimated full-fledged structural model with all hypothesized paths included

The structural model with the path between "perceived reliability of travel information" and "preference for travel information" deleted

Table 3-8: Model fit of the structural model with the path between "perceived reliability of travel information" and "preference for travel information" deleted

N	Chi-square	d.f.	P-value	CFI	TLI	RMSEA	SRMR
261	136.378	107	0.0291	0.975	0.968	0.032*	0.047

**: Estimate: 0.032; 90 Percent C.I.: 0.011 ~0.048; Probability RMSEA ≤ 0.05: 0.973*

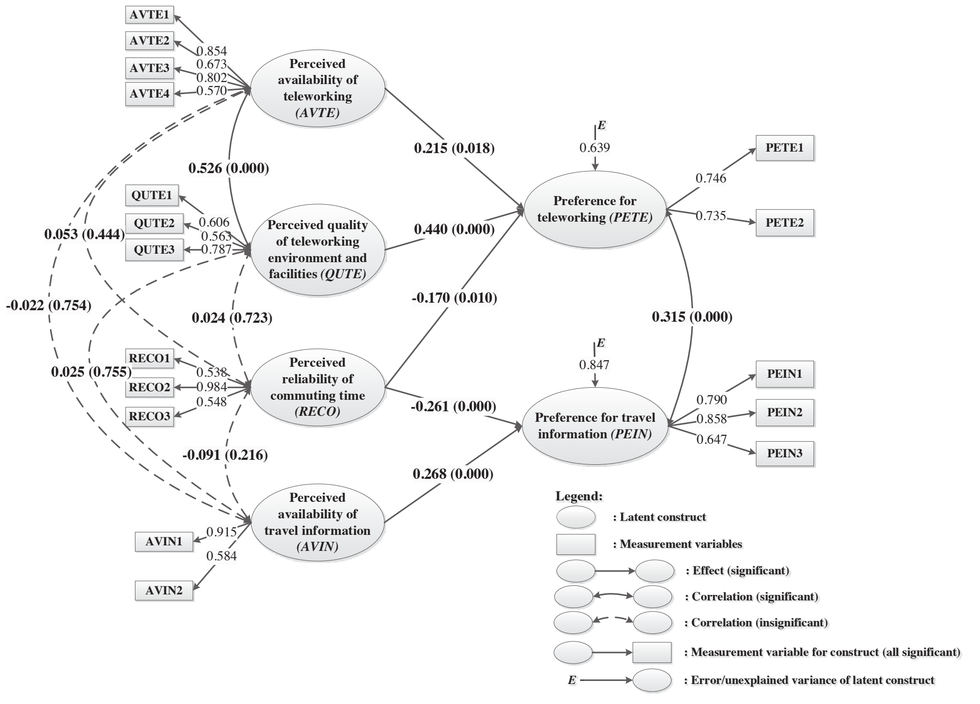

Figure 3-4: The estimated structural model with the path between "perceived reliability of travel information" and "preference for travel information" deleted

4 The effects of different forms of ICT on accessibility – A behavioral model and numerical examples

Lu, R., Chorus, C., & Van Wee, G.P., (2014). The effects of different forms of ICT on accessibility - a behavioural model and numerical examples. *Transportmetrica A: Transport Science*, 10(3), 233-254.[95]

Abstract

This paper develops a utilitarian model that captures the effects of different forms of ICT (information and communication technologies) on accessibility. The role of constraints that an individual may face when making decisions is explicitly considered, as well as the presence of uncertainty. Two major forms of ICT are considered: travel information provided by ICT and teleactivities that may be performed using the ICT. The model is developed to measure the combined effects of both travel information and teleactivities as well as their potential interaction effects on accessibility. Numerical examples show the plausibility of the model in capturing the effects of different forms of ICT on accessibility and reflect the combined effects of travel information and teleactivities on accessibility in different situations.

[95] Note that in this thesis, as is common practice, *Chapter 4* is presented in a way, without any adaptation, as the published paper.

4.1 Introduction

Accessibility is a key concept for both policy makers and researchers and it is studied by scholars of several disciplines, such as transport engineering, economics, geography, and sociology. Although defined and operationalised in various ways, accessibility is widely used to describe the correlation between land use patterns and transportation systems (Dong et al., 2006) and one definition of accessibility proposed by the U.S. Department of Environment (1996) is the ease and convenience of access to spatially distributed opportunity with a choice of travel. It is important at this point to note that the notion of accessibility over the past decades has been operationalised in numerous ways by transportation researchers and geographers (see Geurs and van Wee (2004) for an overview), and that these different operationalisations are not necessarily all mutually consistent. As will become clear below, in this paper we operationalize accessibility as being the utility of a choice set, which in this paper is operationalised as the utility of the most preferred alternative in that set. This approach, in our view, is in line with the LogSum-approach to accessibility as developed by Ben-Akiva and Lerman (1985) – but note that we forego the use of error terms in our model, hence we arrive at a deterministic equivalent of the well-known LogSum-formulation. However, we anticipate that there will be readers who find this operationalization of accessibility less appropriate or useful, and we of course respect this. Those readers may to rather interpret our measure of accessibility as being a measure of user benefits (which is a more general and neutral concept); these readers are invited to substitute the term “accessibility” for the term “user benefits” throughout the remainder of this paper.

A paramount goal of transport policy is to improve accessibility. Whereas in past decades, most attempts to increase accessibility have focused on the development of transportation infrastructure (roads, railways), it is to be expected that Information and Communication Technologies (ICTs[96]) may also have a large impact on accessibility. For example, travel information may help travellers reduce travel times, and the option to telework may make someone’s office very accessible also when roads are heavily congested. In light of this intuitive relation between ICT and accessibility, it is surprising that most ICT-related studies in the field of transportation and geography have focused on the effects of ICT on travel behaviour[97], while there is few effort in measuring the effects of ICT on accessibility – the ease and convenience of access to spatially distributed opportunities with a choice of travel.

Two main streams of literature concerning the effects of ICT on travel behaviour can be distinguished. One stream focuses on the effects of travel information on travel behaviour in the context of uncertain travel times (see e.g., Chorus et al., 2006b), and another stream deals with teleactivities, such as teleworking and teleshopping, that are enabled by ICT (see e.g., Andreev et al., 2010). Hardly any literature exists that combines both streams, whereas in real life most ICTs (such as laptops, mobile phones) combine both functions. Furthermore, we know of no study that explicitly deals with possible interactions between the effects of travel

[96] In our research, *ICT* refers to all the technologies that provide access to information or teleactivities. We consider ICT broadly, including “old” ICT such as radio and television and “new” ICT such as the Internet and mobile phones. We in particular distinguish the two major functions of ICTs: information technologies and communication technologies (section 4.3.1).

[97] In our research, travel behaviour refers to personal activities and related travel, examples of which include commuting to work and travel to shopping.

information and teleactivities (e.g., a commuter might assess travel times for his or her route to work, before deciding whether or not to work from home for a few hours or the entire day).

As mentioned above, there is hardly any literature on the effects of ICT on accessibility (Van Wee et al., 2013), and, to the best of our knowledge, no literature exists that discusses the combined effects of on the one hand travel information and on the other hand teleactivities on accessibility. Choices with respect to travel information and teleactivities could be mutually dependent, as do related accessibility benefits. For example, in the above described situation where a commuter decides whether or not to telework based on received travel information, the value of travel information depends on the availability of the option to telework, and vice versa. In other words, it is likely that in many situations, interactions between travel information and teleactivities (in terms of accessibility benefits) exist. Ignoring such interactions could lead to an under- or over-estimation of the effects of combined ICT on accessibility.

This paper aims to fill the identified gaps in the literature by presenting a model that is able to capture the combined effects of different forms of ICT on accessibility, including possible interactions. The model adopts the utility paradigm (see, Ben-Akiva and Lerman, 1979), where the maximum utility that an individual can derive from a set of activity-travel pattern options is considered to be a measure of accessibility. We apply the recently developed constrained multinomial logit model (see, Martínez et al., 2009) to capture the impact of constraints on travel behaviour and accessibility. Our model aims at allowing analysts to quantitatively measure and evaluate the impact of different forms of ICT accessibility when travellers are faced with uncertainty and constraints.

The remaining part of this paper is structured as follows. Section 4.2 gives an overview of literature on ICT's (potential) effects on accessibility. Section 4.3 firstly introduces at a conceptual level the behavioural model of ICT's effects on accessibility, followed by a formal derivation of the model. Section 4.4 presents numerical examples to show the model's plausibility and investigate the combined effects of different forms of ICT on accessibility. Finally, Section 4.5 summarizes the main conclusions and discusses the model's applicability and paths for further research.

4.2 ICT's effects on accessibility: an overview of literature

This Section gives an overview of literature on ICT's effects on travel behaviour (Section 4.2.1) and on modelling efforts performed by other researchers to measure ICT's effects on accessibility and travel behaviour (Section 4.2.2).

4.2.1 Literature overview: ICT's effects on travel behaviour

To understand the (potential) effects of ICT on accessibility we first discuss ICT's effects on travel behaviour using both streams of literature addressed in the introduction. As mentioned, one stream of literature focuses on teleactivities enabled by ICT (e.g., teleworking, teleshopping, teleleisure activities) (see e.g., Andreev et al., 2010). These teleactivities may not only substitute location-based activities but also generate complementary activities (see e.g., Mokhtarian, 1990; Mokhtarian, 1998; Salomon, 1986). Furthermore, teleactivities may help people relax or even avoid the constraints they may face especially time-space constraints (see e.g., Hägerstrand, 1970), as well as budgets-related constraints (see e.g., Axhausen, 2000). Moreover, the disutility of travel can be reduced by ICT because travellers conduct ICT-based activities while travelling (see e.g., Jain and Lyons, 2008). In addition, ICT-based multitasking (travel related or not) increases people's activity participation (see e.g., Kenyon and Lyons, 2007). Finally, people's activity-travel patterns are increasingly being fragmented by the space where activities are conducted, the time when activities are accomplished, and the manner in which activities are performed (see e.g., Alexander et al., 2010b; Couclelis, 2000; Lenz and Nobis, 2007).

The other stream of literature focuses on travel information provided by ICT. It is widely acknowledged that travel information has the potential to substantially affect people's travel behaviour. For example, travel information may generate new unknown travel alternatives or help assess known alternatives (Chorus et al., 2007a). Travel information may play a central role in reducing uncertainty and persuading travellers to act in particular ways, resulting in for example activity-travel rescheduling decisions (see e.g., Sun et al., 2012) and changes in transport demand (see e.g., Zito et al., 2011). Travel information may also support travel decision adaptations (see e.g., Wang and Khattak, 2011). Largely discussed in traffic-related papers, traffic information, as a subcategory of travel information provided by ICT, can change travel behaviour, examples being route choice and departure time choice (see e.g., Bogers, 2009; Ettema and Timmermans, 2006).

We now continue with the discussion of ICT's effects on accessibility. The behavioural changes as addressed above result from having additional options within access, or from enabling a better choice among known options, or from increased awareness of available options, thanks to ICT – and this can be interpreted as an increase or change in accessibility[98]. However, as mentioned earlier there is practically no literature that explicitly discusses ICT's effects on accessibility, let alone on the combined effects of both travel information and teleactivities on accessibility. Because of the interaction effects of ICT and the importance of such interactions for both accessibility and travel behaviour, there is a need to develop methodologies in this area –see Section 4.2.2.

4.2.2 Literature overview: modelling ICT's effects on accessibility and travel behaviour

A wide range of accessibility measures have been developed with different focuses and intended applications. Several authors have conducted extensive reviews of the developed accessibility measures. To name some, Miller (1999) reviewed three major approaches of accessibility measures – space-time accessibility measures, attraction accessibility measures, and utility-based measures. Geurs and van Wee (2004) identified four main approaches of accessibility measures – infrastructure-based, location-based, person-based, and utility-based measures. Neutens et al. (2010) evaluated the use of various place-based and people-based measures of accessibility in the context of public service delivery.

However, few formal or quantitative models exist that are able to measure ICT's effects on accessibility, despite the wide range of accessibility measurements and the knowledge at a conceptual level of the (potential) effects of ICT on accessibility.

[98] The distinction between the terms "*access*" and "*accessibility*" needs to be clarified. Geurs & Van Wee (2004) define access from a person's perspective and accessibility from a location's perspective: a location is accessible by persons and a person has access to locations. Both terms in the literature are often used indiscriminately (see e.g., Van Wee et al., 2013). In this paper, we use accessibility for both the location and person's perspective.

One strand of the few modelling efforts focuses on the extensions of classical time-geographic concepts to accessibility in virtual realm via introduction of new conceptualizations of space-time. For example, Janelle (1995) developed a framework to classify communication modes based on their spatial and temporal constraints. Spatial constraints require either physical presence or telepresence, whereas temporal constraints require either synchronous or asynchronous communication. Miller (2005a), based on the Janelle's framework, proposed a space-time measurement model of human interaction with telepresence. Miller introduced two new time-geographic objects – portals and message windows – into the existing time-geographic objects such as the path and prism, and extended the time-geographic measurement theory to include indirect (virtual) interaction. Kwan (2007) proposed a conceptual model Hypertext to measure accessibility in the age of mobile communications. The hypertext model assumes that each individual has several nodes connecting to different social networks, while each link represents the possibility of interactive coordination between individuals. Kwan argued that the hypertext model may be a useful framework for conceptualising the effect of real-time interactivity enabled by mobile communications and social networks on urban travel. These conceptual models, however, have not yet well developed in quantitative ways and hence, to the best of our knowledge, have not yet been applied into other studies. As a result, it is widely acknowledged that there is still a preeminent need of new analytical frameworks and methodologies for better measuring ICT's effects on accessibility (Neutens et al., 2011).

Other examples of the few modelling efforts refer to the efforts in modifying or extending traditional measures of accessibility via inclusion of certain ICT-related factors in the measures. Scott (2000) used the notion of functional travel time, instead of actual travel time, in the traditional doubly constrained gravity accessibility measures for the study of the supply and demand of jobs and workers. The functional travel time, considered as the costs related to spatial interactions of jobs and workers, was compared to the actual travel times underlying the assumption that transportation and telecommunication technologies have impact on urban spatial structure and spatial interactions between places. Shen (2000) developed a model to measure job accessibility with competition by distinguishing the job seekers who have telecommunication capabilities and who have not. The model, developed based on the traditional gravity accessibility measure, also distinguishes the job opportunities accessible via transportation or telecommunications. Ettema and Timmermans (2007) discussed the effects of travel information on accessibility by extending the framework of the utility-based space-time accessibility and the travel time scheduling framework. These models provide useful ways to measure effects of certain *specific* ICTs on accessibility or measure ICT's effects on *specific* categories of accessibility, e.g., job accessibility. However, they do not generically consider both travel information and teleactivities, let alone the interactions between them, and therefore are not (yet) applicable to measure the combined effects of ICT on accessibility.

Secondly we discuss the modelling efforts in measuring ICT's effects on travel behaviour. The majority of these modelling efforts have centred upon the effects of information on travel behaviour. For example, Emmerink et al. (1995) developed behavioural models to discuss the effects of information on road transport networks with recurrent congestion. Dia (2002) developed an agent-based approach to model driver route choice behaviour under the influence of real-time information. Levinson (2003) developed a model to calculate the value of advanced traveller information systems for route choice. Chorus et al. (2006a) developed behavioural models of perceived value of travel information that take into account satisficing as well as maximizing behaviour. Sun et al. (2012) developed a heterogeneous latent class model for activity rescheduling, route choice and information acquisition decisions under multiple uncertain events. Illenberger et al. (2011) investigated the potential benefits of route-guidance information to risk-sensitive travellers. Although these modelling efforts lay solid foundations for developing new analytical frameworks and methodologies for accessibility measurement under the influence of ICT, they do not measure accessibility. In addition, it appears that there is a lack of study efforts aimed at quantitatively modelling the effects of teleactivities on travel behaviour.

In short, it can be argued that there is a need for a generic, integrative and quantitative model that is able to measure the effects of different forms of ICT on accessibility, which includes the possible accessibility-interactions between travel information provided by ICT and teleactivities enabled by ICT.

4.3 ICT's effects on accessibility: a behavioural model

This Section first presents at a conceptual level the integrative model of ICT's effects on accessibility (Section 4.3.1), followed by a formal derivation of the model from these conceptual notions (Section 4.3.2).

4.3.1 Conceptualisations

We conceptualise the maximum utility that an individual can derive from a set of activity-travel pattern options as a measure of accessibility. This conceptualisation is in line with the utility-based approach to accessibility measurement. While accessibility has been defined and operationalised in several ways, utility-based accessibility measures are considered effective measures of accessibility with a high level of theoretical rigor and practical usability (see, Ben-Akiva and Lerman, 1979; Geurs and van Wee, 2004; Niemeier, 1997). In particular, we assume the individual to be a utility-maximiser in the sense that he or she attaches utilities to activity-travel patterns before execution and chooses the pattern alternative that has the maximum utility (Ben-Akiva and Lerman, 1985; McFadden, 1974; Train, 2003). The accessibility from the individual's perspective is the utility of the (to be) chosen pattern. Note that in our conceptualisation, we adopt the individual's perspective rather than the analyst's perspective from which the accessibility should be defined as the expected maximum utility of the choice set within the random utility paradigm. Given these behavioural assumptions, the effects of different forms of ICT on accessibility can be conceived in terms of their impact on people's activity-travel pattern alternatives and the associated utilities.

Despite the wide range of ICT-types currently available to travellers, we only distinguish between ICT's two major functions: information technologies [99] versus communication technologies [100] (Van Wee et al., 2013). In particular, we focus on travel information concerning known pattern alternatives (e.g., travel time information), and ICT that enables teleactivities (e.g., teleworking, teleshopping). Such a categorization based on ICT's functions, rather than categorizations based on other dimensions (e.g., its technical specifications), ensures that the developed approach for capturing ICT's effects on

[99] We use the term information technologies to refer to all the technologies that provide access to travel information (e.g., radio or apps on mobiles phones that provide traffic information).

[100] We use the term communication technologies to refer to all the technologies that provide access to teleactivities (e.g., the Internet and online shops that provide people with teleshopping opportunities).

accessibility remains generally applicable in the context of the wide variety of different ICTs currently available. In addition, it ensures that the modelling approach can be durably applied in a relatively long term regardless of the rapidly changing nature of ICT.

In an attempt to more fully capture ICT's effects on accessibility along these two dimensions, we, in addition to a conventional utility component for each alternative, include a utility component related to the constraints that people may face when scheduling their activity-travel patterns[101]. Via the conventional activity-travel pattern utility component, we are able to measure one aspect of the utility change that may be caused by ICT, such as the reduction of travel disutility caused by people's multitasking during travel. The inclusion of the constraint-related utility component enables us to capture another major effect from ICT – it may help people relax or even avoid constraints. We use the recently introduced constrained multinomial logit (CMNL) model (Bierlaire et al., 2010; Martínez et al., 2009), which features a constraint-related utility component with the following characteristics: a person may incur a penalty if an alternative violates certain "soft" constraints (meaning that the constraint can be violated to some extent, e.g., person's preferred arrival time at the office). If a person's alternative violates certain "hard" constraints (meaning that the constraint cannot be violated, e.g., the closing time of shops, after which people cannot do in-store shopping), the constraint-related penalty becomes extremely large, making this alternative de facto not available to the individual. No penalty is incurred if the alternative does not violate any soft or hard constraints.

4.3.2 Formalisations

We first introduce the traveller's utility-based decision rule (4.3.2.1), after which we show how constraints are modelled in the utility-function (4.3.2.2). After that, we integrate the two and derive our model of accessibility (4.3.2.3).

4.3.2.1 An expected utility-based decision rule

Without loss of generality, suppose that an individual faces a choice set $\overline{S}$ consisting of I activity-travel patterns S_i (different combinations of activities and travels):

$$\overline{S} = \{S_1,..,S_i,...,S_I\} \qquad \text{Eq.4-1.}$$

The individual (note that we do not index individuals for the sake of readability) attaches a perceived utility U_{S_i} to activity-travel pattern alternative $S_i, \forall i \in \{1,...,I\}$ which is a function of the alternative's attributes stacked in vector X_{S_i} . The individual, however, may be uncertain about particular attributes. We model this by assuming that he or she perceives the attribute values in terms of a probability density function $f(X_{S_i})$. The alternative utility U_{S_i}

[101] See for example Mokhtarian (1990), Janelle and Gillespie (2004), and Shaw and Yu (2009) for an in-depth argumentation of why capturing the role of constraints is important for understanding ICT's effects on accessibility.

then becomes the expected utility, which is computed by integrating over this probability density function[102]:

$$U_{S_i} = \int_{X_{S_i}} [U_{S_i}(X_{S_i}) \cdot f(X_{S_i})] \cdot dX_{S_i} \qquad \text{Eq.4-2.}$$

As an expected utility-maximiser, the individual chooses from his or her choice set $\bar{S}$ the activity-travel alternative with the maximum expected utility:

$$\arg\max_{\bar{S}}(U_{S_1},...,U_{S_i},...,U_{S_I}) \qquad \text{Eq.4-3.}$$

4.3.2.2 Inclusion of constraints

As argued, the individual may face constraints when choosing between different activity-travel pattern alternatives. As mentioned earlier, we use the approach adopted in the constrained multinomial logit (CMNL) model (Martínez et al., 2009), which is to include a constraint-related utility component $\Phi_{S_i}(X_{S_i})$ into the (expected) utility function:

$$\begin{aligned} U_{S_i} &= \int_{X_{S_i}} [U_{S_i}(X_{S_i}) \cdot f(X_{S_i})] \cdot dX_{S_i} \\ &= \int_{X_{S_i}} \left[\left(V_{S_i}(X_{S_i}) + \Phi_{S_i}(X_{S_i}) \right) \cdot f(X_{S_i}) \right] \cdot dX_{S_i} \end{aligned} \qquad \text{Eq.4-4.}$$

Here, $V_{S_i}(X_{S_i})$ indicates the utility component that is not constraint-related and $\Phi_{S_i}(X_{S_i})$ indicates the additive constraint-related utility component which has the following characteristics (for ease of presentation, we start with the situation where there is only one constraint, which may be either soft or hard[103]):

$$\begin{cases} \Phi_{S_i}(X_{S_i}) = 0\text{, if the alternative does not violate the constraint or no constraint is perceived as present;} \\ \Phi_{S_i}(X_{S_i}) < 0\text{, if the alternative violates the constraint (case of a soft constraint);} \\ \Phi_{S_i}(X_{S_i}) \to -\infty\text{, if the alternative violates the constraint (case of a hard constraint);} \end{cases} \qquad \text{Eq.4-5.}$$

[102] Note that all the utility functions are formulated from the individual's perspective; hence, no random utility component is included.

[103] In reality, and in our model, whether or not a constraint is soft or hard is of course not a binary but a continuous variable (a constraint is hard or soft to some extent). This notion will be operationalised further below.

In the more realistic situation where there are multiple constraints, $\Phi_{S_i}(X_{S_i})$ can be defined as a function of a K-dimensional composite cut-off factor $\phi_{S_i}(X_{S_i})$, which is composed of a set of K lower cut-off factors $\phi^L_{kS_i}$ and upper cut-off factors $\phi^U_{kS_i}$:

$$\Phi_{S_i}(X_{S_i}) = \ln[\phi_{S_i}(X_{S_i})] = \ln\left[\prod_{k=1}^{K}(\phi^L_{kS_i}\cdot\phi^U_{kS_i})\right] \qquad \text{Eq.4-6.}$$

Here, $\phi^L_{kS_i}$ and $\phi^U_{kS_i}$ are the elementary cut-off factors associated with constraint k and determined by k's lower cut-off a_{kS_i} and its upper cut-off b_{kS_i} in relation to the alternative S_i. For example, a_{kS_i} and b_{kS_i} may reflect the time of day on which a shop opens, respectively closes, in which case $\phi^L_{kS_i}$ and $\phi^U_{kS_i}$ reflect the disutility associated with arriving at that store before it has opened or after it has closed, respectively. The elementary cut-off factors can be defined as follows:

$$\begin{cases} \phi^L_{kS_i} = \dfrac{1}{1+\exp[\omega_{kS_i}(a_{kS_i} - X_{kS_i} + \rho_{kS_i})]} = \begin{cases} 1 & if\ (a_{kS_i} - X_{kS_i}) \to -\infty \\ \eta_{kS_i} & if\ a_{kS_i} = X_{kS_i} \end{cases} \\ \phi^U_{kS_i} = \dfrac{1}{1+\exp[\omega_{kS_i}(X_{kS_i} - b_{kS_i} + \rho_{kS_i})]} = \begin{cases} 1 & if\ (b_{kS_i} - X_{kS_i}) \to \infty \\ \eta_{kS_i} & if\ b_{kS_i} = X_{kS_i} \end{cases} \end{cases} \qquad \text{Eq.4-7.}$$

Here, ρ_{kS_i} is the scaling parameter which is itself determined by two parameters $\eta_{kS_i} \in (0,1)$ and $\omega_{kS_i} > 0$. In combination, these two parameters determine the value of the scaling parameter as follows: $\rho_{kS_i} = \dfrac{1}{\omega_{kS_i}} \cdot \ln(\dfrac{1-\eta_{kS_i}}{\eta_{kS_i}})$. As Martinez et al. (2009) and Bierlaire et al. (2010) argue, η_{kS_i} can be interpreted as the probability that an alternative is considered by the individual when its attribute value is at the boundary, and ω_{kS_i} reflects the degree of hardness/softness of the constraint. Lower values for η_{kS_i} and higher values for ω_{kS_i} imply a higher disutility associated with crossing a constraint.

4.3.2.3 A measure of ICT's effects on accessibility

In order to understand how our model measures the impact of different forms of ICT on accessibility, it is useful to distinguish between five different choice-situations. The first situation is one where no constraints are present, and no form of ICT is available. In the second situation, one or more constraints are present, and no form of ICT is available. The third situation involves constraints and the availability of one form of ICT: travel information about one or more uncertain quality aspects of one or more travel alternatives (such as travel times for known routes). The fourth situation differs from the third in the sense that no travel information is available, but there is a teleactivity-option: for example, one may telework or teleshop using the ICT-device. The fifth situation involves constraints while both forms of ICT are available (travel information and a teleactivity-option). By computing the accessibility associated with each of these five choice-situations, the role of constraints and the impact of different forms of ICT on accessibility can be readily understood.

Situation 1: as defined in words in Section 4.3.1, the accessibility ACC of a choice set that is not affected by constraints and does not contain travel information or teleactivity-options can be defined as the maximum expected utility associated with the choice set[104]:

$$ACC = \max\left(U_{S_1},...,U_{S_i},...,U_{S_I}\right) \qquad \text{Eq.4-8.}$$

Situation 2: when the individual faces constraints, his or her accessibility, denoted ACC_{con}, is determined by the maximum constrained expected utility (see function Eq.4-4.) associated with the individual's choice set. The difference between ACC and ACC_{con} then by definition gives the loss in accessibility caused by the presence of the constraints.

Situation 3: when an option, denoted r, to acquire travel information about the uncertain attributes of some activity-travel pattern S_i is available but no teleactivity-option is available, the accessibility ACC_r associated with the choice situation can be defined as:

$$ACC_r = \max\left(U_{S_1},...,U_{S_i},...,U_{S_I},U_r\right) \qquad \text{Eq.4-9.}$$

In line with the value of travel information specified by Chorus, et al. (2010), we conceptualise U_r as the *anticipated* expected utility to be derived from the choice set of activity-travel patterns after having received the information about S_i. Since the individual does not know beforehand what message he or she will receive when acquiring the information, the utility of information is formalised by taking the expectation over the probability density function that represents the traveller's perception of what messages may be received when acquiring the information about S_i. Under the assumption that the information is perceived by the traveller as being fully reliable, it can be shown (Chorus et al., 2010) that this probability density function in fact equals the probability density function that gives the traveller's perception of the vector of uncertain attributes ($f(X_{S_i})$). Furthermore, the assumption of fully reliable information implies that after having received the information, the attributes of S_i to which the information refers are no longer uncertain, and that the initial perception of these attributes (which was a probability density function) is replaced by the received message. Together, this gives the following formalisation of the value of information option *r* (where C_r indicates the cost related to the information):

[104] Note that when the utility is considered as a random utility from the analysts' view, accessibility can be defined as the expected maximum utility of the choice set. When the random utility component is i.i.d. Gumbel distributed, accessibility can then be written as the LogSum of the deterministic utilities of the alternatives in the choice set (Ben-Akiva and Lerman, 1985).

$$U_r = \int_{X_{S_i}} \left\{ \max[U_{S_1}(X_{S_1}),....,U_{S_i}(X_{S_i}),....,U_{S_I}(X_{S_I})] \cdot f(X_{S_i}) \right\} \cdot dX_{S_i} - C_r \qquad \text{Eq.4-10.}$$

In words, the value of travel information lies in its ability to help select the highest expected utility activity-travel alternative from the set, by means of reducing the uncertainty associated with one or more attributes of one or more of these activity-travel alternatives. As will be highlighted further below, the role of information becomes especially important when constraints are present, because as argued earlier these can result in very high disutilities. Take the situation where a traveller is uncertain whether or not the travel time associated with a particular route is such that the opening hours of a shop he or she plans to visit are violated. We will show further below that in such a situation, the availability of travel information is likely to be even more valuable than in choice situations without constraints.

Situation 4: when a teleactivity-option, denoted q, is available and there is no option to acquire travel information, the accessibility ACC_q associated with the choice situation can be defined as:

$$ACC_q = \max\left(U_{S_1},...,U_{S_i},...,U_{S_I},U_q\right) \qquad \text{Eq.4-11.}$$

Here, U_q indicates the utility of the teleactivity-option q, which can be illustrated as:

$$\begin{aligned} U_q &= \int_{X_q} [U_q(X_q) \cdot f(X_q)] \cdot dX_q \\ &= \int_{X_q} \left[\left(V_q(X_q) + \Phi_q(X_q)\right) \cdot f(X_q)\right] \cdot dX_q \end{aligned} \qquad \text{Eq.4-12.}$$

Here, $U_q(X_q)$ is the utility of teleactivity-option q which itself is a function of the teleactivity-option's attributes X_q. Some of these attributes are related to the ICT such as, for example, the speed of the internet-connection and the quality of audio-visual support. Other attributes may refer to, for example, the breadth of assortment of particular webshops. As a result, one or more of these attributes may be perceived by the decision-maker as uncertain. The utility of the teleactivity-option includes – just like the utility of activity-travel alternatives – a conventional utility component $V_q(X_q)$ and a constraint-related utility component $\Phi_q(X_q)$. Function $\Phi_q(X_q)$ has the same characteristics as addressed in Section 4.3.2.2. $f(X_q)$ is the probability density function representing the individual's perception of q's attribute values for as far as these are uncertain. By using the teleactivity-option q, the individual may relax or avoid constraints: for example, teleshopping via online shops enables people to avoid the constraint of shops' closing time for in-store shopping. However, other constraints may still play an important role also when a teleactivity-option is present, such as the money-budget constraint.

Situation 5: we now consider the situation where the individual faces one or more constraints and has a choice set containing both the teleactivity-option q and the travel information-option r. In this case, the accessibility associated with the choice set, denoted $ACC_{r,q}$, is defined as:

$$ACC_{r,q} = \max\left(U_{S_1},...,U_{S_i},...,U_{S_I},U_q,U_{r|q}\right) \qquad \text{Eq.4-13.}$$

Here, $U_{r|q}$ indicates the *anticipated* expected utility to be derived from the choice set that contains activity-travel patterns as well as the teleactivity-option, after having received the information. As a result [see function Eq.4-10.], $U_{r|q}$ can be defined in the same way as U_r, the only difference being that now teleactivity-option q is available as well:

$$U_{r|q} = \int_{X_{S_i}} \left\{\max[U_{S_1}(X_{S_1}),...,U_{S_i}(X_{S_i}),...,U_{S_I}(X_{S_I}),U_q(X_q)] \cdot f(X_{S_i})\right\} \cdot dX_{S_i} - C_r \qquad \text{Eq.4-14.}$$

The identification of these five choice situations (with or without constraints, with or without the availability of travel information and/or teleactivity-options) and their associated accessibility, allows us to rigorously evaluate the effects of constraints and different forms of ICT on accessibility. For example, by computing the difference, denoted ΔACC_r, between ACC_{con} and ACC_r, we can measure the effects of the availability of the travel information-option r on accessibility when certain constraints are present. The effects of the availability of the teleactivity-option q on accessibility in the situation involving constraints can be measured via the accessibility difference, denoted ΔACC_q, between ACC_{con} and ACC_q.

Furthermore, our formulations allow us to study the possible presence of interaction effects in terms of accessibility-impacts of different forms of ICT. More specifically, it may be the case that the extent to which the availability of one form of ICT (e.g., travel information) improves accessibility is influenced by the mere availability of the other form of ICT (e.g., teleactivity-option). Formally, these interaction effects IE that may exist between the travel information-option r and the teleactivity-option q are defined as:

$$IE = \Delta ACC_{r,q} - (\Delta ACC_q + \Delta ACC_r) \qquad \text{Eq.4-15.}$$

Here, $\Delta ACC_{r,q}$ indicates the accessibility difference between ACC_{con} and $ACC_{r,q}$, and ΔACC_r and ΔACC_q are as defined earlier.

4.4 Numerical examples

This Section presents some numerical examples based on an arbitrary and highly simplified case where an individual schedules a shopping-travel alternative. Without loss of general applicability, we simplify our examples to the situation where there is only one activity – shopping – and where there are two travel routes with one considered attribute – travel time; furthermore, we consider a simple temporal constraint, which is related to the closing time of the shop. We do not consider other possible attributes nor unobserved factors from the analyst's point of view in order to purely illustrate in the numerical examples how our model captures the effects on accessibility of the travel time and the temporal constraint. Such a simplification does not imply that the model cannot be applied to more complicated and real life-like cases; rather, it serves better for our purpose of showing the workings and plausibility of the model in capturing the effects of different forms of ICT on accessibility. We particularly present, via a range of sensitivity analyses, how the developed model can be used to measure (i) accessibility of distinguished situations, (ii) accessibility effects of travel information and teleshopping, and (iii) their interaction effects, in several scenarios.

4.4.1 Base-case

As base settings (which will be varied in our sensitivity analyses), we arbitrarily set the following settings and attribute values. We suppose a base case that an individual schedules a shopping-travel alternative S including a shopping activity (A) and travel (T). The individual attaches a utility which is a linear function of the utility of shopping $V_S^A = 13$, which may in turn depend on factors such as the shop's assortment and the individual's intrinsic preference for in-store shopping, and the (dis-)utility of travel V_S^T. We assume that V_S^T is solely determined by a travel time TT_S and the associated travel time parameter $\beta_{TT} = -0.1$ (specifically, $V_S^T = \beta_{TT} \cdot TT_S$). The individual is assumed to know two routes, of which the perceived travel times are normally distributed with an average travel time of 40 minutes and a standard deviation of 10 minutes. In order to do shopping before the shop's closing time and have enough shopping time, the individual faces a constraint that the travel time should be no longer than 55 minutes ($TT_{\max} = 55\,\text{min}$). The parameters for constraint specification [see function Eq.4-7.] are assumed to be[105]: $\omega = 2$ & $\rho = 0$. In line with the travel-time scheduling model that includes a penalty for late arrival (Noland and Small, 1995), the individual in our numerical examples may incur a disutility if the travel time violates the constraint. It can be computed that in this base case the expected utilities of the two shopping-travel alternatives without considering the constraint are both 9.00 units. Due to the uncertainty of the travel times, the utilities of the two alternatives decrease from 9.00 units to 8.40 units when the travel time constraint is considered.

We also suppose that the following two ICT-related alternatives may be available to the individual: (i) fully reliable travel time information r may be available, which gives the travel times for both routes for that particular day and time-of-day; (ii) a teleshopping alternative q may be available. In the base case, utility (U_q) equals 8.40 units, which is equivalent to the expected utilities of the two travel alternatives when the opening hour constraint is present.

Using the model developed in Section 4.3.2.3, we compute (for the base case situation depicted above) the accessibility associated with the five distinguished situations. Firstly, the presence of the constraint decreases the accessibility from 9.00 to 8.40 units when no ICT is available. When constraints are present, the availability of the travel information option increases the accessibility to 9.54 units when no teleshopping is available. The information reduces the uncertainty whether the travel times of one or both routes violate the constraint. When one route's travel time violates the constraint but another route's travel time does not,

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[105] The impact on accessibility of variation in the value of the constraint parameter ω and the constraint boundary $TT_{\max}$ is discussed in Section 4.4.2.

the travel information allows the traveller to identify and choose the route that does not violate the constraint instead of having to randomly select an uncertain route and then wait and see what happens. The accessibility remains at 8.40 units for the situation involving constraints when only the teleshopping option is available. The teleshopping option does not contribute to the accessibility because its utility is (assumed to be) the same as the expected constrained utilities of the two travel alternatives. Finally, if both the two forms of ICT options are available, the accessibility becomes 9.59 units. The availability of the teleshopping option in this situation makes the travel information option more valuable, shown by positive synergy effect of 0.05 units. This synergy effect can be explained as follows: when the travel information shows that both routes' travel times violate the shop's opening hour, the traveller may decide to teleshop because in that situation, the utility associated with in-store shopping is lower than the utility associated with teleshopping. In sum: although the presence of a teleshop option does not add to accessibility in isolation (because its *expected* utility is the same as the *expected* utility of in-store shopping), it does increase accessibility when travel information is present.

Now that we have defined the base case, we go on to present several numerical examples in Sections 4.4.2-4.4.4 to discuss the model's face validity and to study the combined impact of ICT on accessibility. In Section 4.4.2 we vary constraint specifications and discuss the effects of constraints on accessibility. In Section 4.4.3 we explore the accessibility benefits of the information and the teleshopping alternative when we vary the utility of one travel alternative and the utility of the teleshopping alternative. Section 4.4.4 shows the possible interaction effects that emerge when combining the two forms of ICT. In each example the settings remain the same as in the base-case except for the modifications that are explicitly mentioned.

4.4.2 Constrained accessibility

We illustrate in Figure 4-1 the constrained accessibility as a function of (i) the travel time constraint $TT_{\max}$ in the interval from 40 to 70 min, and (ii) the constraint parameter ω (0 to 10). More specifically, Figure 4-1 (a-d) shows the constrained accessibility (a) when neither of the two ICT options are available; (b) when only the travel time information option is available; (c) when only the teleshop alternative is available (in addition to the travel alternatives); and (d) when both ICT options are available. It is easily seen that the four sub-figures in Figure 4-1 reflect the model's capability of giving plausible results in case of capturing effects of constraints on accessibility and the effects of ICT on accessibility. Figure 4-1 (a) shows that the constrained accessibility is very low when $TT_{\max} = 40\,\text{min}$ and $\omega = 10$. This makes sense because in this situation the travel alternatives are highly likely to violate the constraint at this point and because the constraint is very 'hard'. When the constraint becomes softer ($\omega\downarrow$) and the maximum travel time becomes larger ($TT_{\max}\uparrow$), the constrained accessibility increases to a value comparable to the non-constrained accessibility (9.00 units), which is to be expected. Figure 4-1 (b) reflects that the availability of travel information has a positive impact on accessibility especially when constraints are 'hard' and alternatives are likely to violate the constraints. For example, at the point where $TT_{\max} = 40\,\text{min}$ and $\omega = 10$ the availability of information strongly impacts accessibility, which increases from -30.00 (no information) to 0.00 units. This – as we argued further above – is fully in line with expectations. Figure 4-1 (c) reflects that when a teleshop-option is available, the individual can avoid the constraint and maintain relatively high accessibility values by teleshopping. This effect again becomes most pronounced at the point of $TT_{\max} = 40\,\text{min}$ and $\omega = 10$, where the accessibility now remains at 8.40 units. Note that the impact of $TT_{\max}$ and ω on accessibility is relatively small when the teleshop-option is available; also when constraints are 'hard' and the chance that a route's travel time violates the constraint is not that small, teleshopping is a good alternative for travelling. Figure 4-1 (d) shows the accessibility benefits arising from the joint availability of travel information and the teleshopping alternative. In this situation, there is practically no effect of $TT_{\max}$ and ω on accessibility, which is in line with expectations as well: when a traveller has the option to acquire information, and when a non-travel option is present as well, the utility of his or her choice set is only marginally affected by possible decreases in the travel options' utilities. In sum, the results presented in Figure 4-1 (a-d) are in line with intuition and as such provide a first sign of the model's validity.

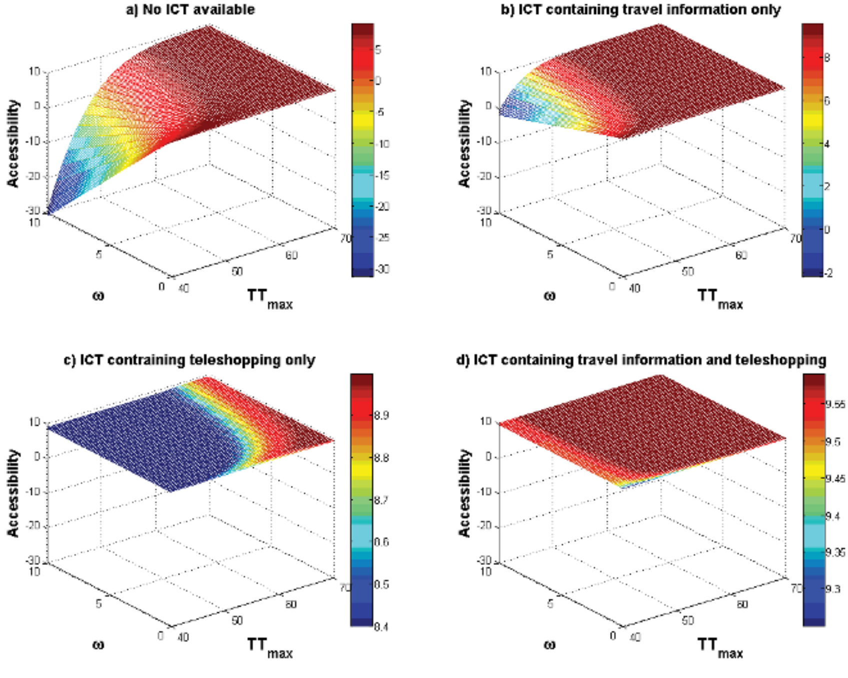

Figure 4-1: Constrained accessibility as a function of the constraint parameter ω and the constraint boundary $TT_{\max}$

4.4.3 Accessibility benefits of travel information and teleshopping

Figure 4-2 illustrates the accessibility benefits of making a travel information option and/or a teleshopping option available to the traveller when we fix the constrained utility U_{1con} of travel alternative 1 at 8.40, and vary both the utility U_{2con} of travel alternative 2 and the teleshopping utility U_q. The Figure shows that the utility differences between alternatives are of relevance when studying the effects of the availability of information and teleactivity-options on accessibility. Figure 4-2 (a) shows the accessibility benefits associated with the situation where information is available, but teleshopping is not an option. The accessibility benefit of making travel information available reaches its maximum when the expected constrained utility of alternative 2 is comparable to that of alternative 1 (8.40 units). In other words, the travel information is of value to the traveller to the extent that it is able to break the tie between two similar alternatives, and tends to lose its value when the best of two alternatives is easily identifiable without help of information. Figure 4-2 (b) shows the accessibility benefits caused by making teleshopping available to the traveller in a situation where travel information is not available. As is to be expected, the teleshopping benefits the individual's accessibility only when its utility outweighs the utilities of both the travel alternatives. For example, the accessibility benefit associated with making available the teleshopping option equals 11.6 when $U_{2con} = -10$ and $U_q = 20$, and it equals 0 when $U_{2con} = -10$ and $U_q = 0$. Figure 4-2 (c) shows the combined accessibility benefits of making available the two ICT options jointly. It again reflects that the effects of ICT on accessibility depend on the utility differences between alternatives. If U_q is (much) larger than both U_{1con} and U_{2con}, the information tends to lose its value: assessing which of the two travel alternatives is best becomes irrelevant when the teleshopping alternative is to be preferred anyway. If U_q is (much) smaller than either U_{1con} or U_{2con}, the teleshopping loses its accessibility benefits as well, for obvious reasons. The information, however, becomes more valuable (compared to the situation where U_q was very high) since assessing the two travel alternatives becomes relevant; the accessibility-benefits associated with making travel information available to the traveller again reaches a maximum when the two travel alternatives are hardly distinguishable (i.e., when $U_{1con} = U_{2con} = 8.40$).

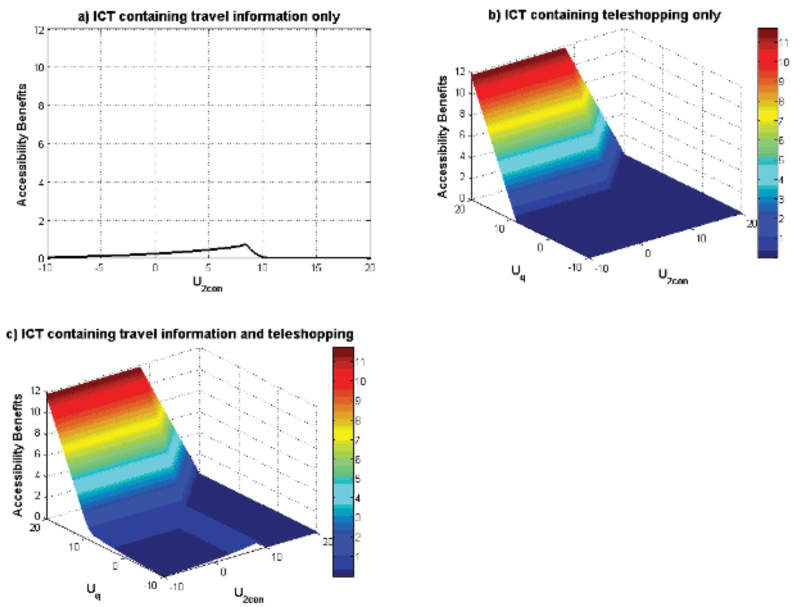

Figure 4-2: Accessibility benefits of the ICT options as a function of the constrained expected utility of alternative 2 (U_{2con}) and the teleshopping utility (U_q)

We use the settings of this example to derive a numerical example of the interaction effects between the travel information and the teleshopping on accessibility in the next section.

4.4.4 Interaction effects

The third and last example (Figure 4-3) illustrates the possible interaction effects (in terms of accessibility benefits) associated with the joint availability of the two ICT options. Settings are the same as for the second numerical example presented in Section 4.4.3 (fixing the constrained utility U_{1con} of travel alternative 1 as 8.40, and varying both the utility U_{2con} of travel alternative 2 and the teleshopping utility U_q). The interaction effects are computed via function Eq.4-15 in terms of the difference between i) the accessibility benefits associated with the joint availability of both forms of ICT and ii) the sum of the accessibility benefits associated with the availability of the teleshopping alternative and the accessibility benefits associated with the availability of the travel information.

We may expect the following results. (i) No interaction effects are expected to be achieved in cases where one travel alternative is superior to the other travel alternative and the teleshopping alternative. In those situations, the availability of the teleshopping option does not contribute to the accessibility even when information is available, and its availability does not make the information more valuable. (ii) Positive interaction effects are expected to be achieved when the individual has a teleshopping alternative whose expected utility is comparable to the expected utility of the most attractive travel alternative. In that situation, the information can be used to effectively to help the traveller choose between this most attractive travel alternative and the teleshopping option. Such an effect on accessibility of the availability of travel information is not achieved when the individual easily identifies which of the two travel alternatives has the higher utility and no teleshopping option is available. (iii) Negative interaction effects are expected to be achieved if the individual faces two comparable travel alternatives and a superior teleshopping alternative. In this case, the accessibility is determined by the utility of the teleshopping alternative. The information to assess the two travel alternatives then becomes redundant due to the availability of the teleshopping alternative.

The occurring trends shown in Figure 4-3 reflect and comply with these expectations. (i) For example, there is no interaction effect at point 1, where the constrained expected utility of alternative 2 (20.00 units) is much larger than the constrained expected utility of alternative 1 (8.40 units), while being equal to that of the teleshopping option. This also holds for point 1b and point 1c, where one travel alternative simultaneously outperforms the other travel alternative and the teleshopping option. (ii) The individual gains positive interaction effects at point 2 where the teleshopping-option's expected utility is equivalent to the expected utility of alternative 1 (8.40 units), and the expected utility of travel alternative 2 is much smaller (equalling -10.00 units). The mere availability of the teleshopping-option in this case makes the information more valuable, resulting in the positive interaction effects. (iii) The individual incurs negative interaction effects at point 3, where the teleshopping utility (20.00 units) is much higher than the expected utilities of the two travel alternatives (both 8.40 units). The availability of the teleshopping alternative depletes the information's value in assessing the two travel alternatives, and therefore results in the negative interaction effects. Interestingly, when comparing the interaction effects (Figure 4-3) and the combined accessibility benefits of the two ICT options [Figure 4-2 (c)], it becomes apparent that the points where maximum or minimum interaction effects are obtained do not coincide with the points where combined accessibility benefits of the two ICT options reach their maximum or minimum.

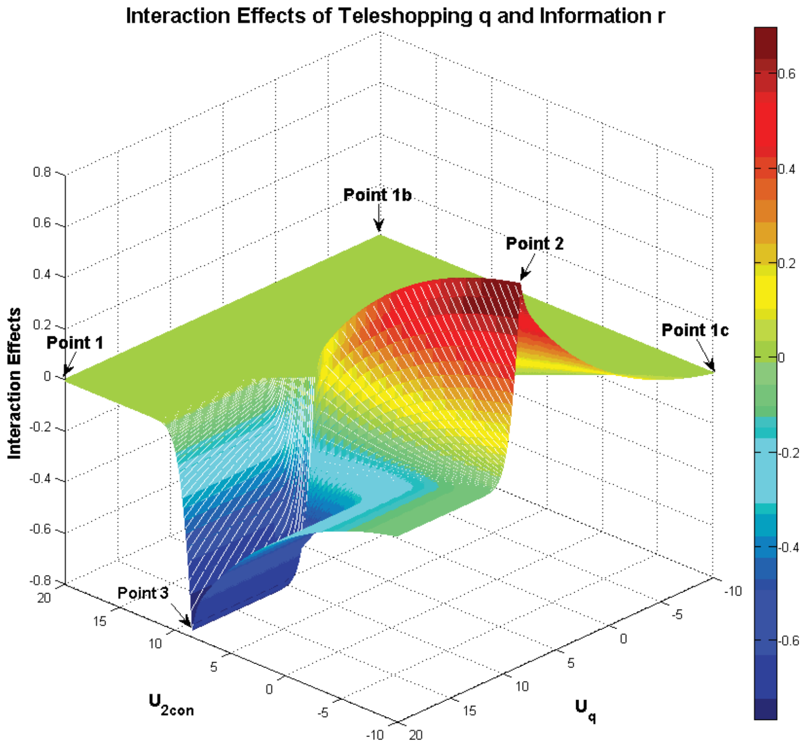

Figure 4-3: Interaction effects of the travel information and the teleshopping option as a function of the constrained expected utility of alternative 2 (U_{2con}) and the teleshopping utility (U_q)

4.5 Discussion and Conclusions

Using a utility-based measurement of accessibility and a constraint multinomial logit model framework this paper presents an integrative and quantitative model to measure the effects of different forms of ICT on accessibility when the decision-maker is faced with uncertainty and constraints. The model integrates both accessibility effects associated with travel information provided by ICT and effects associated with teleactivities enabled by ICT. The core of the model highlights the combined effects of these two categories of ICT on accessibility including potential interaction effects between them. Numerical examples not only provide a first sign of the model's face validity, but also reflect the combined effects of travel information and teleactivities on accessibility. Congruent with intuition and behavioural realism, the numerical examples show that when teleactivities or travel information are available, the negative impact of constraints on accessibility is reduced. In addition, the accessibility benefits of different forms of ICT and their interaction effects vary depending on the presence of constraints and the composition of traveller's choice set. Our developed model framework and the numerical examples contribute to the literature by trying to disentangle the effects of different forms of ICT on accessibility. The model framework aims to help pave the way for further model developments and for empirical studies about ICT's effects on accessibility.

For example, our model may be extended towards capturing additional facets of travellers' decision-making regarding ICT and travel, which may involve travel substitution and generation, activity-travel pattern fragmentation, multitasking, and other types of more complicated space-time constraints. Another path for further model development would be to combine our framework with discrete-continuous choice models (see e.g., Bhat, 1998, 2005; Habib, 2013; Wang and Li, 2011), or hazard-based duration models (see e.g., Bhat, 1996; Hensher and Mannering, 1994) to capture the role of activity duration allocation and activity pattern scheduling in the context of ICT-availability.

An important direction for further research would be to translate the approach presented in this paper towards a real-world situation. This translation has at least two dimensions: first, it would be interesting to study how the models presented here can be operationalised in an empirical survey and second, there is a question how empirically validated models can be used to support planning and policy making processes in real life.

The operationalisation into an empirical survey may build upon recent work by Chorus et al. (2013) who use a dynamic discrete choice experiment (of the travel simulator-type) to empirically observe behaviour concerning travel information acquisition and route choices. These studies have shown that based on these observed choices, models like the one derived in this paper can be successfully estimated, including the subtle interactions that may result from travellers' forward-looking behaviour (e.g., information utility being a function of the anticipated utility of travel options after having received the information). Although the mentioned studies did not include teleworking or other teleactivities (and as such also did not include possible interactions and synergies between teleactivities and travel information), there is no reason why these effects could a priori not be captured using a similar form of data collection and analysis. A critical success factor in this regard is that traveller perceptions of choice alternatives and the uncertainty related to attribute-values (such as travel times) are correctly observed by the analyst. While this does not pose particular difficulties when using stated choice or travel simulator data, it may be expected that when using revealed data great care must be exercised in terms of measuring traveller perceptions of choice sets, choice alternatives, and attributes (including the associated attribute-uncertainty).

Moving to the second dimension of translating our models to real-world situations: how can empirically estimated and validated models be used in actual planning and policy-design processes? Basically, there are two ways in which we feel that our models, when estimated on empirical data, can be put to use: first, estimated models may be used in an exploratory sense to identify possibilities for obtaining synergy between investments or other policies in different forms of ICT. For example, estimated models may be applied to identify in what situations investments in travel information and/or teleworking facilities may lead to a situation where benefits of these investments in the two types of ICT might reinforce one another, leading to addition user benefits at least in terms of increases in accessibility. Second, estimated models may be used to predict accessibility effects of ICT-investments in general, and these effects can subsequently be used in Cost-Benefit analyses used in transportation planning – ultimately leading to a more informed process of policy-development.

Furthermore, it should be noted that our model is built around several assumptions, which may be relaxed in the context of future research. Firstly, the model focuses on individual accessibility rather than on aggregate accessibility which considers interactions between people. Examples of such interactions between people in the context of ICT use can be found in Janelle (1995), Miller (2005a), Kwan (2007) and Soo (2009). Secondly, the model focuses on short-term potential accessibility. That is, instead of considering experienced or realized accessibility (see e.g., Chorus and de Jong, 2011; Kahneman et al., 1997; Scott, 2000), we focus on accessibility in the sense that we consider the moment right *before* an individual has received information and/or right *before* he or she has made choices between location-based alternatives and, possibly, the teleactivity-option. Furthermore, we do not consider long-term accessibility effects related to, for example, changes in land use patterns (see e.g., Eliasson, 2010; Neuteboom and Brounen, 2011; Van Wee, 2002). A third assumption we apply is that the individual considered in the model is assumed (to know that her or she is) fully capable of using the different forms of ICT; that is, we do not consider potential limitations in people's ICT-use capabilities (see e.g., Dijst, 2004). Fourthly, in our model the travel information is assumed to be fully reliable. As a result, in light of the theoretical and empirical results obtained in other studies into traveller response to information (see e.g., Bogers, 2009; Chorus et al., 2006a), it is likely that our analyses provide a somewhat optimistic picture of the impact of travel information on accessibility. A final assumption we make is that the information only refers to known travel alternatives. As such we ignore the situation where the information service is also able to generate previously unknown alternatives. It should be noted, however, that each of these assumptions has been made to keep the model's tractability at an acceptable level. Model extensions can be made to address these assumptions, although this is likely to come at the cost of non-trivial increases in model complexity. Relaxing these model assumptions without sacrificing too much tractability is an important topic for further research in this area.

Acknowledgements

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5 Methodologies to study travelers' use of ICT under conditions of risk and constraints: a discrete choice model and a travel simulator experiment[106]

This chapter, together with the *epilogue*, has formed the basis of the paper: Lu, R., Chorus, C., & Van Wee, G.P., (2014). Travelers' use of ICT under conditions of risk and constraints: an empirical study based on stated and induced preferences. *Environment and Planning B: Planning and Design*, 41(5), 928-944.

Abstract

Chapter 5 presents an econometric (discrete-choice-based) specification of the developed 'representative individual' model for measuring ICT's effects on travel behavior and accessibility that is developed in *Chapter 4*; and, more importantly, this chapter presents

[106] In this chapter, the focus is on modeling and data collection; therefore, model estimation results are mainly discussed in light of what they imply in terms of face validity of the model and the travel simulator experiment. Implications at a more substantive level, as well as policy implications that can be (partly) based on the results presented in this chapter, are provided in the subsequent *Conclusions-chapter.*

the model estimation results based on the data collected via a travel simulator experiment *(stated preference experiment)*.

This chapter translates the developed representative individual model (*Chapter 4*) into an estimable discrete choice model form, and discusses how data were collected to estimate the choice model; furthermore, model estimation is discussed in order to test the validity of the developed model and to get related estimates for derivation of insights into travelers' use of ICT under conditions of risk and constraints.

5.1 Introduction

As introduced in *Chapters 1 and 2*, over the years the interest in how Information and Communication Technologies (ICTs) may impact activity-travel behavior of individuals (and resulting accessibility) has resulted in what appears to be two separate strands of literature (Van Wee et al., 2013) – one having looked into the acquisition of travel information (the 'I' in ICT) and its impact on traveler behavior (e.g., Chorus et al., 2009; Ettema and Timmermans, 2006), and one having focused on the impact of telecommunication facilities (the 'C' in ICT) on individuals' choices to engage in physical travel (e.g., Alexander et al., 2011; Farag et al., 2006; Mokhtarian, 1990; Salomon, 1986). However, as argued, travelers' use of the "I" and "C" in ICT are likely to be interrelated in some cases: for example, travelers' use of travel information and of teleworking facilities could be partly driven by the same set of underlying preferences and believes (e.g., preferences for use of technologies). The decision to acquire travel information could also be dependent on the availability of a telework-option, and vice versa. For example, a traveler may choose to work from home after having received travel information at home that his/her route from home to work is severely congested. Alternatively, the mere availability of a telework-option to him/her might make him/her more inclined to acquire travel information (given that he/she would like to base the decision whether or not to work from home on the information).

Based on these considerations, in *Chapter 4*, we develop a representative individual model for measuring the effects of different forms of ICT – information-related technologies for travel information and telecommunication-related technologies for teleactivities, including their potential interactions – on accessibility. The model takes into consideration a traveler's decision to travel or telework, and/or to acquire travel information to capture the possible mutual interdependencies described above. The model also captures the potential impact of constraints (e.g., arrival time-related) on traveler's decisions. However, although the numerical examples presented in *Chapter 4* highlight this representative individual model's face validity, we do not test our model empirically, nor do we provide an econometric formulation in *Chapter 4*: the presented model is formulated for a representative individual rather than being formulated as a discrete choice model allowing for behavioral heterogeneity in the population. As such it does not include a discussion of how to specify error term distributions in a way that is in line with the subtle preference-structure the model presupposes.

This chapter hence aims to address these two issues. First, it provides an econometric (discrete choice-based) specification of the developed behavioral model in *Chapter 4*. Error term distributions are specified in order to make the underlying theory of the representative individual model operational. Second, and more importantly, this chapter tests the resulting operationalized model based on empirical data. The data that are used to test the specified discrete choice model are collected by means of a stated preference travel simulator experiment specifically designed for this purpose; in the experiment, travelers face a series of risky choices amongst routes, under various arrival time constraints. Choice sets include, in addition to a set of routes from home to work, the option to acquire travel information and the option to work from home.

The remainder of this chapter is structured as follows: section 5.2 presents the discrete choice model of traveler response to the two forms of ICT (travel information and teleworking). The stated preference simulator experiment is presented in section 5.3. Section 5.4 presents model estimation results based the stated preference experiment; the final section provides conclusions.

5.2 A model of travelers' use of ICT under conditions of risk and constraints

This section introduces the representative individual model developed in *Chapter 4* and presents the operationalization of the model – which consists of including different forms of error terms to capture alternatives' unobserved utilities and inter-alternative correlations.

First, the model is introduced as follows with error terms included, and is specified to represent choice behavior in the following situation[107]: at the start of a given weekday a traveler faces a choice among three travel options. Travel times of the three routes are risky, and there may be arrival time constraints, such as a business meeting having a fixed starting time. The traveler may have the option to telework from home to substitute travels and to perform all related work, and the option to acquire fully reliable travel information about the travel times of two of the three routes simultaneously[108]. In the experiment, if information is

[107] For ease of communication, the presented model is operationalized according to the type of choice situation that was presented to participants during the experiment (see the next section). However, it is easily seen that the model's applicability reaches well beyond this specific situation, and may be used to cover a range of relevant activity-travel choice situations in the presence of ICTs and in the context of risk and constraints.

[108] In other words, here and in the remainder of the chapter, we consider the situation where the traveler has a choice set containing five alternatives and makes a single choice from that set: 3 routes, an information acquisition option, and a telework option. As will become clear further on (e.g. *Footnote 111*), the experiment used for data collection can also be framed as a choice sequence where a traveler first decides whether or not to acquire information, and after having made this decision (and after potentially having received information) chooses between the three routes and the telework option. We also estimated models based on this perspective of sequential decision-making, albeit it should be acknowledged that due to time constraints we were only able to use a rather low number of draws for the evaluation of integrals (i.e., 50 MLH draws). Results suggest that the sequential formulation leads to a six-point increase in final log-likelihood (i.e., -2985 vs -2991); parameter estimates are statistically indistinguishable from those obtained by the simultaneous model which is based on a single choice from a five-alternative choice set. A potential exception concerns the estimated sigmas for ICT-use and for travel (see text further below and figure 5.1 for an elaboration of the role of these sigmas), which appear to differ modestly between models: σ_{ICT} equals 1.90 in the simultaneous model and 2.42 in the sequential one (SE = 0.31 in the simultaneous model and 0.32 in the sequential one); σ_{travel} equals 2.45 in the simultaneous model and 1.04 in the sequential one (SE = 0.32 in the simultaneous model and 0.37 in the sequential one). However, it should be noted that this difference may well be the result of the low number of draws used for estimation of the sequential model.

not available or no information is acquired in one trip, the traveler makes a choice among the three routes (the travel times are risky) and, if available, the telework option. If information is available and acquired in one trip, the travel times for the two routes are made known to the traveler, and the traveler makes a choice between the three routes (two of which are not risky anymore) and, if available, the telework option. Note that the model is presented for the choice situation where both travel information- and teleworking-options are available. However, the model can be easily modified for the experiment situations where either of the options, or both, is not available. In addition, as mentioned above, experiment participants made a maximum of two choices per 'trip': if they acquired information in a trip, they were asked – after having been given the information – to choose between the available routes and, if available, the telework-option. These follow-up choices are straightforward to model, and are therefore not being described in more detail in this section. They are however used in the estimation process.

Consider a traveler n who faces a choice set containing $\overline{S} = \{S_1, S_2, S_3, S_q, S_r\}$ alternatives: three routes $S_i, i = 1,2,3$ from home to work, a telework option S_q, and a travel information option S_r. The traveler is assumed to maximize utility:

$$\max_{S_i \in \overline{S}} U_{S_i} = \max_{S_i \in \overline{S}} (V_{S_i} + \xi_{S_i}), i = 1,2,3,q,r \qquad \text{Eq.5-1.}$$

Here, V_{S_i} is the observed utility of the S_i's option, and ξ_{S_i} is the associated unobserved utility of that option. Further below, the section will focus more in-depth on the unobserved utilities; for now, the observed utilities of the three types of alternatives (routes, telework, travel information) are first defined. The observed utilities of the three routes are assumed to only depend on their travel times $TT_{S_i}, i = 1,2,3$. The fact that these travel times are risky is represented in terms of the probability density function $f(TT_{S_i}), i = 1,2,3$, and by writing the utility of a route as an expected utility (by integrating over this density function):

$$U_{S_i} = V_{S_i} + \xi_{S_i} = \int_{TT_{S_i}} [u_{S_i}(TT_{S_i}) \cdot f(TT_{S_i})] \cdot dTT_{S_i} + \xi_{S_i}, i = 1,2,3 \qquad \text{Eq.5-2.}$$

A constraint-related utility component is introduced into the utility function in order to explicitly capture the effects of possible arrival time constraints. Following the constrained MNL-model presented in Martinez et al. (2009), the utility $u_{S_i}(TT_{S_i}), i = 1,2,3$ is decomposed into a not constraint related component $\Psi_{S_i}(TT_{S_i}), i = 1,2,3$ and an additive constraint related component $\Phi_{S_i}(TT_{S_i}), i = 1,2,3$. The fully utility function of route $U_{S_i}, i = 1,2,3$ now reads as follows:

$$\begin{aligned} U_{S_i} &= \int\limits_{TT_{S_i}} [u_{S_i}(TT_{S_i}) \cdot f(TT_{S_i})] \cdot dTT_{S_i} + \xi_{S_i} \\ &= \int\limits_{TT_{S_i}} \left[\left(\Psi_{S_i}(TT_{S_i}) + \Phi_{S_i}(TT_{S_i}) \right) \cdot f(TT_{S_i}) \right] \cdot dTT_{S_i} + \xi_{S_i}, i = 1,2,3 \end{aligned} \quad \text{Eq.5-3.}$$

Depending on the type of the constraint (it can either be soft or hard[109]), and on whether the constraint is violated or not, $\Phi_{S_i}(TT_{S_i}), i = 1,2,3$ takes on different values:

$$\begin{cases} \Phi_{S_i}(TT_{S_i}) = 0, \text{ if the alternative does not violate the constraint or no constraint is perceived as present;} \\ \Phi_{S_i}(TT_{S_i}) < 0, \text{ if the alternative violates the constraint (case of a soft constraint);} \\ \Phi_{S_i}(TT_{S_i}) \to -\infty, \text{ if the alternative violates the constraint (case of a hard constraint);} \end{cases} \quad \text{Eq.5-4.}$$

In a case where the traveler faces an arrival time constraint, $\Phi_{S_i}(TT_{S_i})$ can be defined as a function of an elementary cut-off factor $\phi_{S_i}^U$ associated with the arrival time constraint:

$$\Phi_{S_i}(TT_{S_i}) = \ln[\phi_{S_i}^U], i = 1,2,3 \quad \text{Eq.5-5.}$$

The cut-off factor $\phi_{S_i}^U$ can be further defined as a function of the maximum travel time $TT_{\max}$, given a fixed departure time, allowed by the arrival time constraint:

$$\phi_{S_i}^U = \frac{1}{1 + \exp[\omega \cdot (TT_{S_i} - TT_{\max} + \rho_{S_i})]} = \begin{cases} 1 & , if\ (TT_{\max} - TT_{S_i}) \to \infty \\ \eta_{S_i} & , if\ TT_{\max} = TT_{S_i} \end{cases} \quad \text{Eq.5-6.}$$

Here, scaling parameter ρ_{S_i} is determined by two parameters: $\eta_{S_i} \in (0,1)$ and $\omega > 0$, in the following way: $\rho_{S_i} = \frac{1}{\omega} \cdot \ln(\frac{1-\eta_{S_i}}{\eta_{S_i}})$. Here, η_{S_i} represents the probability that a route is considered by the traveler when its travel time implies arriving exactly at the preferred arrival time, and ω represents the degree of hardness of the constraint, as perceived by the traveler. Higher values for ω reflect a higher penalty associated with violating a constraint.

[109] A soft constraint can be violated to some extent without serious consequences (think of a traveler's preferred arrival time at the office). A hard constraint cannot be violated (think of the closing time of an office, after which it is impossible to perform the activity 'working' at the office location). Alternatively, a hard constraint can be considered an availability-dummy: after closing hours, the alternative 'working at the office' is not available anymore.

The utility of the telework-option is specified purely in the form of a variable V_{S_q} (since no telework attributes were included in the experiment), giving the traveler's overall preference for working from home given the particular telework-facilities at his or her disposal.

The utility of acquiring fully reliable information concerning the travel times of a subset of routes $\{S_1, S_2\}$ is specified according to the formulations presented in Chorus et al. (2013): the value of the information equals the anticipated utility to be derived from the choice set containing all routes and the telework option, after having received the travel information for a subset of routes. From the analyst's viewpoint, this latter utility should be conceived an *expected* utility, in light of the unobserved utilities of the routes (this is represented by the E(max)-operator in the equation below). Furthermore, also from the traveler's viewpoint the utility to be derived from the choice set after having received the information constitutes an expected utility, in light of the fact that she does not know beforehand what message will be received. This expectation is represented by the integration over the joint density function of the travel times of the subset of routes for which information is acquired. Finally, note that there may be a cost C_{S_r} associated with the travel information (monetary and/or in terms of time, effort and attention), as well as an unobserved utility component ξ_{S_r}.

$$U_{S_r} = V_{S_r} + \xi_{S_r} = \int_{TT_{S_1}} \int_{TT_{S_2}} \left\{ E\left(\max \begin{bmatrix} u_{S_1}(TT_{S_1}) + \xi_{S_1}, \\ u_{S_2}(TT_{S_2}) + \xi_{S_2}, \\ U_{S_3}, U_{S_q} \end{bmatrix} \right) \cdot f(TT_{S_1}) \cdot f(TT_{S_2}) \right\} \cdot dTT_{S_1} \cdot dTT_{S_2} \qquad \text{Eq.5-7.}$$

$$-C_{S_r} + \xi_{S_r}$$

Having presented the model, which is specified according to the experiment's choice situation and added with error terms, we now discuss in more detail how we specify these alternatives' unobserved utilities most effectively in order to make the underlying theory of the model operational.

It seems reasonable to expect that a variety of correlations may occur between the unobserved utilities of the alternatives in the choice set: firstly, it seems likely that the utilities of the two ICT-options (telework, travel information) are to some extent correlated. This expectation is intuitively reasonable and also in line with the findings from the survey study that is presented in *Chapter 3*. This potential correlation is captured by means of an individual-specific error component δ_{ICT} which is to be added to the utilities of the two ICT options; this error component captures intrinsic preferences or dislikes for ICT-based services in general. The error is assumed to be normally distributed with mean zero and estimable standard deviation σ_{ICT}. Furthermore, it seems likely that to some extent the unobserved utilities of the routes and the travel information option are correlated, since all relate to actual, physical travel – as opposed to working from home. This potential correlation is captured by means of an individual-specific error component δ_{travel} which is to be added to the utilities of the routes and the travel information option; this error component represents a preference for physical travel. The error is assumed to be normally distributed with mean zero and estimable standard deviation σ_{travel}. These two error components together create a cross-nested model structure, as shown in Figure 5-1. Note that by specifying these errors as individual-specific and invariant across choices made by the same individual, these error components also allow us to accommodate the panel nature of the data (each individual made 20 choices in the experiment).

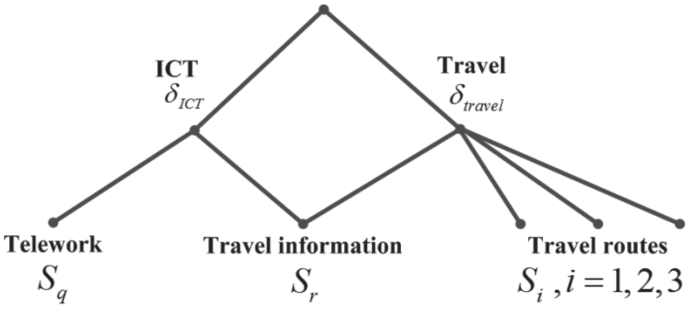

Figure 5-1: Depiction of the cross-nested model structure

In addition to these individual-specific error components, each alternative is assigned an Extreme Value Type I-error which is iid across individuals and choice situations. Chorus et al. (2013) show how, given the assumption of iid Extreme Value error components, the expected maximum mentioned in Equation 7 can be replaced by a more convenient LogSum-formulation:

$$U_{S_r} = V_{S_r} + \xi_{S_r}$$
$$= \int_{TT_{S_1}} \int_{TT_{S_2}} \left\{ \ln \begin{bmatrix} \exp[u_{S_1}(TT_{S_1}) + \delta_{travel}] + \exp[u_{S_2}(TT_{S_2}) + \delta_{travel}] \\ + \exp[V_{S_3} + \delta_{travel}] + \exp[ASC_{S_q} + \delta_{ICT}]) \end{bmatrix} \cdot f(TT_{S_1}) \cdot f(TT_{S_2}) \right\} \cdot dTT_{S_1} \cdot dTT_{S_2} \quad \text{Eq.5-8.}$$
$$- C_{S_r} + \delta_{travel} + \delta_{ICT} + \varepsilon_r$$

Furthermore, the convenient iid Extreme Value assumption imply that, conditional on particular realizations of the two individual-specific error terms δ_{ICT} and δ_{travel}, the probabilities of the routes, the telework option and the travel information option can be written as logit-probabilities:

- Choice probability that the traveler chooses one of the route options, for example route *i*:

$$P(S_i \mid \delta_{travel}, \delta_{ICT})$$
$$= \frac{\exp(V_{S_i} + \delta_{travel})}{\sum_{S_i} [\exp(V_{S_i} + \delta_{travel})] + \exp(ASC_{S_q} + \delta_{ICT}) + \exp(V_{S_r} + \delta_{travel} + \delta_{ICT})}, i = 1,2,3 \quad \text{Eq.5-9;}$$

- Choice probability that the traveler chooses the telework option S_q:

$$P(S_q \mid \delta_{travel}, \delta_{ICT}) = \frac{\exp(ASC_{S_q} + \delta_{ICT})}{\sum_{S_i}[\exp(V_{S_i} + \delta_{travel})] + \exp(ASC_{S_q} + \delta_{ICT}) + \exp(V_{S_r} + \delta_{travel} + \delta_{ICT})}, i = 1,2,3 \quad \text{Eq.5-10;}$$

- Choice probability that the traveler acquires the travel information S_r:

$$P(S_r \mid \delta_{travel}, \delta_{ICT}) = \frac{\exp(V_{S_r} + \delta_{travel} + \delta_{ICT})}{\sum_{S_i}[\exp(V_{S_i} + \delta_{travel})] + \exp(ASC_{S_q} + \delta_{ICT}) + \exp(V_{S_r} + \delta_{travel} + \delta_{ICT})}, i = 1,2,3 \quad \text{Eq.5-11.}$$

5.3 Data collection: travel simulator experiment based on stated preference

This section presents the travel simulator (section 5.3.1) that was designed to collect the type of data needed to estimate the choice model presented in the previous section. Also, this section briefly discusses participants' background characteristics (section 5.3.2). Subsequently, participants' evaluation of the experiment is presented (section 5.3.3).

5.3.1 The travel simulator experiment

In the experiment[110], participants were asked to perform 20 trips that were randomly selected as a subsample from all the possible combinations of the given choice scenarios and the different designed attribute levels (to be elaborated later). Figure 5-2 provides a screen shot of an example of a trip that was presented to experiment participant. The top portion of the screen presents the choice situation to the participant, in terms of (i) the preferred arrival time and the importance of being on time for that given day; (ii) the availability of a telework option; and (iii) the availability of fully reliable travel time information for a subset of routes. The left portion in the middle of the screen presents an abstract road 'network', consisting of three routes from home to work. Two routes are highways, and there is a secondary route. Travel times (communicated to participants as being door-to-door) for these routes during peak hour are represented on the right hand side, in the middle portion of the screen. Riskiness of travel times is communicated to participants in terms of a best guess travel time,

[110] Extensive discussions of the usefulness and limitations of travel simulators for data collection can be found in Bonsall (2004), Mahmassani (2006), Chorus et al. (2007b), and Chorus et al. (2013).

and a range of possible travel times, for each route. The lower portion of the screen represents the travel information service[111] (which refers to the two highway routes only).

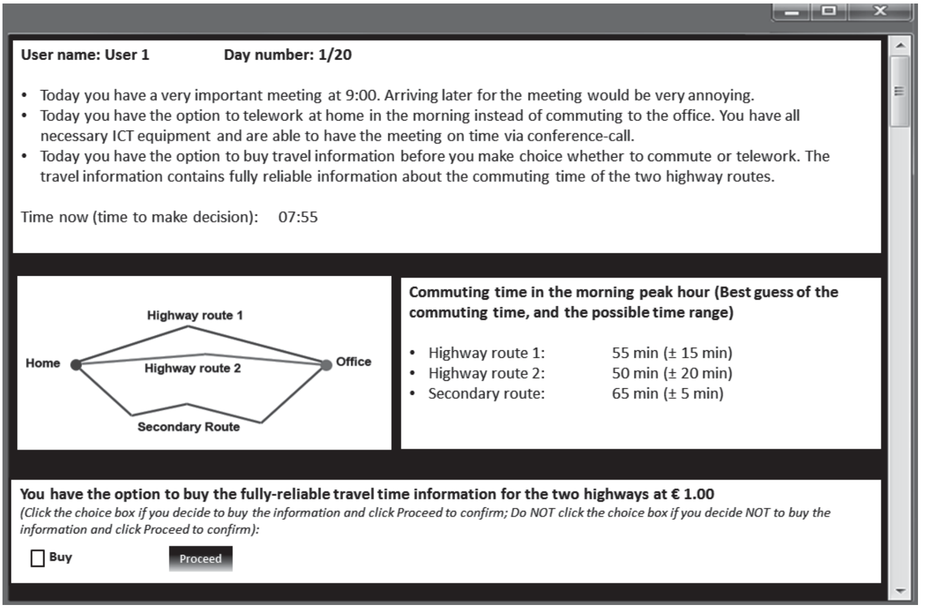

Figure 5-2: A screen shot of one randomly selected choice situation of the simulator[112]

After extensive deliberation, and a round of testing using synthetic data, the following attribute-levels were chosen: highway 1's best guess travel time is varied between 55 minutes and 60 minutes, and its range varies between ±10 minutes and ±15 minutes. Highway 2's best guess travel time is varied between 45 minutes and 50 minutes, and its range varies between ±20 minutes and ±25 minutes. That is, highway option 1 is the slower (on average) but less risky route, whereas highway option 2 is the faster (on average) but more risky route. The secondary route's best guess travel time is fixed at 65 minutes, with a fixed range of 5 minutes (which makes it the slowest (on average) but almost riskless route). Concerning the choice-context, five different scenarios were available, which were systematically varied across trips:

[111] The simulator, after having presented the traveler with the full set of choice options (routes, telework option, and the travel information acquisition option), actually first presents a binary choice regarding whether or not to acquire the available travel information. At first sight this may seem to be different from how the choice probability for travel information is formulated in the choice model (being framed in a multinomial context). However, the full choice set was visible for participants during their decision whether or not to acquire the information, and they were explicitly told that after they had acquired information (if they would), they would be asked to choose from the set of travel route and teleworking options given the received information. This implies that mathematically as well as behaviorally speaking the choice to acquire information or not can be cast as being made in the context of a multinomial choice set. See also *footnote 108*.

[112] The screen shot is adapted from the original one where Dutch instead of English is used in the simulator.

the commuter is told that (1) she has no meetings at the office, and she has no preferred arrival time; (2) she has no meetings at the office, but she would like to arrive at the office at 9AM; (3) she has an informal meeting with one colleague at 9AM, and being late would be slightly annoying but not a big deal; (4) she has a multilateral meeting at 9AM for which she would rather not be late; (5) she has a very important meeting at 9AM, and being late would be very embarrassing. The departure time for each choice round is given and is varied among 7:50AM, 7:55AM and 8:00AM. The commuter, therefore, may run the risk of arriving later than the preferred arrival time mentioned in the given scenarios. Finally, trips vary in terms of the availability of the telework option, and of the travel information service. Teleworking, if available, does not cost anything; it was communicated to participants that teleworking would imply having a conference-call from home, in case the scenario featured a meeting. Participants were asked to imagine the situation where they had all the right ICT-tools available for working from home. The cost of information, if available, varies across trips, and can take on the values €0.5, €1, €1.5, and €2.

If information is acquired, the travel times for the two highway-routes are shown, and the traveler is subsequently asked to make a choice between the three routes (two of which are not risky anymore) and, if available, the telework option. If no information is acquired, the traveler is asked to make a choice based on risky travel times for all three routes. In case a route is chosen (as opposed to the telework option), the travel time for the chosen route is shown on screen, as is the arrival time at the office.

5.3.2 The experiment participants

Participants were asked to perform 20 trips, and the average duration of the experiment equaled roughly 30 minutes. Participants were offered two ways to participate: they could do the experiment from home (online), or they could come to one of our university's computer rooms. In the former situation, the introduction was presented on screen, while in the latter situation, the introduction was presented by one of the graduate students (as well as being available on screen). Participants received a fixed fee for participating. Participants who came to our university's computer room to do the experiment received €25, and those that did the experiment from home (through the internet) received €10. These participants were asked to identify with the choice situations as if these were real, and to make choices accordingly based on the particular travel time distributions, information costs, and contextual scenarios. Participants were recruited by means of ads in local newspapers. It was made clear, although no actual screening was implemented, that participants were expected to have experience with commuting to work or university by car. In total, 137 participants were recruited for the stated preference experiment – Table 5-1 shows their socio-demographic characteristics of the participants to the stated preference experiment, and distinguishes between the online versus computer room setting.

Table 5-1: Characteristics of participants

Variable	Stated preference treatment (N=137)			
	Computer room (N=35)		Online (N=102)	
	Frequency	%	Frequency	%
Age				
15-24	8	22.9	20	19.6
25-34	13	37.1	37	36.3

35-44	9	25.7	29	28.4
45-54	3	8.6	12	11.8
55-64	2	5.7	4	3.9
65 or older	0	0.0	0	0.0
Occupation				
Employee	23	65.7	76	74.5
Volunteer	1	2.9	4	3.9
Student	10	28.6	20	19.6
Others	1	2.9	2	2.0
Gender				
Male	20	57.1	57	55.9
Female	15	42.9	45	44.1
Highest completed education[113]				
Elementary school	0	0.0	0	0.0
Secondary school	4	11.4	16	15.7
Vocational education	3	8.6	19	18.6
Higher education	28	80.0	65	63.7
Others	0	0.0	2	2.0
Net monthly household income (€) [114]				
No income	1	2.9	2	2.0
<1000	7	20.0	16	15.7
1000-2000	7	20.0	18	17.6
2000-3000	5	14.3	19	18.6
3000-4000	6	17.1	13	12.7
4000-5000	5	14.3	9	8.8
>5000	3	8.6	7	6.9
I do not want to answer or I do not know	1	2.9	18	17.6
Main commuting mode				
Car (as a driver)	20	57.1	65	63.7
Car (as a passenger)	2	5.7	2	2.0

[113] The categories of education are classified based on Dutch education system, which were used to ask participants in the study: a) Elementary school includes *Basisonderwijs*, b) Secondary school includes *VMBO*, *MAVO*, *HAVO*, *VWO*/*Gymnasium*, and *VAVO*, c) Vocational education includes *MBO*, and d) Higher education includes *HBO* and *WO*.

[114] The income only includes the income of the participant and his/her partner, if any.

Public Transport	6	17.1	21	20.6
Motorcycle/Moped	0	0.0	2	2.0
Bicycle	6	17.1	10	9.8
By foot	0	0.0	0	0.0
Others	1	2.9	2	2.0

5.3.3 The experiment evaluation

Participants were asked five survey questions to evaluate the experiment after they finished the experiment. These questions took the form of propositions (e.g., "I found it difficult to concentrate during the experiment"), with associated Likert-scale answer categories (1 = totally disagree; 5 = totally agree). Results (Table 5-2) suggest that participants of the experiment in general enjoyed the experiment, and did not find it hard to concentrate or identify with the choice situations and contextual scenarios presented to them. Mean scores quite strongly resemble those obtained in a previous simulator study where the same questions were asked to participants (Chorus et al., 2007b).

Table 5-2: Evaluation of the experiment (stated-preference)

Questions	Mean Score
1. Difficult to concentrate during the experiment	1.88
2. Easy to understand the experiment	4.11
3. Difficult to empathize the choice situations	2.09
4. Nice to do the experiment	4.28
5. Problematic to stay motivated during the experiment	1.74

5.4 Estimation results (stated preference experiment)

This section discusses how the choice model is operationalized to fit the specifics of the data collected by means of the simulator experiment (section 5.4.1). Subsequently in section 5.4.2, model estimation results are discussed.

5.4.1 Model operationalization, parameterization and estimation

The following assumptions were made to operationalize the model in light of the specifics of the data collection effort: participants' perceptions of risky travel times are given by a normal distribution having as mean the best guess travel time, and as standard deviation on fourth of the certainty-interval provided on the screen. For example, if a route's travel time was communicated in terms of a best guess of 60 minutes and a certainty interval of ±15 minutes, it was assumed that this route's travel time perceived by the traveler was distributed normally with mean 60 minutes and standard deviation 7.5 minutes (implying that in the perception of the traveler, 95% of travel times are within the specified certainty interval). As mentioned above in section 5.2, we assume that a traveler expects that, when she acquires information, messages will be drawn from this travel time distribution as well (see Chorus et al. (2005) for a justification of this assumption).

The following parameters are estimated – a travel time parameter, an information cost parameter, and five constants for information acquisition (each one representing one of the five contextual scenarios described in the previous section 5.3.1). Diverse attempts to allow for random travel time- and information cost-parameters did not result in empirically identifiable models. Hence, these two parameters are kept fixed in the final model presented in Table 5-3. Furthermore, four parameters[115] $\omega^m, m = 2 \sim 5$, representing the perceived hardness of constraints in the four contextual scenarios, are estimated (see section 5.2 for a more elaborate discussion of the role of parameters ω^m in the constraint function). In line with previous studies using the constrained MNL-model (Bierlaire et al., 2010; Martínez et al., 2009), parameter ρ_{S_i} is set to zero due to identification issues[116]. Furthermore, the standard deviations of the additional individual-specific error components δ_{ICT} and δ_{travel} are estimated to capture panel and nesting effects as explained in section 5.2. Finally, a scale parameter μ_{online} is estimated to reflect the possibility that there are scale differences between choices made online (from home) and choices made in our university's computer room.

MLHS draws (Hess et al., 2006) were used to evaluate the various integrals: 200 draws were used to simulate the error term components δ_{ICT} and δ_{travel}, and 200 draws were used to simulate the two-dimensional integral representing the risky travel times for the two highway routes and the secondary route. Experimenting with increasing numbers of draws showed that this number of draws was enough (that is: parameters did not change when the number of draws was doubled). Estimation was performed using PythonBiogeme (Bierlaire, 2003, 2009).

5.4.2 Estimation results

A first glance at model statistics and parameter estimates (Table 5-3) shows that the model achieves a reasonable fit with the data (adjusted rho-square = 0.283), and that, more importantly, parameters are all significant and of the expected sign. This provides a first sign of the face validity of the model presented in section 5.2, and of the operationalization described in section 5.4.1, and the stated preference experiment used for data collection.

Table 5-3: Estimation results (stated preference experiment)

Model statistics	
Sample size	3131
Init. log-likelihood	-4196.844

[115] Since no constraint is present, there is no constraint parameter for the baseline scenario.

[116] See Castro et al. (2012) for an in-depth discussion of the identification issues of constrained-MNL model.

Final log-likelihood		-2990.546		
Rho-square		0.287		
Adjusted Rho-square		0.283		
Parameter [a)]		**Value**	**Robust Std. Error** [b)]	**p-value** [c)]
Scale parameter between online-experiment data and computer room-experiment data	μ_{online}	0.625	0.069	0.00
Deterministic utility of teleworking option	$V_{S_q}^1$	-8.080	0.902	0.00
	$V_{S_q}^2$	-9.630	0.994	0.00
	$V_{S_q}^3$	-10.000	1.070	0.00
	$V_{S_q}^4$	-10.200	1.070	0.00
	$V_{S_q}^5$	-10.000	1.040	0.00
Travel time parameter	β_{TT}	-0.154	0.016	0.00
Perceived hardness of constraint	ω^2	0.377	0.136	0.01
	ω^3	0.405	0.144	0.00
	ω^4	0.570	0.210	0.01
	ω^5	0.861	0.328	0.01
Travel information cost-parameter	β_r	-0.913	0.216	0.00
Travel information constant	$ASC_{S_r}^1$	-3.540	0.609	0.00
	$ASC_{S_r}^2$	-3.300	0.575	0.00
	$ASC_{S_r}^3$	-2.810	0.506	0.00
	$ASC_{S_r}^4$	-0.791	0.369	0.03
	$ASC_{S_r}^5$	0.933	0.372	0.01
Error terms	σ_{ICT}	1.900	0.312	0.00
	σ_{travel}	2.450	0.323	0.00

a): For context-dependent parameters (deterministic utility of teleworking option, perceived hardness of constraint and travel time constant), the superscripts 1~5 indicate the five contextual scenarios respectively.

b): t-test for difference from zero

c): associated p-value of the t-test for difference from zero

A more detailed look at the estimates reveals some more interesting results: first, estimation results show that the scale parameter μ_{online} used to scale the utilities of the online-experiment with respect to those of the computer room experiment (i.e., $\mathrm{var}(\varepsilon_{laboratory}) = \mu_{online}^2 \cdot \mathrm{var}(\varepsilon_{online})$) is significantly smaller than 1 (the associated *t*-value equals 5.43), implying that there is more randomness (or, more strictly speaking, variation in unobserved utility) in the online setting when compared to the computer room setting. This result is intuitive, and in line with previously formulated expectations (Kagel and Roth, 1995).

When combining the travel time parameter with the information cost parameter, a proxy value of time can be computed by taking their ratio (this gives the amount of money one is willing to pay to get information which helps reduce travel time with one minute). The resulting proxy-value of time equals 10.12 €/hour, which appears reasonable.

The specified model of traveler response to ICT crucially relies on the role of constraints (in the form of preferred arrival times): they enter the utilities of travel alternatives, and as a result also indirectly impact travelers' willingness to use ICTs to acquire travel information and/or work from home. Estimation results indeed show that parameters $\omega^m, m = 2 \sim 5$, which characterize constraints in terms of their perceived hardness, are all significant. In line with intuition, the constraint parameter associated with contextual scenario 5 is the largest, followed by the constraint parameter associated with scenario 4. Parameters associated with scenarios 2 and 3 are almost equal, however, suggesting that these two scenarios were perceived as being similar by participants in terms of their constraints.

The estimates of the deterministic utilities for the telework option are all negative and significantly different from zero, implying the dis-utilities to work from home. The deterministic utilities of the telework option for contextual scenarios 2, 3, 4 and 5 $V_{S_q}^m, m = 2 \sim 5$ are not significantly different from one another, but all are significantly more negative than the utility associated with the baseline scenario of having no meetings at the office. This implies that teleworking becomes disliked to a greater extent when meetings (teleconferences) are involved; this finding is in line with intuition and realism that face-to-face meeting is in general more favorable than virtual conference-call.

Constants for the information acquisition option are all negative, except for the scenario where a very important business meeting is planned. Although this seems to be in line with intuition, it should be noted that the hardness of the preferred arrival time constraints in the different scenarios already enters the utility of information (see section 5.2, equation Eq.5-7.). In other words, the fact that the information acquisition constant in the 5^{th} scenario is larger than in the other scenarios suggests that there are aspects of information value that are not fully captured by the model's conceptualization of information value. This should not come as a surprise, given the subtle behavioral relations between risk, constraints, teleworking and travel information acquisition that the model has tried to capture.

Finally, the estimated standard deviations for the two individual specific error components δ_{ICT} and δ_{travel} are highly significant and also substantial, implying that there is considerable correlation between the unobserved utilities of alternatives in the travel nest (routes and travel information), and the ICT nest (travel information and teleworking). Analyses not reported here indicate that the final model with these error components performs (in terms of model fit) a lot better than the model without these error components. These results also highlight the usefulness of the chosen (cross-)nesting structure presented in Figure 5-1.

5.5 Conclusions

This Chapter aims to provide an econometric (discrete choice-based) specification of the behavioral model for measuring ICT's effects on accessibility in *Chapter 4*, and aims to test the resulting discrete choice model based on empirical data. First, this chapter translates the representative traveler accessibility model in *Chapter 4* towards an estimable discrete choice model form. The choice model is operationalized to integrate the notion of arrival time constraints (building on the constrained MNL-model presented in Martinez et al. (2009)) to help capture travelers' use of travel information and teleworking options in light of risky travel times and the presence of preferred arrival times. Error components are introduced to capture correlations between different ICT-options, and between different routes. Secondly, the model is estimated on the data collected by means of a stated preference travel simulator experiment that is recently performed among 137 participants.

The model estimation results show that the developed choice model fits the stated preference data well. Model fit and parameter estimates suggest that the model captures many of the behavioral mechanisms that may be present when travelers consider the acquisition of travel information, or the option to work from home, in the context of risky travel times, and arrival time constraints of varying 'hardness'. This signals that the representative traveler behavioral model for measuring ICT's effects on accessibility presented in *Chapter 4*, with an appropriate set of unobserved utility components and parameters, can be empirically operationalized into a choice model that is capable of describing travelers' actual behavior with regard to travel information-acquisition and teleactivity-engagement and capturing the interrelations between travelers' choices of travel information and teleactivities in a range of relevant activity-travel choice situations in the presence of ICTs and in the context of risk and constraints.

It should be noted that the situation that is designed in the simulator is rather simplified in order to keep the study at a tractable level, and the generic model that is presented in *Chapter 4* is operationalized in a way according to the simplified situation for ease of communication. However, several limitations of the study (both the simulator experiment and the operationalized model) that leave room for further research should be mentioned. First, whereas the travel information is considered fully reliable in the study, it is acknowledged that travel information may be (perceived as) unreliable, in particular in the context of real-time travel information (as is most relevant in the present situation) (see, e.g. Chorus et al., 2009; Ettema and Timmermans, 2006 for more discussion of travel information unreliability). Taking the unreliability of travel information into consideration would increase the realism of the model and the simulator experiment. Secondly, the departure times are pre-given in the experiment, while in reality people may reschedule their departure times when faced with arrival time constraints. To extend the model to accommodate travelers' rescheduling behavior and to consider this in the experiment is an interesting path for further research. Thirdly, the travel options included in the experiment are only concerned with commuting by cars via various routes, and only travel time and travel time uncertainty are varied as the attributes of travel options in the experiments. It would be interesting to consider other attributes (e.g., travel cost), or even other travel options (e.g., commuting by public transport) in addition to commuting by car, in future research. Fourthly, the utility of the teleworking option in the study is specified purely in the form of a variable, which is assumed to represent all relevant factors. However, it should be acknowledged that the decision whether to telework (and to conduct telemeeting when meetings are involved) is much more complicated in reality. While travel information-acquisition may be often spontaneous, adoption of teleworking could be spontaneous in some cases (as the setting in the present experiment) and be habitual in others.

For example, some individuals may spontaneously adopt teleworking when they found out that their commuting routes are highly congested, whereas many others may base the decision on enduring factors such as obligation of child-care. The decision may become more complicated when meetings are involved, as people's need for face-to-face meeting may play a critical role (see, e.g. Aguiléra, 2008; Denstadli et al., 2013). To further detail the teleworking option (including telemeeting when meetings are involved) in terms of attributes related to the context is an interesting path for further research. Note that, although relaxing these limitations would increase the realism of the study and increase the rigor of the operationalized model, it would also increase the model complexity and computational difficulty for model estimation. It remains challenging to relax these limitations without sacrificing too much tractability, especially in light of the already high computational times for model estimation based on the present collected data.

6 Conclusions, recommendations and reflection

6.1 Introduction

This chapter draws the main conclusions from, and reflects on, the research presented in this thesis. Section 6.2 gives an overview of the research conducted in this thesis. Section 6.3 presents the main research conclusions that address the two research goals specified in *Chapter 1*. Section 6.4 presents the recommendations for future research and those for policy makers with a special focus on the SAR-program. Finally, section 6.5 reflects on the research conducted in this thesis.

6.2 Overview of the research presented in this thesis

This thesis aims to *increase the understanding of the effects of ICT on accessibility*. This thesis develops a formal behavioral model to measure the effects of different forms of ICT on accessibility, and also provides related substantive insights. The following research is conducted in this thesis. First of all, this thesis conducted a literature overview, including a) an overview the physical accessibility measures that do not consider ICT-related factors and the models that have been developed to measure ICT's effects on accessibility; b) an overview of ICT's (potential) effects on accessibility; and c) an overview of the models and the methods (including data collection and analysis methods) for studying travelers' choice of ICT and ICT's effects on travel behavior. Secondly, this thesis conducted a web-survey that collected data about commuters' preferences for using travel information and teleworking. The collected data were analyzed using structural equation modeling (SEM). The potential interrelations between travelers' preferences for travel information and teleworking services were investigated. This thesis further developed a theoretical model for measuring the combined effects of both travel information (the "I" in ICT) and telecommunication facilities (the "C" in ICT) on accessibility. Numerical examples were used to demonstrate the plausibility of the model and to reflect the combined effects of travel information and telecommunication facilities on accessibility. The theoretical model was subsequently translated into a model using an estimable discrete choice model form. The data used for estimating the behavioral model were collected via a stated preference travel simulator experiment. Travelers in the experiment faced a choice set of a number of commuting routes with uncertain travel time, the options to acquire travel information and to work from home, under various arrival time constraints. In addition to the stated preference experiment conducted to collect data for model estimation, an induced preference experiment involving a predefined incentive structure was also conducted. The induced preference experiment used the same travel simulator but featured a reward which was related to the participant's choices. As presented in the epilogue of this thesis, the results from these two experiments were compared and the value of the induced preference approach was explored[117].

The remainder of this chapter presents the main conclusions from these studies, provides recommendations, and reflects on this research.

6.3 Conclusions

In order to better understand the conclusions of this thesis, the motivation for this research and the research aims (*Chapter 1*) should be revisited.

> Improving accessibility is a paramount goal of transport policies. Utilizing information and communication technology (ICT) is being increasingly recognized as a (potential) measure to help achieve the goal of improve accessibility (Van Wee et al., 2013). However, a lack of generic formal analytical models for measuring ICT's effects on accessibility limits our knowledge in this regard. This also limits our capabilities to make use of ongoing advances in ICT to improve accessibility. Given this research background, this thesis aims to develop and test a generic model for measuring the effects of ICT on accessibility, and aims to provide substantive insights into these effects.

First of all, this thesis conducted a study of the literature (*Chapter 2*), which leads to the following two main conclusions:

- Traditional physical accessibility measures, and the very few models that have been recently developed to measure ICT's effects on accessibility, are not yet suitable to measure ICT's effects on accessibility.

  First, traditional accessibility measures developed within the physical realm do not consider any ICT-related factors (e.g., virtual access to places/activities via telecommunication) into formalizations. They are therefore not able to fully measure the effects that ICT could have on accessibility (e.g., when virtual connection to

[117] Note that the conclusions of the comparison of the results between the two experiments and the discussions on the usefulness of the induced preference approach are not presented in this chapter, but in the *epilogue*.

workplace is involved). Although it is theoretically expected that these measures can be extended in order to measure such effects, they are not ready yet to be used in practice for this purpose.

Secondly, the very few models that have been recently developed to measure ICT's effects on accessibility are either difficult to operationalize and apply (e.g., some models are only developed at a conceptual level), or limited in their application (e.g., some models only focus on certain *specific* ICTs – e.g., travel information only – or *specific* categories of accessibility – e.g., job accessibility).

- We still lack insight into the effects of different forms of ICT on accessibility – both travel information (the "I" in ICT, e.g., smartphone apps for traffic information) and communication technologies (the "C" in ICT, e.g., virtual desktop connected to workplace), and their potential interactions.

  First, the ample literature on ICT's effects on travel behavior reveals that ICT has a significant impact on people's travel behavior. However, although the changes in travel behavior due to ICT-use are expected to result in changes to traveler's accessibility, our current knowledge of ICT's effects on accessibility is still limited given sparse literature, particularly empirical studies, in this regard.

  Secondly, the literature related to ICT's effects on travel behavior focuses either on the impact of travel information on travel behavior, or on the impact of the telecommunication facilities on people's engagement in physical travels. Hardly any literature concerning ICT's effects on travel behavior considers both aspects. This is despite the fact that it seems more than reasonable to expect that a traveler's responses and preferences for travel information and telecommunication facilities could be interrelated. More ICT devices have both travel information- and telecommunication-related facilities. Moreover, a traveler's use of travel information and telecommunication facilities can also be mutually influenced (e.g., a traveler chooses to work from home after having received travel information that his or her route to work is severely congested). The preferences can also be driven by the same factors or personal traits. While such potential interactions could possibly result in a synergy, our knowledge of the effects of such interactions between the "I" in ICT and the "C" in ICT on traveler's accessibility is still too limited to draw any firm conclusions in this regard.

In order to increase our understanding of ICT's effects on accessibility, this thesis conducted a series of studies (see section 6.1 for an overview of the research). The main conclusions of the studies are as follows.

The web-survey study (*Chapter 3*) concludes that **a *traveler's preferences for and use of travel information- (the "I" in ICT) and telecommunication-facilities (the "C" in ICT) are, to a certain extent, interrelated.***

Driven by the expectation of the joint and interrelated nature of travel information and telecommunication-functionalities of ICT, the research explores the relations between commuters' preferences for teleworking from home and for acquiring travel information before their morning commutes (as well as a set of possible related factors). The study found that commuters' preferences for teleworking from home and for acquiring travel information before commuting are, to a certain extent, interrelated:

- Common underlying factors or personal traits can jointly affect commuters' preferences for acquiring travel information before commuting and their preferences for teleworking from home. Driven by these common factors or personal traits, commuters who like using travel information seem to also like teleworking, and vice versa. The reliability of commuting time, *inter alia,* has a significant negative effect on both commuters' preferences for acquiring travel information and their preferences for teleworking. Commuters who perceive their commuting times less reliable are more likely to acquire travel information. Similarly, it appears that the less reliable their commuting times are, the more they prefer to telework. But the study shows that compared to the preferences for teleworking, commuters' preferences for travel information is more sensitive to the reliability of commuting time. That is, the reliability of commuting time perceived by a traveler appears to have a larger impact on his or her preference for travel information than on his or her preference for teleworking, *ceteris paribus*.

In addition, the following relations are found in the sample of the study:

- The extent to which it is possible for them to telework from home perceived by the commuters is positively associated with their preferences for teleworking from home. The possibility for teleworking may be determined by aspects such as the type of the traveler's work (e.g., whether or not the type of work can be performed via teleworking) and the culture of work environment (e.g., whether or not teleworking is acceptable and common at the commuter's employer);

- The quality of the teleworking environment and facilities perceived by travelers (e.g., the easiness to access files and software for teleworking, the availability of sufficient ICT equipment) is positively related to their preferences for teleworking from home – the better the quality is, the more commuters prefer teleworking;

- Travelers' perception of the extent to which travel information is available to them is positively related to their preferences for travel information. The perceived availability of travel information may reflect, for example, whether someone finds it difficult to find travel information;

Two other results from the web-survey study are worth mentioning:

- Among the sample respondents, the perceived reliability of travel information does not seem to significantly affect their preferences for travel information. However, this finding should be treated with caution, since the literature has well established that the reliability of travel information can affect travelers' choice of travel information. Restricted by the available data collected in this study, it is yet uncertain whether this finding is valid. Further study is therefore advised before any conclusion can be made. But the investigation on this result reveals that this finding does not affect the other conclusions mentioned above.

- For the sample respondents in the study, the perceived availability of teleworking and the perceived quality of teleworking environment and facilities do not affect their preferences for travel information, while the perceived availability and reliability of travel information do not affect their preferences for teleworking. While it is reasonable to expect that such interaction effects could exist between these factors (e.g., a traveler may

> have a stronger preference for travel information if the option to telework is more available to him or her), at least the sample respondents in this study do not show such subtle interactions. This is an interesting yet important result, as it contrasts the expectation that is addressed throughout this thesis and formulates the fundamental essence for the research. That is, it is expected that interactions may exist between the "I" and the "C" in ICT, and such interactions may play a role in travelers' choices of ICT-use. This could in turn result in interactions in terms of their effects on accessibility. Further study is advised to draw firm conclusions whether this result is specific to the sample in the web-survey or generally valid, while the experimental data collection conducted later in this thesis (see *Chapter 5*), compared to the web-survey, allows for a more systematic assessment to what extent such expected interaction plays a role.

Although the survey results do not suggest the existence of the expected interactions between the "I" and the "C" in ICT, based on theory and introspection of behavioral realism, it is still believed that such interactions may exist and play a role in traveler's choices concerning ICT-use and in turn in their effects on accessibility. Therefore, this is still considered as one important aspect in order to better understand ICT's effects on accessibility. As a result, such expected interactions are still embedded in the model developed in this thesis for measuring ICT's effects on accessibility (see *Chapters 4*). This accessibility model (and hence the interactions) is tested later in *Chapter 5* using a set of data collected via a tailor-made simulator experiment:

> This thesis (*Chapter 4*) develops an accessibility model that takes into account individual travel behavior (choice process) and measures the effects of two different forms of ICT – information-related technologies (for travel information) and telecommunication-related technologies (for teleactivities) – on accessibility. The model focuses on individual-, utility-based, short-term potential accessibility. It considers both the riskiness related to alternatives and the constraint that a traveler may face when making decisions in order to capture the negative effects they may have on the traveler's accessibility. In particular, not only does the model measure the effects of both travel information and teleactivities on accessibility, but it also considers the possible interaction between the two forms of ICT. A traveler's perception of the value of travel information for assessing alternatives can differ in cases whether a teleactivity option is present or not. The difference results from the expectation that, when a teleactivity option is also considered by a traveler as an alternative in his or her choice set, acquiring travel information may not only help assess the physical activity-travel alternatives, but also help him or her to make choices between the teleactivity option and the physical alternatives. In turn, the effects of ICT on accessibility in situations where both forms of ICT are available may be different from the effects in situations where only one of them is present. However, it should be noted that the existence of such interaction effects per se is not arbitrarily imposed in the developed model. Rather, such interactions follow directly from the underlying assumption that the model is developed based on. That is, while the teleactivity option is an alternative to the physical activity-travel alternatives for a traveler, the value of travel information is conceptualized in terms of the utility of the traveler being able to choose from the choice set – including the teleactivity option – after having received the information.

The accessibility model is tested via *numerical examples* (*Chapter 4*), and is operationalized into *the LogSum format* (i.e., the LogSum approach to accessibility (Ben-Akiva and Lerman, 1985) – also to be discussed later in section 6.5). It is also translated into *a choice model that is estimated based on a dataset collected via a simulator study* (*Chapter 5*). The numerical examples and the estimation results show that the accessibility model can be used to measure the negative effects of the riskiness and the constraints related to alternatives on accessibility, and the combined effects of travel information and teleactivities on accessibility. Also, these results show that the accessibility model can be empirically operationalized into a choice model that is capable of describing travelers' actual behavior with regard to travel information-acquisition and teleactivity-engagement and capturing the interrelations between travelers' choices of travel information and teleactivities in a range of relevant activity-travel choice situations in the presence of ICTs and in the context of risk and constraints.

In particular, the following findings are derived from the numerical analyses of the accessibility model and the estimation of the choice model via the simulator experiment data:

- ***The riskiness and constraints related to alternatives may, but not always, have a negative impact on accessibility:***

  The research shows that the *riskiness associated with alternatives perceived by a traveler in combination with the constraints that an individual may face when making decisions may, but not always, have a negative impact on an individual's accessibility.*

  It is shown that the riskiness and constraints related to travelers' alternatives may have a negative impact on accessibility. A commuter's accessibility would be reduced in the case that he or she has an arrival time constraint (e.g., to arrive at the office before a certain time for an appointment) while has the chance of being late due to risky commuting time. It is also found that the more likely such a constraint is to be violated (e.g., due to larger riskiness) or the harder such a constraint is (i.e., the higher disutility it incurs associated with crossing a constraint), the larger the negative impact is.

  However, the results also reveal that the mere presence of constraints and/or riskiness does not always cause a negative impact on accessibility. When a traveler expects that a present constraint is unlikely to be violated or no disutility would be incurred by crossing a constraint, the present constraint and alternative riskiness would not have a negative impact on the traveler's accessibility. In the above-mentioned case, when the commuter perceives very little chance of being late (e.g., due to a sufficiently early departure), the arrival time constraint would not cause a negative impact on the commuter's accessibility even when the commuter is faced with a highly unreliable commuting time.

- ***Travel information (I) and teleactivities (C) may, but not always, benefit accessibility:***

  The research shows that *the option for acquiring travel information to assess alternatives and the option for conducting teleactivities to substitute travel may, but not always, have benefits on accessibility.*

First, the research shows that travel information positively influences a traveler's accessibility, when he or she perceives the travel information, if acquired, to be able to help reduce the uncertainties related to alternatives. The benefits are even enhanced in the presence of multiple risky alternatives with similar expected likelihood to violate certain constraint faced by the traveler.

Secondly, the research shows that having the option of conducting a teleactivity increases a traveler's accessibility when he or she perceives the teleactivity option with a higher utility than the other travel-involved alternatives. This could happen when the traveler perceives the teleactivity option to be able to not only substitute physical travel but also help relax or avoid constraints.

However, the results also reveal that travel information and teleactivities do not always have these benefits on accessibility. In a traveler's eyes, the travel information option for assessing alternatives tends to become redundant if he or she can easily identify the best of the available alternatives without the help of information (compared to the situation where he or she has similar alternatives and the information can help assess alternatives and break the tie between these alternatives). Similarly, the teleactivity-option also has no benefits to the traveler's accessibility if it is strongly disliked by the traveler[118].

These two results are not new or surprising as they are not only in line with the expectation based on behavioral realism, but also well established in the literature (see *Chapter 2*). However, this shows that the developed model has face validity – i.e., that it produces results that are in line with expectations and as described in the literature. Furthermore, although these results seem open doors (and hence serve to validate the developed model), the developed model does allow for a quantification of the relative magnitude of these effects. In this regard, this can be considered as a methodological, but not a substantive, contribution of the research, which is also in line with the research goals.

However, more importantly, following the quantification of the effects of ICT (taking into consideration of both travel information and teleactivities) on accessibility via the application of the model, it is found that:

[118] Note that, however, whether or not the options of travel information and teleactivity are considered redundant often differs according to different situations in reality, even for one individual. For example, one may strongly dislike teleworking in some cases (where the teleworking option becomes redundant and hence there is no accessibility benefit from the teleworking option), while like teleworking in some other cases. This may still result in benefits from teleworking on his/her accessibility to work as a whole. In addition, from the perspective of analysts who cannot completely observe/measure individual's preferences, whether or not travel information- and teleactivity-options are redundant to someone is not always certain, and thus neither is whether or not they have accessibility benefits.

- ***There is possible synergy between travel information (I) and teleactivities (C) with respect to their effects on accessibility – the joint availability of travel information and teleactivities to travelers may reinforce the accessibility benefits of both of them.***

  The research shows that *in some situations there could be synergy (a positive interaction effect) between travel information and teleactivities with respect to their effects on accessibility, while no or negative interaction effects may occur in other situations*.

  The research shows that different interaction effects of travel information and teleactivities on accessibility may occur in different scenarios where the traveler's choice composition – the availability of travel information- and telecommunication-facilities – varies:

  - ***A positive interaction effect (synergy)*** occurs when a traveler has a physical activity-travel alternative that has uncertainties (e.g., perceived by the traveler in terms of its attributes) but still can be easily identified as the most preferred among all available physical activity-travel alternatives to him or her. In addition, the traveler has a teleactivity-option that is comparable to this most-preferred physical activity-travel alternative (in terms of the utilities perceived by him or her). In these situations where there is uncertainty regarding the best physical activity-travel alternative, travel information for assessing the activity-travel alternatives, if acquired, can be used to effectively help the traveler reduce the uncertainties related to the physical activity-travel alternative. This in turn helps the traveler choose between the most-preferred alternative and the teleactivity option with comparable utility. Without the teleactivity-option, the travel information option becomes redundant as the traveler can easily identify the best of the available alternatives without the help of acquired information.

  - ***No interaction effect*** occurs in situations where one physical activity-travel alternative is considered to be superior to all the other alternatives (including the teleactivity option) by a traveler. In these situations, the availability of the teleactivity option does not contribute to the accessibility (because the teleactivity-option is considered inferior and disliked). Its availability does not make the information more valuable because the traveler does not need travel information to compare between the teleactivity option and the superior physical activity-travel alternative.

  - ***A negative interaction effect*** occurs in situations where a traveler faces comparable yet uncertain physical activity-travel alternatives, while also provided with a superior teleactivity option (in terms of their utilities perceived by the traveler). In these situations, the traveler's accessibility would be determined by the superior teleactivity option as viewed by the traveler. Providing travel information for assessing the physical activity-travel alternatives does not add value due to the superior teleactivity option. On the contrary, if the teleactivity option is not available, the travel information can add value as it can help the traveler assess these comparable, yet uncertain, physical activity-travel alternatives.

In summary, with its two aims – to develop a model for measuring ICT's effects on accessibility and to derive related substantive insights – this thesis reaches the following conclusions, with respect to these two aims.

First of all, this thesis identified that a traveler's preferences for and use of travel information- (the "I" in ICT) and telecommunication-facilities (the "C" in ICT) are, to a certain extent, interrelated. The research on commuters' preferences for teleworking from home and their preferences for acquiring travel information finds out that common personal traits or underlying factors (e.g., reliability of commuting time) can jointly affect commuters' preferences for teleworking and travel information.

Secondly, this thesis develops an accessibility model that takes into account individual travel behavior (choice process) and measures the effects of different forms of ICT – technologies for travel information and those for teleactivities, including their potential interactions – on a traveler's accessibility. This model can be used to measure the effects of riskiness and constraints of alternatives on accessibility, and to capture the combined effects of travel information and teleactivities on accessibility. The research shows that the accessibility model can be empirically operationalized into a choice model that is capable of describing travelers' actual behavior with regard to travel information-acquisition and teleactivity-engagement. In addition, it is able to capture the interrelations between travelers' choices of travel information and teleactivities in a range of relevant activity-travel choice situations in the presence of ICTs and in the context of risk and constraints. It furthermore implies that, based on a series of relatively straightforward assumptions, such a model can indeed be built and can describe the very subtle behavioral effects of ICT on accessibility (which is described in the following point).

Finally, this thesis shows that, although no interaction effect or even a negative effect could occur, there *could* be synergy between travel information and teleactivities with respect to their effects on accessibility. The joint availability of technologies for travel information and supporting teleactivities to travelers may reinforce the accessibility benefits of each category of technologies separately. When a traveler has an obviously preferred, yet uncertain, physical activity-travel alternative, providing a comparable teleactivity alternative to the traveler reinforces the value of acquiring travel information which can help the traveler compare these two alternatives and in turn help the traveler in decision making. Acquiring the travel information does not add such value in case of the teleactivity alternative being not available.

It should be noted that these conclusions are subject to limitations. The limitations and in turn the recommendations for future research are discussed in section 6.4.3.

6.4 Recommendations, with a special focus on the SAR-program

This section presents recommendations for three aspects. First, section 6.4.1 provides policy recommendations and implications for utilizing ICT to improve accessibility, with a special focus on the SAR-program. Section 6.4.2 provides recommendations for how to utilize the model that is developed in this research for measuring ICT's effects on accessibility. Section 6.4.3 gives recommendations of areas for future research based on the limitations of this research.

When reading these recommendations, the reader should note that this thesis is a product of the SAR-program, which focuses on increasing the accessibility of the Dutch Randstad area in particular. As a consequence, many of the recommendations formulated below should be understood within this context, which I briefly state before moving to the actual recommendations. As addressed in the Dutch National Policy Strategy for Infrastructure and Spatial Planning (*Structuurvisie Infrastructuur en Ruimte*) (Ministerie van Infrastructuur en Milieu, 2012), improving accessibility is one paramount goal of Dutch transport policies. Given this background, the Sustainable Accessibility of the Randstad (SAR) research program[119] is initiated by the Dutch Ministry of Infrastructure and the Environment and the Dutch Ministry of Economic Affairs, Agriculture and Innovation, and administered by NWO (Netherlands Organization for Scientific Research). The program aims to give vision on what is needed to guarantee the accessibility of the Randstad in the long run. In particular, information and communication technology (ICT) is being considered as a (potential) measure, *inter alia*, to help achieve the goal of improving accessibility (Van Wee et al., 2013).

This research is part of the TRISTAM (Traveler Response and Information Service Technology: Analysis and Modeling) sub-program[120] in the SAR program. According to the approved research proposal of the TRISTAM program, "this research project is expected to extend the reach of utility-based measures of accessibility by incorporating travelers' use of ICT as a possible substitute for travel, and travelers' limited awareness and learning from travel information. A choice model is expected to be developed within the traditional paradigm of discrete-choice analysis, and be tested empirically using data collected in a tailor-made laboratory setting. Insights about using ICT in transport policies for improving accessibility are expected." (Texts are quoted from the research proposal).

6.4.1 Policy recommendations and implications for utilizing ICT to improve accessibility

The following recommendations aiming for practitioners and policy makers with regard to how to utilize ICT to improve accessibility of the Dutch Randstad area are derived from two perspectives. The first perspective gives recommendations in terms of the important factors that are recommended to be taken into consideration when developing ICT-related policies for improving accessibility of the Dutch Randstad area. The second perspective gives a discussion on the implications on how certain ICT-related policy instruments could be used based on the findings of this research.

From the first perspective, four major aspects that are critical and recommended to be considered in developing ICT-related policies to improve accessibility of the Dutch Randstad area can be highlighted. While the first two aspects can be considered as the derivation from the overview of the previous studies in the literature, the following two aspects are derived from this research.

> First, it is critical to address this fundamental question on how accessibility shall be defined before any policy strategies are developed, to avoid misinterpretation and also to ensure that any ICT-related policies can be objectively evaluated. While

[119] More information of the SAR program can be found on the program's official site: http://dbr.verdus.nl.

[120] More information of the TRISTAM sub-program can be found on the program's official site: http://dbr.verdus.nl/pagina.asp?id=744

improving accessibility is widely acknowledged of importance to people and is a paramount goal of transport policies in the Netherlands, the term “accessibility” tends to be defined and interpreted in many different ways. It is partly because there are a wide range of accessibility definitions, but also because accessibility seems to be often poorly defined in many contexts. It is therefore recommended to clearly define the concept of accessibility. The definition and measures should be acceptable for policy-makers and practitioners. This also leads to the second advice.

Secondly, it is essential to introduce new accessibility measures in addition to those that are currently used by the Dutch government and policy makers (see Hoogendoorn-Lanser et al., 2012 for an overview of the measures that are commonly used by the Dutch government and policy makers). Despite their advantages, to the best of the author’s knowledge, these current accessibility measures that are mostly used ignore the role of ICT largely, and are not sufficient to capture ICT’s effects on accessibility. These measures can fall short in their capability to evaluate whether and to which extent the developed ICT-related strategies could result in improvements of accessibility of the Dutch Randstad area. For example, someone’s office/work can be highly inaccessible by car due to congestion, but at the same time be very accessible by ICT – the measures that ignore the role of ICT largely then become insufficient to capture the increase of accessibility due to ICT in this case. An accessibility measure that is based on a wider-scope definition becomes desirable in this sense, while this research shows that the so-called LogSum accessibility measure, which adopts a utility-based accessibility definition and takes discrete choice model-format, can be effectively and tangibly extended to incorporate traveler’s preferences for ICT into the measurement. It in turn can be used to effectively measure ICT’s effects on accessibility (e.g., for the above-described example where a traveler’s office/work is highly inaccessible by car while very accessible by ICT). The LogSum measure of accessibility is therefore strongly advised to be introduced into use when ICT-related policies for improving accessibility are to be planned and to be evaluated.

Thirdly, it is important to take travelers’ choices of and preferences for ICT into consideration when ICT-related policy strategies for improving the accessibility of the Dutch Randstad area are being developed. Although it has been increasingly acknowledged that ICT has impacts and may benefit a traveler’s accessibility, travelers’ preferences and choices with regard to the usage of ICT seem to be often ignored. This is largely because, on the one hand, the current accessibility measures that are mostly used for policy development do not consider these to a large extent, and, on the other hand, we have relatively limited related knowledge. This research, however, shows that varying travelers’ preferences and choices of the usage of ICT play a critical role in determining whether and to which extent ICT could help improving accessibility. Ignoring this aspect is most likely to result in biased estimation of the effectiveness of certain ICT-related policies and strategies for improving accessibility, and in turn to result in difficulty in evaluating these candidate policy options to improve accessibility. As without knowledge of travelers’ preferences in this regard, doing a proper assessment (e.g. cost-benefit analysis) of these policy options becomes difficult. It is therefore advisable for practitioners and policy makers to explicitly incorporate travelers’ preferences and choices in measuring the effects of ICT on accessibility and in developing and evaluating related policies.

Finally, it is advisable for Dutch policy makers to take into account both components – both travel information- and teleworking/telecommunication-services – when considering policies, rather than two separate policies, in developing policies for improving accessibility of the Dutch Randstad area. This is because synergy benefits can be reaped. It is not only because both types of services are increasingly being provided via the same technology devices and media, but also because a traveler's use of travel information- and teleworking/telecommunication options, as shown in the research, can result in synergy. That is, travel information that can help a traveler to assess travel alternatives and make choices becomes more valuable when the option to telework is present (and considered by the traveler as one of the choices) in addition to the travel alternatives available to the traveler. The option to telework also becomes more valuable when appropriate travel information is provided, as a traveler can decide on a specific day whether or not to telework at home based on the travel information. Such interaction in turns results in synergy as well for their effects on travelers' accessibility. Therefore, it is strongly advisable to take into account both the "I" and the "C" in ICT when considering policies or investments in order to gain more benefits in utilizing ICT to improve traveler's accessibility of the Dutch Randstad area.

Having discussed the recommendations from the first perspective, it is also of practical interest and relevance to discuss how certain ICT-related policy instruments can be used to improve accessibility for the Dutch Randstad area. Note that different from the above recommendations that are derived directly from this research, the following points are indirectly derived from the findings in this research on what types of factors could affect a traveler's preferences for use of travel information- and teleworking-services and what types of factors could affect a traveler's accessibility. These following points should be better regarded as conditional advice with implications of practical and policy relevance, while further in-depth investigations for the related points are still recommended before adopting or implementing them in practice.

First, it tends to be worthy of efforts to first investigate the critical factors and constraints that travelers are faced with and affect their accessibility most. The obtained information then can be used to evaluate what types of ICT-related instruments can be utilized most cost-effectively. It is shown in this research (*Chapters 4* and *5*) that, while constraints may cast negative effects on a traveler's accessibility, the extent to which these negative effects will occur is largely affected by the tendency of the constraints being violated by the alternatives available to the traveler. This finding, to an extent, implies that the effectiveness of ICT policies in improving travelers' accessibility is subject to the effectiveness of the related ICT-services (for what types of travelers in which area) in helping travelers relax or even avoid constraints. For example, it can be reasonably expected, although it is not particularly validated in this research, that travelers who commute to workplaces by car via routes with less reliable commuting time and more chances of congestion, may tend to be more affected by travel constraints (e.g., being late for work due to higher chances of congestion), resulting in reduction in accessibility more often. Policies to increase the chances of teleworking for these travelers could be more cost-effective and beneficial for their accessibility than implementing the same policies, e.g., for those commuting by bicycle (who would be less affected by congestion than those commuting by car).

Secondly, while it has been advised to take travelers' preferences for ICT into consideration, it is still advisable to further clarify the related contexts in developing or evaluating ICT-related instruments, in particular when both travel information- and telecommunication-services are concerned. As shown in this research, different interaction effects could result from travelers having different preferences for travel information- and telecommunication-service subjective to different context. These findings indicate that the effectiveness of ICT in improving accessibility and the synergy between travel information- and telecommunication-services are largely subjective to the different contexts where travelers are situated. Therefore, it is advisable for practitioners and policy makers to distinguish the contexts and to further evaluate travelers' preferences for travel information- and telecommunication-services according to the particular contexts when evaluating ICT-related policy instruments to be implemented in the Dutch Randstad area.

Finally, a number of factors that could affect commuters' preferences for acquiring travel information and teleworking are concluded from the research, giving implications to what kinds of policy strategies and measures can be utilized to promote commuters' use of travel information and teleworking. These factors include: a) the reliability of commuting time. This factor has a significant negative effect on commuters' preferences for acquiring travel information and for teleworking – implying that implementing ICT-services may be more beneficial to travelers who commute via routes with more unreliable commuting time than to those whose commuting times are more reliable (as also mentioned in the above first point); b) the extent to which commuters are allowed to telework from home. This factor may be determined by the aspects such as the type of work and the culture of work environment, and it has a positive effect on commuters' preference for teleworking from home; c) the quality of the teleworking environment and facilities (e.g., the easiness to access files and software that are needed for teleworking, the availability of sufficient ICT equipment for teleworking), which has a significant positive effect on commuters' preferences for teleworking from home, and d) the extent to which travel information is perceived available to travelers (e.g., how difficult it is for a traveler to find travel information), which has a significant positive effect on travelers' preference for travel information.

6.4.2 Recommendations for utilizing the model developed in this research for measuring ICT's effects on accessibility

In light of these implications addressed above in section 6.4.1, this thesis contributes in this regard – the developed model (the accessibility model developed within the utility-based paradigm and its discrete choice model-form variant) in this thesis provides an alternative to the current available models in the literature and in practice. This model provides an alternative to more effectively measure the effects of both forms of ICT on accessibility, as it explicitly takes travelers' choices and preferences, and both the "I" and the "C" in ICT into consideration. This contributes to the lack of such models in the literature and in practice. This section further discusses and provides recommendations with regard to how to apply the developed model in case of studies, and how the model can be utilized in actual planning and policy-design processes.

First of all, it is believed that there are two ways in which the model can be put into practice.

One way is that the model can be used in an exploratory sense to identify possibilities for obtaining synergy between investments or other policies in different forms of ICT. For example, the model may be applied to identify in what situations investments in travel information and/or teleworking facilities may lead to a situation where benefits of these investments in the two types of ICT might reinforce one another, leading to additional user benefits at least in terms of increases in accessibility.

Another way is to utilize the model to predict and quantify accessibility benefits of ICT-investments in general. These effects can subsequently be used in the assessment (e.g., cost-benefit analyses) of policy options in transportation planning – ultimately leading to a more informed process of policy-development.

However, it should be noted that it is critical to properly specify the developed model according to real-world situations, and to empirically estimate and validate the model in advance of any applications in actual planning and policy-design processes, for the following reasons.

First, to identify the choice set composition in real-world situations – the alternatives that are available in reality and actually considered by travelers when they make choices – is important before applying the model. As heterogeneity exists among individual travelers, the effects of the same ICT-related services on different traveler's accessibility differ. The heterogeneity in terms of the alternatives available and actually considered by different travelers should be considered in using the model to quantify accessibility benefits of ICT in order to more objectively evaluate the follow-up planning and policy design. It becomes more critical to properly define individuals' perceptions of the choice sets when exploring the synergy effects between travel information and teleactivities. For example, while the decision to acquire travel information, in general, may be often spontaneous, the choices of teleworking can be driven by (relatively) long-term factors such as the obligation of child-care and the residential location. For the people who decide to telework only based on these long-term factors rather than short-term factors such as commuting times, the option of travel information to assess the expected commuting time before commuting would probably not affect their choices of teleworking and therefore no synergy effects would be achieved in this example.

Secondly, it is important to properly identify relevant alternative attributes related to travel information and teleactivities in the model. As shown by the survey study (*Chapter 3*), in addition to those that are considered in the study, there are many other factors that are relevant to travelers' preferences for travel information and teleactivities. Literature also identifies a wide range of factors that could impact travelers' choices of travel information and teleactivities (see *Chapter 2*). To properly define related attributes in operationalization of the model in real-world situations according to the particular study aim becomes increasingly important.

Having addressed the importance to properly specify choice sets, choice alternatives and alternative attributes in model specifications, another challenging yet important task is to collect sufficient empirical data in order to estimate and validate the specified model.

It is critical for analysts to correctly observe and measure travelers' perceptions of choice sets, alternatives, and attributes (including the uncertainties related to alternative attributes). The research (travel simulator study and model estimation) in

Chapter 5 shows that the model can be successfully estimated based on travel simulator data, and the estimated model is able to capture many of the behavioral mechanisms that have been presented by the sample in the study. It is also expected that it does not pose particular difficulties when using stated choice data. However, it becomes difficult and hence becomes a challenge when the model is to be applied to case studies and to planning and policy-designing where revealed data are often used. Great care must be exercised in terms of measuring traveler perceptions of choice sets, choice alternatives and attributes (including the associated attribute-uncertainty).

Finally, the developed model is built around several assumptions. It is important to note these assumptions when applying the model in practice and in turn interpreting and using the results derived from the applications for planning and policy-designing.

First, the model places fairly strict assumptions on traveler's behavior, in which the traveler is assumed to be fairly rational and a utility-maximizer, and as such the measure of accessibility is conceptualized and operationalized within the RUM (random-utility-maximization) paradigm (i.e., the LogSum approach to accessibility (Ben-Akiva and Lerman, 1985)). As addressed in *Chapter 2* and also reflected later in section 6.5, despite the advantages, the assumption of travelers being rational and utility-maximizers in such conceptualization and operationalization of accessibility (and hence the subtle computations and relations for the value of teleactivity and travel information assumed in the model) may be considered as not realistic from a psychological or bounded rationality perspective. Some of the assumptions are hence open to debate due to their (lack of) behavioral validity. It should also be noted that the operationalization of the accessibility measure as a LogSum in this research is one option among many others, and all the results derived in this research given the related assumptions might not hold for different ways of operationalization. Secondly, the model focuses on *individual* accessibility rather than on *aggregate* accessibility. That is, the model is developed from a perspective of a representative individual traveler and considers the individual's choices of ICT, while aggregate accessibility should also take into consideration interactions between people (e.g., the interactions of ICT-use between different household members). Thirdly, the model focuses on expected (valuation of) accessibility at the time of making the decision instead of experienced or realized accessibility. That is, the model focus on the moment right *before* an individual has received information and/or right *before* he or she has made choices between location-based alternatives and, possibly, the teleactivity-option. In addition, this thesis does not consider *long-term* accessibility effects related to, for example, changes in land use patterns. Another assumption is that the individual considered in the model is assumed (to know that he or she is) fully capable of using different forms of ICT. That is, the potential limitations in people's ICT-use capabilities are not explicitly considered. Furthermore, in the model, the travel information is assumed to be fully reliable, while it is often perceived unreliable in reality by travelers. It is therefore likely that any application of the model without any relaxation of this assumption would yield a somewhat optimistic picture of the impact of travel information on accessibility. A final assumption that is made is that the information only refers to known travel alternatives. As such the model does not consider the situation where the information service is also able to generate previously unknown alternatives, which is considered as one possible aspect for further model extension.

Each of these assumptions has been made to keep the model's tractability at an acceptable level. However, it is important to be aware of these assumptions when the model is to be applied.

6.4.3 Recommendations of areas for future research

This section points out two areas for future research in general based on the limitation of the research (one being *model-oriented* and one being *outcome-oriented*).

The *model-oriented* area for further research is with regard to the developed model in this thesis. Several aspects are recommended for future research aiming at better *measuring* ICT's effects on accessibility.

> One avenue for future research is to extend the scope and applicability of the current model. As addressed in *Chapter 4* and in the above section 6.4.2, the model is developed based on several assumptions, and is therefore limited in its scope of application. The aspects that are recommended for model extension include, but are not limited to: a) people's capability to use ICT equipment – the current model assumes that a traveler is capable of using different forms of ICT, while the usage of ICT is actually constrained by individual capabilities (see related literature in *Chapter 2*); b) ICT's effects on aspects such as activity-travel pattern fragmentation, multitasking, or other types of more complicated space-time constraints – the current model focuses on ICT's general effects on travel alternatives' attributes and constraints, while ICT can affect travel behavior and in turn a traveler's accessibility in multiple ways (see *Chapter 2*); and c) activity duration (re-)allocation and activity pattern (re-)scheduling – the current model is concerned with a traveler's discrete choices, while ICT-use could result in activity duration (re-)allocation and activity pattern (re-)scheduling. In order to increase the capability to capture the different facets of ICT's effects on travel behavior and accessibility, to further extend the current model or even to develop new models to incorporate these factors into the model is advisable for future research.
>
> Another model-oriented avenue for future research is to extend the model into other paradigms or even develop new model within these paradigms. The model in this thesis is developed within the Random Utility Maximization-paradigm (LogSum accessibility measure) and focuses on individual potential accessibility. There are several interesting directions for model extension or new model development within other paradigms. First, it is interesting to adopt *another decision-theory paradigm*, such as random regret minimization (Chorus, 2012a, b), to capture traveler's choice of ICT and ICT's effects on travel behavior and accessibility. The second paradigm for future model extension or new model development is concerned with the so-called *realized* or *experienced* accessibility. It has been argued that accessibility should preferably be conceptualized and operationalized in terms of experienced-utility (i.e., traveler's evaluation of a chosen alternative after the choice has been made) (Chorus and de Jong, 2011). A third interesting paradigm for model extension or development is *aggregate accessibility* for (a subset of) population, rather than individual accessibility. Another paradigm is to extend the model or develop new models to measure *long-term accessibility* and ICT's effects related to, for example, changes in land use patterns and accessibility (see e.g., Eliasson, 2010; Neuteboom and Brounen, 2011; Van Wee, 2002).

The *outcome-oriented* area for further research is concerned with the limitations of the empirical studies conducted in this thesis. Three possible aspects for future research aiming at better *understanding* of ICT's effects on accessibility are described as follows.

> One aspect for future research is concerned with the web survey study (*Chapter 3*). First, it is found that common underlying factors or personal traits can affect travelers' preferences for travel information and their preference for teleworking. However, as addressed in *Chapter 3* and section 6.3, the results show that the perceived availability of teleworking and the perceived quality of teleworking environment and facilities do not affect the survey respondents' preferences for travel information. The perceived availability and reliability of travel information do not affect their preference for teleworking. This contrasts with what is reflected by the results from the simulator experimental study (*Chapter 5*). Compared to the web-survey, the experimental simulator data collection allows for a more systematic assessment to what extent the expected interaction plays a role. The simulator study results also prove the existence of such interaction effects. However, further in-depth investigation is still recommended. One possible avenue is to utilize the web-survey study in this thesis, but in a modified format – for example, to test on another/bigger sample or use different measurement variables to operationalize the constructs. Secondly, it is advisable to extend the scope of the factors that might be relevant to travelers' preferences for ICT, in addition to the variables that were considered in the web survey study.

> Another interesting aspect for future research is to collect other data sources, in particular revealed preference data, to estimate the choice model. This research collected data via a travel simulator experiment, and used the travel simulator data to estimate the choice model (*Chapter 5*). The model estimation results shows that the developed model in this research captures many of the behavioral mechanisms that may be present when travelers consider the acquisition of travel information, or the option to telework from home, in the context of risky travel times and arrival time constraints of varying 'hardness'. However, it would also be an interesting avenue to collect other data sources, in particular revealed-preference data, to estimate the choice model.

> The third aspect for future research is to apply the developed accessibility model (and the related choice model) into case studies, in order to derive more empirical insights into ICT's effects on accessibility. One interesting aspect is to explore the interaction effects between travel information and telecommunication services among a group of travelers in real-life situations, in order to gain more empirical insights into the effects of ICTs on accessibility and the possible synergy between the "I" in ICT and the "C" in ICT.

6.5 Reflection

This section reflects on the research in terms of the methods used in the research and the related outputs. The reflection on the research focuses on two main aspects: a) the use of random utility-based accessibility measure in this research; and b) the focus and the scope of the model developed in this research for measuring ICT's effects on accessibility.

First, it should be noted that the random utility-based accessibility measure (i.e., the LogSum approach to accessibility (Ben-Akiva and Lerman, 1985)) also has its own advantages and limitations.

> This research uses the *random utility-based accessibility* measure to develop the model for measuring ICT's effects on accessibility. The random utility-based measure, rather than other types of measures, is adopted given its theoretical soundness, behavioral realism (particularly for study of ICT's effects) and the advantages in economic evaluations of transport and spatial planning policies. It should be noted, however, that random utility-based measures have also been criticized for the difficulty of being interpreted and communicated. In addition, it is also arguable with regard to the ambiguity of what they actually measure (measure of accessibility or evaluation of accessibility, and measure of experienced utility or decision utility). (see, e.g. Chorus and de Jong, 2011; Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004 or *Chapter 2* of this thesis for more detailed discussions). The long debate on the advantages and limitations of different types of measures does not result in agreement on best measure of accessibility for any situations or aims. No simple and perfect solution would seemingly appear soon for the general dilemma that accessibility measures being more theoretically sound tend to be less practically favorable in terms of interpretability and communicability. Rather, different context and different demand for different situations or aims could result in different choices of accessibility measures. In particular, random utility-based accessibility is adopted in this research given, on the one hand, the context and the aim of this research, and, on the other hand, the advantages of random utility-based measures. However, it is anticipated that some may still hold different perspectives from what is adopted in this research – i.e., accessibility being operationalized as the maximum utility that an individual can derive from a set of activity-travel choice. Whoever finds LogSum approach less appropriate being adopted as a measure of accessibility are invited to interpret it as being a measure of people's evaluation of accessibility (which seems a more acceptable concept in general), or even being a measure of user benefits (which seems a more general and neutral concept).

Secondly, it is believed that the developed model contributes to both the literature and future research. It is also believed that it is of potential to be extended or applied to capture more types of ICT's effects than those considered in this research. However, it should be noted that the developed model in its current form does not fully capture all types of effects that ICT could have on accessibility, for the following reasons.

> This research develops a generic model that focuses on short-term individual potential accessibility, and focuses on the two major effects of ICT – both teleactivities and travel information (including their potential interactions) – on accessibility. It is believed that this model contributes to both the literature and future related research. It also has the potential to be extended or applied to capture more types of ICT's effects on accessibility than those considered in this research. However, it is acknowledged that the developed model in its current form does not fully capture all types of effects that ICT could have on accessibility. As presented in *Chapter 2*, literature has identified various (potential) effects of ICT – travel information and teleactivities, respectively – on accessibility. The effects of ICT such as activity-travel fragmentation, multitasking, or activity-pattern re-scheduling due to ICT-use are not considered in the model, even though they may play an important

role in people’s daily use of ICT. Moreover, different context involves different sets of factors to be considered, such as interactions between people with regard to ICT-use for aggregate accessibility, and land-use pattern due to ICT-availability for long-term accessibility. These examples of factors seem to be less important when individual and short-term accessibility is concerned. They are therefore not considered in the model in this research in order to keep model tractability at an acceptable level. But they may become critical once a different context is concerned. Given these arguments, there is still plenty of room for further research for better or even fully capturing the various effects that ICT could have on accessibility at various levels. In particular, given the complexity of the topic, it seemingly remains an important yet challenging topic for further research to develop models that could capture all types of ICT’s effects on travel behavior and in turn on accessibility at different levels, without the cost of losing too much tractability and practicality.

7 Epilogue: Induced preference approach for collecting travel choice data: an explorative empirical comparison with stated preference approach

This *epilogue*, together with *Chapter 5*, has formed the basis of the paper: Lu, R., Chorus, C., & Van Wee, G.P., (2014). Travelers' use of ICT under conditions of risk and constraints: an empirical study based on stated and induced preferences. *Environment and Planning B: Planning and Design*, 41(5), 928-944.

Abstract

This *epilogue* aims to explore the usefulness of the induced preference approach as an alternative paradigm for collecting travel choice data via a comparative study of the results between the stated and the induced preference experiments that were conducted in this research for data collection. Different from the stated preference experiment which featured a fixed participation fee, the induced preference experiment featured a reward which was related to participants' choices. The collected induced preference experiment data were pooled together with the stated preference data to estimate the discrete choice model for travelers' use of ICT under conditions of risk and constraints presented in *Chapter 5*. The results between the stated and induced preference experiment are compared. The comparison results suggest that evidence for the usefulness of the induced preference approach for collecting travel choice data is mixed, at best.

7.1 Introduction

The discussion on the usefulness and limitations of the induced preference approach for collecting travel choice data presented in this epilogue is based on the stated preference experiment and the induced preference experiment conducted in this research. The same simulator as for the stated preference experiment (see the details of the stated preference experiment in *Chapter 5*) is used for the induced preference experiment: travelers are provided with the option to acquire travel information and the option to work from home, in addition to a set of routes from home to work with uncertain commuting time, under various arrival time constraints. But a difference between the two experiments is that the induced preference experiment was designed to induce preferences among participants, by explicitly relating their fee for participation to the choices they made during the experiment. Depending on the type of travel context, travel times and late arrivals are penalized more or less strongly; information acquisition is costly. As such, participants faced a so-called 'induced preference' experiment grounded in the experimental economics tradition. The stated preference experiment, while being otherwise exactly the same as the induced preference experiment, offered participants a fixed fee for participating (in line with the stated preference paradigm that is central to a majority of empirical discrete choice studies in transportation). To highlight any differences between the two approaches, the pooled stated and induced preference data collected from the two experiments are used for the estimation of the developed discrete choice model for travelers' use of ICT. While *Chapter 5*[121] focuses on the estimates related to the stated preference experiment and discussion on whether the developed model captures subtle behaviors related to ICT-use, the epilogue focuses on the comparison of the results between the stated and induced preference experiment to explore the usefulness of using an induced preference approach for collecting travel choice data in travel behavior research.

Although we do not a priori wish to argue which of the two data collection approaches (stated versus induced preference) might be preferred in the context of the study, we do wish to highlight possible reasons why the induced preference approach might be considered in the first place. The most important reason is that the choice model we wish to estimate is rather complicated from a behavioral viewpoint in the sense that the implied trade-offs that we hypothesize are being made by participants in the experiment are fairly subtle. For example, as presented in *Chapter 5*, the information value is formulated in terms of the anticipated utility associated with being able to choose from the set of travel alternatives after having received the information. In combination with the presence of constraints of various degrees of 'hardness', the model makes fairly large demands in terms of individuals' capabilities to grasp the subtle relations that in our view potentially influence decisions to acquire information, choose a particular route, or work from home. Experimental economics studies have convincingly argued that, in situations like what are designed in the simulator experiment where complicated decision-making mechanisms are tested empirically, the employment of induced preference experiments may help increase levels of involvement and motivation among participants[122] (e.g., Davis and Holt, 1993; Smith, 1976) and facilitate the estimation of choice models (Harrison and Rutström, 2009).

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[121] Note that only the stated preference experiment data were used for model estimation in *Chapter 5*.

[122] But note that other studies present more mixed evidence in that regard (e.g., Camerer and Hogarth, 1999).

Although the induced preference approach is a very popular method in fields adjacent to transportation such as consumer research (see, e.g. Müller et al., 2012), its application in travel behavior research is rare. Notable exceptions include: Denant-Boèmont & Petiot (2003), who study travelers' acquisition of travel information using the experimental economics-approach; Ben-Elia et al. (2008), who study the impact of information on travelers' route choices; and Ziegelmeyer et al. (2008), who study the impact of information on congestion in a multi-traveler game-theoretical setting.

To the best of our knowledge, this study is the first in the field of transportation to compare results obtained from an induced preference experiment with results obtained from a conventional stated preference experiment. Note that it obviously does not make sense to directly compare the two experiments in terms of behavioral parameters (like travel time- and cost-related parameters), since parameters obtained from the induced preference experiment reflect the incentive scheme designed by the researcher. However, as will be explained further below in section 7.3.2, a number of other comparisons can be made to gain further insight into the usefulness of the induced preference approach as an alternative paradigm for collecting travel choice data.

The remainder of this epilogue is structured as follows: section 7.2 presents the incentive scheme and the participants of the experiments. Section 7.3 presents model estimation results, and a comparison between both experiments; the final section provides conclusions. Note that this epilogue does not repeatedly introduce the discrete choice model for travelers' use of ICT under risk and constraints, the travel simulator, and the tactics for model operationalization, parameterization and estimation that have been elaborated in *Chapter 5*. Readers can refer to *Chapter 5* for related details.

7.2 Data collection: the incentive scheme and the participants

This section presents the incentive scheme (section 7.2.1) and the participants of the both experiments (section 7.2.2). The induced preference experiment was conducted parallel with the stated preference experiment using the same simulator, but the participants were randomly assigned to either the stated or the induced preference conditions. Two options for participation were offered as well for the induced preference experiment – from home (online), or at one of our university's computer rooms.

7.2.1 The incentive scheme

Fifty per cent of experiment participants were randomly assigned to the 'stated preference' condition; these individuals received a fixed fee for participating. Participants who came to our university's computer room to do the experiment received €25, and those that did the experiment from home (through the internet) received €10. These participants were asked to identify with the choice situations as if these were real, and to make choices accordingly based on the particular travel time distributions, information costs, and contextual scenarios.

The other fifty per cent were assigned to the 'induced preference' condition. These individuals received a fixed fee of €20 (computer room participation) or €5 (participating from home), and they were told that they would receive a bonus depending on the choices made during the experiment. The incentive scheme was designed to meet the conditions for successful induced preference research as specified by Smith (1976), referring to monotonicity (more reward should always be considered better by participants; there should be no satiation), salience (the reward should be coupled directly to the choices made in the experiment, and participants should understand this), and dominance (the reward should be more important than any other factor that may influence choice behavior, such as fatigue).

The following incentive scheme was adopted in the induced preference experiment. For each new day or trip in the experiment, the participant was endowed with an initial virtual amount of €20. Any choices that participant made in the day or trip would incur an amount of costs or penalties that was computed based on the values of the chosen alternatives' attributes. The costs or penalties would be subtracted from the initial endowment €20, resulting in a payoff of the day or trip (note that it was taken care of that it was impossible during any given trip to lose more money than the initial endowment). The final bonus to each participant in the induced preference condition was computed as the average payoff over all trips that the participant completed during the experiment, and was added to the fixed fee at the end of experiment.

The following monetary values for alternatives' attributes were used based on extensive numerical pre-tests, and were communicated to the induced preference experiment-participants: each minute of travel time costs €0.2. The penalty for late arrival varies across contextual scenarios as follows: €0 per minute for scenario 1 (no meeting and no preferred arrival time); €0.5 per minute for scenario 2 (no meeting, but preferred arrival time); €1 per minute for scenario 3 (bilateral and informal meeting); €1.5 per minute for scenario 4 (rather important multilateral meeting); and €2 per minute for scenario 5 (very important meeting). Penalties were also introduced for the telework option, to reflect the fact that, depending on the type of work to be done, the telework option may be considered less effective or pleasant than working at the office. Penalties were set at €8 (scenarios 1 and 2), €10 (scenario 3), €12 (scenario 4), and €15 (scenario 5). The costs of information equaled those presented to the participant on the screen; these costs varied between trips and could take on the values €0.5, €1, €1.5, and €2.

7.2.2 The participants

In total, 137 participants were recruited for the stated preference experiment, and 134 participants were recruited for the induced preference experiment, respectively – Table 7-1 shows their socio-demographic characteristics, and distinguishes between the induced versus stated preference treatment and the online versus computer room setting.

Table 7-1: Characteristics of participants

Variable	Stated preference treatment (N=137)				Induced preference treatment (N=134)			
	Computer room (N=35)		Online (N=102)		Computer room (N=25)		Online (N=109)	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Age								
15-24	8	22.9	20	19.6	3	12.0	12	11.0
25-34	13	37.1	37	36.3	13	52.0	46	42.2
35-44	9	25.7	29	28.4	3	12.0	29	26.6
45-54	3	8.6	12	11.8	3	12.0	15	13.8
55-64	2	5.7	4	3.9	2	8.0	5	4.6

65 or older	0	0.0	0	0.0	1	4.0	2	1.8
Occupation								
Employee	23	65.7	76	74.5	17	68.0	82	75.2
Volunteer	1	2.9	4	3.9	0	0.0	4	3.7
Student	10	28.6	20	19.6	7	28.0	17	15.6
Others	1	2.9	2	2.0	1	4.0	6	5.5
Gender								
Male	20	57.1	57	55.9	19	76.0	53	48.6
Female	15	42.9	45	44.1	6	24.0	56	51.4
Highest completed education[123]								
Elementary school	0	0.0	0	0.0	1	4.0	0	0.0
Secondary school	4	11.4	16	15.7	3	12.0	24	22.0
Vocational education	3	8.6	19	18.6	2	8.0	22	20.2
Higher education	28	80.0	65	63.7	19	76.0	63	57.8
Others	0	0.0	2	2.0	0	0.0	0	0.0
Net monthly household income (€) [124]								
No income	1	2.9	2	2.0	2	8.0	3	2.8
<1000	7	20.0	16	15.7	5	20.0	9	8.3
1000-2000	7	20.0	18	17.6	5	20.0	20	18.3
2000-3000	5	14.3	19	18.6	7	28.0	21	19.3
3000-4000	6	17.1	13	12.7	4	16.0	13	11.9
4000-5000	5	14.3	9	8.8	0	0.0	9	8.3
>5000	3	8.6	7	6.9	1	4.0	2	1.8
I do not want to answer or I do not know	1	2.9	18	17.6	1	4.0	32	29.4
Main commuting mode								
Car (as a driver)	20	57.1	65	63.7	21	84.0	73	67.0

[123] The categories of education are classified based on Dutch education system, which were used to ask participants in the study: a) Elementary school includes *Basisonderwijs*, b) Secondary school includes *VMBO*, *MAVO*, *HAVO*, *VWO*/*Gymnasium*, and *VAVO*, c) Vocational education includes *MBO*, and d) Higher education includes *HBO* and *WO*.

[124] The income only includes the income of the participant and his/her partner, if any.

Car (as a passenger)	2	5.7	2	2.0	0	0.0	3	2.8
Public Transport	6	17.1	21	20.6	2	8.0	20	18.3
Motorcycle/Moped	0	0.0	2	2.0	0	0.0	1	0.9
Bicycle	6	17.1	10	9.8	2	8.0	8	7.3
By foot	0	0.0	0	0.0	0	0.0	0	0.0
Others	1	2.9	2	2.0	0	0.0	4	3.7

7.3 Estimation results and comparison of the stated and induced preference experiments

This section first presents the estimation results and secondly presents the comparison of the stated and induced preference experiments.

7.3.1 Estimation results

Table 7-2 shows the estimation results of the model based on the pooled data collected from the stated and induced preference experiments. The parameters for the stated preference experiment and the parameters for the induced preference experiment are estimated separately but simultaneously in the joint model (that is, the iid Extreme Value error terms are added over the pooled data)[125]. Note that estimation of separate models (one for each experimental type) led to the same parameter estimates (in a statistical sense) as the ones obtained in the context of the joint model estimated on the pooled data. Furthermore, in addition to the scale parameter μ_{online} for computer-room setting data, we also estimated another scale parameter for the unobserved utility components between the stated and induced experiment data to measure whether there is any stochastic difference caused by the two experiment approach and the analyses showed that there was no scale difference (i.e., the scale parameter is statistically equal to 1) between the stated and induced experiment data; as such the final joint model reported in Table 7-2 does not feature this scale parameter.

As argued in section 7.1, parameters obtained from the induced preference experiment are a direct result of the incentive scheme proposed by the researchers while parameters obtained from the stated preference experiment reflect actual preferences of participants. Hence, we a priori did not expect the two parameter sets to be the same. It also does not make sense to directly compare the two experiments in terms of behavioral parameters (like travel time- and cost-related parameters), since parameters obtained from the induced preference experiment have little behavioral meaning in the sense that they are simply a reflection of the incentive scheme adopted by the researcher. However, a number of interesting comparisons, which will be presented in the next section, can be made based on these estimated parameters between the two experiments.

[125] See *Chapter 5* for details of the model specification, the tactics for model operationalization, parameterization and estimation, and the interpretation of these parameters. Note that 100 draws were used to evaluate the integrals in the joint model estimation in the epilogue, rather than 200 draws that were used for the model estimation of the stated preference experiment data in *Chapter 5*.

Table 7-2: Estimation results based on the pooled stated and induced preference data

Model statistics									
Sample size		6439							
Init. log-likelihood		-8177.319							
Final log-likelihood		-5641.260							
Rho-square		0.310							
Adjusted Rho-square		0.305							
		Stated preference experiment – parameters				**Induced preference experiment – parameters**			
Parameter [a)]		**Value**	**Robust Std. Error**	**Robust t-test** [b)]	**p-value** [c)]	**Value**	**Robust Std. Error**	**Robust t-test** [b)]	**p-value** [c)]
Scale parameter between online-experiment data and computer room-experiment data	μ_{online}	0.618	0.068	9.06	0.00	0.757	0.075	10.17	0.00
Deterministic utility of teleworking option	$V_{S_q}^1$	-8.350	0.940	-8.88	0.00	-8.210	0.836	-9.81	0.00
	$V_{S_q}^2$	-9.900	1.040	-9.57	0.00	-8.840	0.932	-9.49	0.00
	$V_{S_q}^3$	-10.300	1.100	-9.34	0.00	-10.300	0.959	-10.73	0.00
	$V_{S_q}^4$	-10.500	1.110	-9.48	0.00	-12.300	1.140	-10.84	0.00
	$V_{S_q}^5$	-10.300	1.070	-9.61	0.00	-13.300	1.230	-10.78	0.00
Travel time parameter	β_{TT}	-0.156	0.017	-9.43	0.00	-0.187	0.017	-11.10	0.00
Perceived hardness of	ω^2	0.373	0.132	2.83	0.00	0.126	0.275	0.46	0.65**

constraint	ω^3	0.382	0.138	2.77	0.01	0.537	0.267	2.01	0.04
	ω^4	0.580	0.215	2.69	0.01	0.657	0.362	1.81	0.07*
	ω^5	0.888	0.354	2.51	0.01	0.999	0.454	2.20	0.03
Travel information cost-parameter	β_r	-0.926	0.213	-4.35	0.00	-1.090	0.198	-5.52	0.00
Travel information constant	$ASC^1_{S_r}$	-3.420	0.608	-5.62	0.00	-0.910	0.338	-2.69	0.01
	$ASC^2_{S_r}$	-3.190	0.561	-5.70	0.00	-0.256	0.305	-0.84	0.40**
	$ASC^3_{S_r}$	-2.710	0.495	-5.47	0.00	0.284	0.319	0.89	0.37**
	$ASC^4_{S_r}$	-0.729	0.357	-2.04	0.04	1.050	0.333	3.17	0.00
	$ASC^5_{S_r}$	0.961	0.366	2.63	0.01	1.740	0.362	4.80	0.00
St. dev. error terms	σ_{ICT}	1.810	0.268	6.74	0.00	1.650	0.211	7.83	0.00
	σ_{travel}	2.520	0.389	6.49	0.00	1.960	0.361	5.43	0.00

a): For context-dependent parameters (deterministic utility of teleworking option, perceived hardness of constraint and travel time constant), the superscripts 1~5 indicate the five contextual scenarios respectively.

b): t-test for difference from zero

c): associated p-value of the t-test for difference from zero

*d): *: 0.1>p>0.05*

*e): **: p>0.1*

7.3.2 Comparison of the stated and induced preference experiments

Having presented the estimation results of the experiments, this section compares the results of both experiments. Before comparing results, it is of importance to test whether there are differences (between the two experiments) in terms of background characteristics of participants. Table 7-3 shows that none of the measured socio-demographic factors differs significantly across experimental treatments. This finding greatly facilitates the subsequent analyses (as the need to correct for such differences in socio-demographic variables in the remainder of the analyses can be eliminated).

Table 7-3: Pearson chi-square two-sample test of participants' characteristics

Variable	Chi-square value (p-value; 2-tailed)
Age	8.505 (0.131)
Occupation	2.345 (0.504)
Gender	0.167 (0.682)
Highest completed education	4.788 (0.310)
Net monthly household income (€)	11.702 (0.111)
Main commuting mode	6.058 (0.301)

As a first exploration, participants' evaluation of the experiments is compared. Participants were asked five survey questions to evaluate the experiment after they finished the experiments. These questions took the form of propositions (e.g., "I found it difficult to concentrate during the experiment"), with associated Likert-scale answer categories (1 = totally disagree; 5 = totally agree). Results (Table 7-4) suggest that participants in general enjoyed the experiment, and did not find it hard to concentrate or identify with the choice situations and contextual scenarios presented to them. Mean scores quite strongly resemble those obtained in a previous simulator study where the same questions were asked to participants (Chorus et al., 2007b). What is more surprising is that there is no significant difference between the two experimental treatments: the incentive scheme for the induced preference experiment apparently did little to help motivate participants, or to help them identify with the choice situation. Also in terms of other dimensions, the incentive scheme appears to have hardly any impact on the way participants perceive the experiment and their performance. This is an interesting finding in light of the fact that both literature (see section 7.1 of this epilogue for references) and intuition suggest that incentive schemes are likely to increase levels of motivation and concentration.

Table 7-4: Evaluation of the experiments

Questions	Stated Preference	Induced Preference	t-value (p-value) [a)]
	Mean Score	Mean Score	
1. Difficult to concentrate during the experiment	1.88	2.03	-1.372 (0.171)
2. Easy to understand the experiment	4.11	4.13	-0.162 (0.872)

3. Difficult to empathize the choice situations	2.09	2.07	0.232 (0.817)
4. Nice to do the experiment	4.28	4.40	-1.340 (0.181)
5. Problematic to stay motivated during the experiment	1.74	1.69	0.592 (0.555)

a): Independent two-sample t-test (2-tailed)

Another interesting result is obtained when comparing the scale-parameter μ_{online} (which scales the data obtained in the online experiment to the data obtained in the computer room experiment) across the two experimental treatments (stated versus induced preference) (Table 7-5): it appears that the scale parameter estimated on the stated preference data is smaller (one-sided p-value of independent two-sample Z-test = 0.084) than the one estimated on the induced preference data. This implies that the difference in randomness between the online experiment and the computer room experiment is larger for the stated preference data than for the induced preference data. Although both scale parameters are significantly smaller than 1 (implying that there is more noise in the choice data obtained from the experiments administered online than in the choice data obtained from the experiments administered in the university's computer room), our results do imply that the incentive structure helped reduce the difference in randomness between the online- and computer room-settings. This may be considered a promising aspect of the induced preference approach, in light of the fact that an increasing number of surveys are being administered through the internet.

Table 7-5: Estimates of the scale parameter μ_{online} in the experiments

Scale parameter μ_{online}	Value	Robust Std. Error	Statistical test	
			t-value (p-value) a)	Z-value (p-value) b)
Stated preference	0.618	0.0683	-5.59 (0.000)	-1.38 (0.084)*
Induced preference	0.757	0.0745	-3.26 (0.001)	

a): t-test for difference from one (2-tailed)

b): independent two-sample Z-test of the scale parameter estimates from the two experiments (one-tailed)

*c): *: 0.1>p>0.05.*

To test whether (or: to what extent) individuals behaved in line with the incentive structure presented to them, some additional analyses are performed. First, we focus on the proxy value of time as implied by the ratio of the travel time parameter and the travel information cost parameter. This ratio equals €0.1716 per minute in the induced preference experimental conditions compared to the ratio equaling €0.1685 per minute in the stated preference experimental conditions. The fact that the two ratios are almost equal is noteworthy, as is the fact that the induced preference value-of-time in fact is closer to the value-of-time implied by the incentive scheme (€0.2), than is the stated preference value-of-time.

On a more positive note, it appears that the constraint parameters $\omega^m, m = 2 \sim 5$ in the induced preference experimental conditions (see Table 7-2) (reflecting the perceived hardness of constraints) are in line with the incentive structure (see section 7.2.1): the larger the monetary penalty for arriving late, the larger the value of the associated constraint parameter (note though that not all estimates are significant and not all differences between the constraint parameters are significant). Differences between constraint-parameters are more pronounced (and to a larger extent in the 'right' direction) than was the case in the stated preference experimental conditions. In addition, the larger value of the travel information constant in the induced preference experiments in each scenario implies that under the influence of the incentive-scheme, participants value more the additional aspects of travel information value that are not captured by the developed model as presented in *Eq.5-8.* in *Chapter 5.*

Judging from the above-presented comparison results, on the data collected in the present study, the evidence in favor of the induced preference approach can be considered mixed, at best. An obvious disadvantage of the approach is that parameter estimates are more or less meaningless, because they are heavily influenced by the incentive scheme designed by the analyst. This disadvantage may be offset if one is interested more in decision-making mechanisms, rather than parameters themselves: it has been argued in previous work that by increasing the motivation of participants, an induced preference approach may allow researchers to test the validity of hypothesized behavioral mechanisms more effectively when using induced preference-approaches. However, in our case it appears (1) that the stated preference approach resulted in a good model fit and reasonable parameter values (see Table 7-2 for estimation results and *Chapter 5* for detailed discussion), and (2) that participants' self-reported evaluation of the experiment and their performance did not differ between the stated and induced preference treatment. On the positive side, the induced preference treatment did result in a smaller difference in scale between the subsample that made choices online and the subsample that made choices in the university's computer room. Furthermore, it does appear that participants took the incentive structure seriously when making their choices, as implied by the obtained constraint parameter values.

7.4 Conclusions

The *epilogue* presents the study of the induced preference experiment that was conducted parallel with the stated preference simulator experiment, and compares the results of both experiments to explore the usefulness of using an induced preference approach for collecting travel choice data in travel behavior research. This induced preference approach involves a carefully designed incentive structure to help motivate participants to make the 'right' choices. To the best of our knowledge, this study is the first in the field of transportation to compare results obtained from an induced preference experiment with results obtained from a conventional stated preference experiment. In theory, the induced preference approach may help travelers to identify with the choice situation at hand, which can be important when one tries to estimate choice models that are built around the kind of subtle behavioral mechanisms as the ones that are included in the developed model in this thesis.

Evidence in the study for the usefulness of the induced preference approach is mixed, at best. Although it is clear that participants' choices are well in line with the designed incentive structure, it appears that the induced preference treatment did not result in higher levels of motivation or concentration among participants. In combination with the fact that also without monetary incentives participants appeared to make conscious choices that fit our behavioral model well (as discussed in detail in *Chapter 5*), this suggests a limited contribution of the induced preference approach.

Nonetheless, these results should not be considered definitive before they are replicated on other data. It would be interesting to collect additional datasets from another sample of participants to conduct additional comparison. In addition, it would be interesting for further research to conduct sensitivity analysis of results under different design of incentive schemes. Another interesting path would be to study the predictive ability of induced preference data on hold-out choice tasks. These types of studies would help further reveal the added values and limitations of using induced preference experiment for data collection, and model estimation and validation in travel behavior research.

Summary

Background

Accessibility is of vital importance to society, and is a key concept for both policy makers and researchers. It is studied by scholars in a number of disciplines, such as transport engineering, geography, economics and sociology. Despite the various definitions and different ways of operationalization, the importance of accessibility to human activities and society is widely acknowledged. A paramount goal of transport policies is to improve accessibility. While most attempts in the past decades to increase accessibility have focused on the development of transport infrastructure (e.g., roads, railways) followed by land use planning policies, it is being increasingly recognized that information and communication technology (ICT) could be utilized as a (potential) measure, *inter alia*, to help achieve the goal of improving accessibility. The potential of utilizing ICTs as a measure to improve accessibility stems from two aspects – on the one hand, ICT is rapidly penetrating people's daily lives and society, and, on the other hand, ICT is expected to have a great impact on accessibility – for example, travel information may help travelers reduce travel times, and the option to telework may make someone's office very accessible by ICT when roads are heavily congested.

However, despite the intuitive expected benefits of ICT in helping increasing accessibility, understanding of the effects of ICT on accessibility is still limited. One prominent reason is a lack of generic formal analytical frameworks and methodologies for measuring ICT's effects on accessibility, which limits our knowledge in this regard and our capabilities to make use of ongoing advances in ICT to increase accessibility. In particular, whereas in real life most ICTs combine both functions – to provide travel information via information-related technologies (the "I" in ICT) and to enable people to engage into teleactivities via telecommunication-facilities (the "C" in ICT) – hardly any model or study explicitly considers both functions and deals with possible interactions between the effects of travel information and teleactivities. Furthermore, the traveler's preferences for and use of travel information and telecommunication facilities may be interrelated – e.g., a commuter may choose to work from home after having received travel information that his or her route to work is severely congested, or a traveler may be more inclined to acquire travel information given the option for him or her to telework. Such potential interactions of the traveler's use of travel information and telecommunication facilities could possibly result in synergy effects that have additional positive effects on the traveler's accessibility. However, our knowledge of the effects of such interaction between the "I" in ICT and the "C" in ICT on traveler's accessibility is still too limited to draw any firm conclusions in this regard.

Research goals of this thesis

This thesis predominantly aims to *"increase the understanding of the effects of ICT on accessibility"*. In particular, the primary aim of this thesis is to develop and test a generic formal integrative behavioral model for measuring the effects of different forms of ICT – technologies for travel information and those for teleactivities, including their potential interactions – on accessibility. The second aim of this thesis is to derive and provide substantive insights into their effects, including their potential interactions, on accessibility.

This thesis focuses on individual utility-based accessibility and conceptualizes the accessibility as the maximum utility that a traveler can derive from a set of activity-travel choices. This conceptualization is in line with how accessibility is conceptualized in the well-known utility-based LogSum accessibility measures (Ben-Akiva and Lerman, 1979). LogSum accessibility measures are in general considered effective measures of accessibility with a high level of theoretical rigor and practical usability for economic evaluation compared to a range of other types of accessibility measures (Geurs and van Wee, 2004). In addition, this thesis focuses on ICT according to ICT's two major functions – information technologies (the "I" in ICT) and communication technologies (the "C" in ICT), in order to ensure the developed model being generally applicable in the context of the wide variety of different ICTs currently available to travelers.

Contents of this thesis

To achieve the two main research aims mentioned above, this thesis contains the following studies. This thesis commences with a literature overview (*Chapter 2*), including a) an overview of the physical accessibility measures that do not consider ICT-related factors and the models that have been developed to measure ICT's effects on accessibility; b) an overview of the findings on ICT's (potential) effects on accessibility; and c) an overview of the models and the methods (including data collection and analysis methods) for studying travelers' choice of ICT and ICT's effects on travel behavior. Next, this thesis (*Chapter 3*) investigates the potential interrelations between travelers' preferences for travel information and teleworking services. A structural equation modeling (SEM) approach is used to analyze a set of data collected via a web-survey about commuters' preferences for using travel information and teleworking. This thesis further develops a utilitarian model for measuring the combined effects of both travel information and telecommunication facilities on accessibility. Numerical examples are used to reflect the combined effects of travel information and telecommunication facilities on accessibility (*Chapter 4*). This thesis subsequently translates the utilitarian model into a model with an estimable discrete choice model form, and uses data collected via a stated preference travel simulator experiment to estimate the model (*Chapter 5*). Travelers in the experiment faced a choice set of commuting routes with uncertain travel times, the option to acquire travel information and the option to work from home, under various arrival time constraints. In addition to the above-mentioned stated preference experiment that was conducted to collect data for model estimation, an induced preference experiment that involved a predefined incentive structure was also conducted. The induced preference experiment used the same travel simulator but featured a reward which was related to participant's choices. The results of these two types of the experiments were compared and the value of the induced preference approach was explored (*Epilogue*).

Conclusions of this thesis

This section first presents the main conclusions for each of the *Chapters 2-5*, as well as for the *Epilogue*. Subsequently, this thesis' main conclusions are presented, referring to the two research goals of this thesis.

Chapter 2 provides an overview of literature related to ICT and accessibility, focusing on the three aspects that are mentioned above in the paragraph *contents of this thesis*. A wide range of physical accessibility measures have been developed in the literature, while to date still few formal or quantitative models that are able to measure ICT's effects on accessibility exist yet, despite the increasing efforts to incorporate ICT-related factors into accessibility measures. However, it seems that, notwithstanding their obvious values, these measures and models in the literature are not yet suitable and readily applicable to measuring ICT's effects on accessibility – the physical measures that have been developed within physical realm do not consider any ICT-related factors, while the very few models aimed to measure ICT's effects on accessibility are either difficult to be operationalized and applied in practice (e.g., some models are only developed at a conceptual level) or limited in applicability (e.g., some models only focus on certain specific ICTs or specific categories of accessibility). In addition, it seems that while the ample literature on ICT's effects on travel behavior has shown that people's travel behavior could be substantially changed due to ICT, which is in turn expected to result in changes to traveler's accessibility, our current knowledge of ICT's effects on accessibility is still limited given sparse related literature. In particular, hardly any literature considers the (potential) effects of both travel information and teleactivities on accessibility, while it appears more than reasonable to expect that a traveler's response to and preferences for travel information and teleworking and telecommunication facilities could be interrelated and could result in interaction effects on accessibility as well.

Chapter 3 presents results of a web-survey that was conducted among 261 Dutch commuters. Structural equation modeling (SEM) approach is used for data analysis to investigate the potential interrelations between travelers' preferences for travel information and teleworking services. The analysis results show that travelers' preferences for travel information and teleworking are, to a certain extent, interrelated. Common underlying factors or personality traits exist that influence both travelers' preferences for travel information and teleworking. In addition, the study shows significant effects, on preferences, of other factors, including perceived availability of teleworking, perceived quality of the teleworking environment and facilities, perceived reliability of commuting time, and perceived availability of travel information. However, it appears that for the sample used in this study, there are no cross effects between i) on the one hand the perceived availability of teleworking and the perceived quality of teleworking environment and facilities and on the other hand travelers' preferences for travel information, and ii) on the one hand the perceived availability and reliability of travel information and on the other hand travelers' preferences for teleworking. This is an interesting yet important result, as it contrasts the expectation of such interaction between the "I" and the "C" in ICT that formulates the fundamental essence for the research. Further study is advised to draw firm conclusion whether this result is specific to the sample in the web-survey or generally valid, while the experimental data collection conducted later in this thesis (see *Chapter 5*), compared to the web-survey, allows for a more systematic assessment to what extent such expected interaction plays a role.

Chapter 4 develops an accessibility model that takes into account individual travel behavior (choice process) and measures the effects of two different forms of ICT – technologies for travel information and those for teleactivities – on accessibility. The model focuses on individual-, utility-based, short-term potential accessibility. It considers both the riskiness related to alternatives and the constraint that a traveler may face when making decisions in order to capture the negative effects they may have on the traveler's accessibility. In particular, the model not only measures the effects of both travel information and teleactivities on accessibility, but also considers the possible interaction between the two forms of ICT. Numerical examples show the plausibility of the model in capturing the effects of different forms of ICT on accessibility and reflect the combined effects of travel information and teleactivities on accessibility in different situations. A traveler's perception of the value of travel information for assessing alternatives can differ in cases whether a teleactivity option is present or not. The difference results from the expectation that, when a teleactivity option is also considered by a traveler as an alternative in his or her choice set, acquiring travel information may not only help assess the physical activity-travel alternatives, but also help him or her to make choices between the teleactivity option and the physical alternatives. In turn, the effects of ICT on accessibility in situations where both forms of ICT are available may be different from the effects in situations where only one of them is present. There can be synergy (positive interaction effect) between ICT for travel information and ICT supporting teleactivities in their effects on accessibility. The joint availability of technologies for travel information and teleactivities has more effects on accessibility than the sum of both technologies separately.

Chapter 5 first presents an econometric (discrete choice model) specification of the accessibility model presented in *Chapter 4*. The choice model is operationalized to integrate the notion of arrival time constraints to help capture travelers' use of travel information and teleworking options in light of risky travel times and the presence of preferred arrival times. Error components are introduced to capture correlations between different ICT-options, and between different routes. More importantly, this chapter tests the resulting discrete choice model based on the data collected via a travel simulator experiment (stated preference experiment) that is performed among 137 participants. The model estimation results show that the developed choice model fits the stated preference data well. Model fit and parameter estimates suggest that the model captures many of the behavioral mechanisms that may be present when travelers consider the acquisition of travel information, or the option to work from home, in the context of risky travel times, and arrival time constraints of varying 'hardness'. This signals that the representative traveler behavioral model for measuring ICT's effects on accessibility presented in *Chapter 4*, with an appropriate set of unobserved utility components and parameters, can be empirically operationalized into a choice model that is capable of describing travelers' actual behavior with regard to travel information-acquisition and teleactivity-engagement and capturing the interrelations between travelers' choices of travel information and teleactivities in a range of relevant activity-travel choice situations in the presence of ICTs and in the context of risk and constraints.

The *epilogue* presents an induced preference experiment that was conducted parallel with the stated preference simulator experiment (*Chapter 5*). The epilogue compares the results of both experiments to explore the usefulness of using an induced preference approach for collecting travel choice data in travel behavior research. This induced preference approach involves a carefully designed incentive structure to help motivate participants make the 'right' choices.

To the best of our knowledge, this study is the first in the field of transportation to compare results obtained from an induced preference experiment with results obtained from a conventional stated preference experiment. In theory, the induced preference approach may help travelers to identify with the choice situation at hand, which can be important when one tries to estimate choice models that are built around the kind of subtle behavioral mechanisms as the ones that are included in the developed model in this thesis. However, evidence in the study for the usefulness of the induced preference approach is mixed, at best. Although it is clear that participants' choices are well in line with the designed incentive structure, it appears that the induced preference treatment did not result in higher levels of motivation or concentration among participants. In combination with the fact that also without monetary incentives participants appeared to make conscious choices that fit our behavioral model well (as discussed in detail in *Chapter 5*), this suggests a limited contribution of the induced preference approach.

In conclusion, and focusing on the two aims of this thesis – to develop a model for measuring ICT's effects on accessibility and to derive related insights – the most important conclusions are next.

First of all, this thesis identified that a traveler's preferences for and use of travel information- (the "I" in ICT) and telecommunication-facilities (the "C" in ICT) are, to a certain extent, interrelated. The research on commuters' preferences for teleworking from home and their preferences for acquiring travel information finds out that common personal traits or underlying factors (e.g., reliability of commuting time) can jointly affect commuters' preferences for teleworking and travel information.

Secondly, this thesis develops an accessibility model that takes into account individual travel behavior (choice process) and measures the effects of different forms of ICT – technologies for travel information and those for teleactivities, including their potential interactions – on a traveler's accessibility. This model can be used to measure the effects of riskiness and constraints of alternatives on accessibility, and to capture the combined effects of travel information and teleactivities on accessibility. The research shows that the accessibility model can be empirically operationalized into a choice model that is capable of describing travelers' actual behavior with regard to travel information-acquisition and teleactivity-engagement. In addition, it is able to capture the interrelations between travelers' choices of travel information and teleactivities in a range of relevant activity-travel choice situations in the presence of ICTs and in the context of risk and constraints. It furthermore implies that, based on a series of relatively straightforward assumptions, such a model can indeed be built and can describe the very subtle behavioral effects of ICT on accessibility (which is described in the following point).

Finally, this thesis shows that, although no interaction effect or even a negative effect could occur, there *could* be synergy between travel information and teleactivities with respect to their effects on accessibility. The joint availability of technologies for travel information and supporting teleactivities to travelers may reinforce the accessibility benefits of each category of technologies separately. When a traveler has an obviously preferred, yet uncertain, physical activity-travel alternative, providing a comparable teleactivity alternative to the traveler reinforces the value of acquiring travel information which can help the traveler compare these two alternatives and in turn help the traveler in decision making. Acquiring the travel information does not add such value in case of the teleactivity alternative being not available.

Policy implications, with a special focus on the SAR-program and contribution of this thesis in this regard

This thesis is a product of the SAR-program, which focuses on increasing the accessibility of the Dutch Randstad area in particular. Within this context, the following implications aiming for practitioners and policy makers with regard to how to utilize ICT to improve accessibility of the Dutch Randstad area are derived. In particular, four major aspects that are recommended to be considered in developing ICT-related policies to improve accessibility of the Dutch Randstad area can be highlighted. While the first two aspects can be considered as the derivation from the overview of the previous studies in the literature, the following aspects are derived from this research.

a) First, it is critical to address this fundamental question on how accessibility shall be defined before any policy strategies are developed, to avoid misinterpretation and also to ensure that any ICT-related policies can be objectively evaluated. This is because the term "accessibility" tends to be defined and interpreted in many differently ways. The definition and measures should be acceptable for policy-makers and practitioners.

b) Secondly, it is essential to introduce new accessibility measures in addition to those that are currently used by the Dutch government and policy makers (see Hoogendoorn-Lanser et al., 2012 for an overview of the measures that are commonly used by the Dutch government and policy makers). Despite their advantages, these current accessibility measures that are mostly used seem to ignore the role of ICT largely, and in turn can fall short in the capability to evaluate whether and to which extent the developed ICT-related strategies could result in improvements of accessibility of the Dutch Randstad area. An accessibility measure that is based on a wider-scope definition becomes desirable in this sense, while this research shows that the so-called LogSum accessibility measure, which adopts a utility-based accessibility definition and takes discrete choice model-format, can be effectively and tangibly extended to incorporate traveler's preferences for ICT into the measurement. It in turn can be used to effectively measure ICT's effects on accessibility and is therefore advised to be introduced into use when ICT-related policies for improving accessibility are to be planned and to be evaluated.

c) Thirdly, it is important to take travelers' choices of and preferences for ICT into consideration when ICT-related policy strategies for improving the accessibility of the Dutch Randstad area are being developed. This research shows that varying travelers' preferences and choices of the usage of ICT play a critical role in determining whether and to which extent ICT could help improving accessibility. Ignoring this aspect is most likely to result in biased estimation of the effectiveness of certain ICT-related policies and strategies for improving accessibility, and in turn to result in difficulty in evaluating candidate policy options to improve accessibility. As without knowledge of travelers' preferences in this regard, doing a proper assessment (e.g. cost-benefit analysis) of these policy options becomes difficult. It is therefore advisable for practitioners and policy makers to explicitly incorporate travelers' preferences and choices in measuring the effects of ICT on accessibility and in developing and evaluating related policies.

d) Fourthly, it is advisable for Dutch policy makers to take into account both components – both travel information- and teleworking/telecommunication-services – when considering policies, rather than two separate policies, in developing policies for improving accessibility of the Dutch Randstad area. This is because synergy benefits can be reaped. It is not only because both types of services are increasingly being provided via the same technology devices and media, but also because a traveler's use of travel information- and teleworking/telecommunication options, as shown in the research, can result in synergy.

In light of these implications, this thesis contributes in this regard – the developed model (the accessibility model developed within the utility-based paradigm and its discrete choice model-form variant) in this thesis provides an alternative to the current available models in the literature and in practice. This model provides an alternative to more effectively measure the effects of both forms of ICT on accessibility. There are two ways in which the model can be used in practice when studying ICT's effects on accessibility, and actual planning and policy-design processes.

a) One way is that the model may be used in an exploratory sense to identify possibilities for obtaining synergy between investments or other policies in different forms of ICT. For example, the model may be applied to identify in what situations investments in travel information and/or teleworking facilities may lead to a situation where benefits of these investments in the two types of ICT might reinforce one another, leading to additional user benefits at least in terms of increases in accessibility.

b) Another way is to utilize the model to predict and quantify accessibility benefits of ICT-investments in general. These effects can subsequently be used in the assessment (e.g., cost-benefit analyses) of policy options in transportation planning – ultimately leading to a more informed process of policy-development.

Samenvatting

Achtergrond

Bereikbaarheid is van vitaal belang voor de samenleving, en is een sleutelconcept voor zowel beleidsmakers en onderzoekers. Bereikbaarheid wordt bestudeerd in tal van wetenschappelijke disciplines, zoals transport, geografie, economie en sociologie. Ondanks de verschillende definities en verschillende manieren van operationalisering binnen deze verschillende disciplines, wordt het belang van de bereikbaarheid breed erkend. Een belangrijk doel van transportbeleid het richten op het verbeteren van bereikbaarheid. In de afgelopen decennia heeft dit beleid zich met name gecentreerd op het aanleggen van nieuwe transportinfrastructuur (bijvoorbeeld wegen, spoorwegen), gevolgd door beleid voor ruimtelijke ordening. Recentelijk wordt echter steeds meer ingezien dat mogelijk ook informatie- en communicatietechnologie (ICT) kan worden ingezet om de bereikbaarheidsdoelstellingen te behalen. Het potentieel van het gebruik van ICT als een maatregel om de bereikbaarheid te verbeteren komt voort uit twee aspecten. Ten eerste, ICT speelt een steeds belangrijkere rol in het dagelijks leven en in de maatschappij. Ten tweede, ICT zal naar verwachting een grote impact hebben op de bereikbaarheid. Zo kan reisinformatie bijvoorbeeld helpen reistijd van reizigers te verminderen, en kan de mogelijkheid om te telewerken iemands ‘kantoor’ zeer bereikbaar maken wanneer de wegen zwaar overbelast zijn.

Echter, ondanks de intuïtieve voordelen van ICT in het helpen verbeteren van bereikbaarheid is het inzicht in de effecten van ICT op de bereikbaarheid nog steeds beperkt. Eén van de voornaamste redenen is het gebrek aan algemeen geldende formele analytische raamwerken en methodieken voor het meten van effecten van ICT op de bereikbaarheid. Dit gebrek beperkt de kennis en mogelijkheden om ICT in te zetten om de bereikbaarheid te verbeteren. In het bijzonder, terwijl in het echte leven de meeste ICT toepassingen de twee functies van ICT combineren, d.w.z. reisinformatie verstrekken middels informatie-gerelateerde technologieën (de "I" in ICT), en mensen in staat stellen om deel te nemen in teleactiviteiten via telecommunicatiefaciliteiten (de "C" in ICT), is er momenteel geen model of studie die beide functies van ICT expliciet beschouwt en de mogelijke interacties tussen de effecten van reisinformatie en teleactiviteiten meeneemt.

Daarbij komt dat de voorkeuren van de reiziger met betrekking tot en het gebruik van reisinformatie en telecommunicatievoorzieningen met elkaar verbonden kunnen zijn. Bijvoorbeeld, een forens kan ervoor kiezen om thuis te werken na het zien van de reisinformatie dat zijn of haar route naar werk ernstig is verhinderd. Of, een reiziger kan relatief meer zijn geneigd om reisinformatie te verwerven indien hij of zij de mogelijkheid heeft om te telewerken. Dergelijke mogelijke interacties tussen het gebruik van reisinformatie enerzijds en de telecommunicatievoorzieningen anderzijds zou kunnen leiden tot synergie-effecten welke extra positieve effecten op de bereikbaarheid van de reiziger zouden kunnen hebben. Echter, op dit moment is de kennis ontoereikend om harde conclusies te trekken met betrekking tot de effecten van de interacties tussen de I van ICT en de C van ICT op bereikbaarheid.

Onderzoeksdoelen van dit proefschrift

Het doel van dit proefschrift is "*het verhogen van het begrip van het effect van ICT op bereikbaarheid*". In het bijzonder, het eerste doel van dit proefschrift is het ontwikkelen en testen van een algemeen geldend formeel geïntegreerd gedragsmodel om de effecten van verschillende vormen van ICT, zoals technologieën voor reisinformatie en voor teleactiviteiten, op bereikbaarheid te meten. Het tweede doel van dit proefschrift is het genereren van substantiële inzichten in de effecten van ICT - inclusief die ontstaan als gevolg van potentiele interacties - op bereikbaarheid.

Dit proefschrift richt zich op de individuele nutsgerichte bereikbaarheid en conceptualiseert die bereikbaarheid als het maximale nut wat voor een reiziger kan voortvloeien uit een reeks van actief-reizen keuzes. Deze conceptualisering is in lijn met de manier waarop de bereikbaarheid wordt geconceptualiseerd in de bekende nutsgerichte LogSum bereikbaarheidsmaatregelen (Ben-Akiva en Lerman, 1979). LogSum bereikbaarheidsmaatregelen worden over het algemeen beschouwd als effectieve maatregelen van bereikbaarheid met een hoog niveau van theoretische discipline en praktische bruikbaarheid voor de economische evaluatie in vergelijking met een aantal andere vormen van maatregelen inzake bereikbaarheid (Geurs en Van Wee, 2004). Daarnaast richt dit proefschrift zich op twee belangrijke functies van ICT – informatie- (de "I" in ICT) en communicatie (de "C" in ICT), opdat verzekerd kan worden dat het ontwikkelde model algemeen toepasbaar kan zijn in de context van de grote verscheidenheid van verschillende ICT die momenteel beschikbaar zijn voor reizigers.

Inhoud van dit proefschrift

Om de bovengenoemde onderzoeksdoelstellingen te bereiken bevat dit proefschrift de volgende studies. Dit proefschrift vangt aan met een literatuuroverzicht (*Hoofdstuk 2*). Dit hoofdstuk bevat drie onderdelen. Ten eerste, geeft dit hoofdstuk een overzicht van de natuurkundige maten voor bereikbaarheid. Deze natuurkundige maten laten ICT-gerelateerde factoren en de modellen die zijn ontwikkeld om de effecten van ICT op bereikbaarheid te meten buiten beschouwing. Ten tweede, geeft dit hoofdstuk een overzicht van de bevindingen met betrekking tot de mogelijke effecten van ICT op bereikbaarheid. Ten derde, geeft dit hoofdstuk een overzicht van de modellen en methodieken (inclusief dataverzameling en analysemethoden) welke worden gebruikt om reizigers hun keuze voor ICT, en de effecten van ICT op bereikbaarheid te bestuderen.

Vervolgens, onderzoekt dit proefschrift de potentiele interrelaties tussen de voorkeuren van reizigers voor reisinformatie en telewerk faciliteiten. Een Structural Equation Modelling (SEM) aanpak is gebruikt om een data set te analyseren van voorkeuren van forensen voor het gebruik van reisinformatie en telewerken welke verzameld is via een web-survey. Dit proefschrift ontwikkelt een utilistisch model voor het meten van de gecombineerde effecten van zowel reisinformatie als telecommunicatiefaciliteiten op bereikbaarheid. Numerieke voorbeelden worden gebruikt om te reflecteren op de gecombineerde effecten van reisinformatie en telecommunicatiefaciliteiten op bereikbaarheid (*Hoofdstuk 4*).Vervolgens vertaalt dit proefschrift het utilistisch model in een schatbaar discrete keuze model, en wordt het model geschat op data welke zijn verzameld via een reissimulator experiment (*Hoofdstuk 5*).

Reizigers die deelnamen aan het experiment dienden een keuze te maken uit verschillende reisopties. De opties kenden een onzekere reistijd en dus aankomsttijd. Daarbij kregen deelnemers aan het experiment de mogelijkheid aangeboden om over reisinformatie te beschikken (zodat de reistijd minder onzeker werd) en de optie om thuis te werken (en dus niet te reizen). Naast dit keuze-experiment is aan de deelnemers gevraagd om een keuze te maken tussen verschillende reisopties, terwijl zij een beloning kregen voor de resultaten van hun keuzes. Deelnemers kregen bijvoorbeeld een beloning als zij op tijd aankwamen bij een (fictieve) vergadering en geen beloning als ze te laat aankwamen. In dit proefschrift worden de resultaten van de twee experimenten vergeleken (zie de *epiloog*).

Conclusies van dit proefschrift

Hieronder worden de conclusies van *hoofdstuk 2-5* en de *epiloog* beschreven. Vervolgens worden de hoofdconclusies gerelateerd aan de twee onderzoeksvragen die centraal staan in dit proefschrift uiteengezet.

Hoofdstuk 2 bevat een overzicht van de literatuur gerelateerd aan ICT en bereikbaarheid. Een breed spectrum van natuurkundige bereikbaarheidsmaten zijn ontwikkeld in de literatuur, terwijl er – op dit moment weinig formele kwantitatieve modellen bestaan die het mogelijk maken om effecten van ICT op bereikbaarheid te meten. Dit ondanks het feit dat men probeert om ICT-gerelateerde factoren in bereikbaarheidsmaten te verwerken. Het lijkt erop dat deze bereikbaarheidsmaten nog niet geschikt zijn om effecten van ICT op bereikbaarheid adequaat te meten. De fysieke bereikbaarheidsmaten die momenteel worden gebruikt houden nog geen rekening met ICT-gerelateerde factoren en modellen die proberen ICT-effecten te incorporeren zijn lastig te operationaliseren en toe te passen in de praktijk. Sommige modellen zijn alleen op conceptueel niveau ontwikkeld, andere modellen richten zich alleen op specifieke typen ICT of bereikbaarheidscategorieën. Hoewel verschillende wetenschappelijke publicaties hebben aangetoond dat ICT een substantiële invloed kan hebben op reisgedrag en waarschijnlijk dus ook op bereikbaarheid, zijn er echter weinig publicaties beschikbaar in de literatuur die zich focussen op effecten van ICT op bereikbaarheid. Er zijn met name weinig publicaties te vinden die zich richten op potentiele effecten van zowel reisinformatie en telewerken op bereikbaarheid, terwijl het in de rede ligt dat voorkeuren van reizigers voor reisinformatie en telewerken aan elkaar gelieerd zijn en daarbij kunnen resulteren in interactie-effecten met bereikbaarheid.

Hoofdstuk 3 werkt de resultaten van een web-enquête uit waar 261 Nederlandse forenzen aan hebben deelgenomen. De data is geanalyseerd met Structural Equation Modellering, waarbij onder meer de potentiele verbanden tussen voorkeuren voor reisinformatie en telewerken zijn onderzocht. De resultaten bevestigen dat voorkeuren voor reisinformatie en telewerken tot op zekere hoogte met elkaar verband houden. Gemeenschappelijke onderliggende persoonlijkheidskenmerken beïnvloeden zowel voorkeuren van reizigers voor reisinformatie als hun voorkeuren voor telewerken.

Deze studie laat zien dat de perceptie ten aanzien van verscheidene factoren zoals de mogelijkheid om te telewerken, de kwaliteit van telewerken (in termen faciliteiten en werkomgeving), de betrouwbaarheid van de reistijd, en de beschikbaarheid van reisinformatie significante effecten hebben op voorkeuren van mensen. Echter, deze studie vindt geen aanwijzing voor kruiseffecten tussen 1) enerzijds de perceptie ten aanzien van beschikbaarheid van telewerken en de perceptie ten aanzien van de kwaliteit van telewerken, en anderzijds de voorkeuren van reizigers ten aanzien van reisinformatie, en 2) enerzijds de perceptie ten aanzien van de beschikbaarheid van telewerken en de betrouwbaarheid van reisinformatie, en anderzijds de voorkeuren van reizigers ten aanzien van telewerken.

Dit is een interessant en belangrijk resultaat, omdat het niet overeenkomt met de vooraf gevormde verwachting over de samenhang tussen de 'I' en de 'C' van ICT die centraal staat in dit proefschrift. Het dient aanbeveling om deze samenhang verder te onderzoeken en de mate vast te stellen waarin het verband dat gevonden is in het kader van dit proefschrift generiek is of kan worden toegeschreven aan de specifieke karakteristieken van de steekproef. De experimentele data collectie die verderop in dit proefschrift zal worden beschreven (*hoofdstuk 5*) bevat een meer systematische bestudering van de mate waarin een dergelijke relatie een rol speelt.

Hoofdstuk 4 ontwikkelt een bereikbaarheidsmodel waarin rekening wordt gehouden met individueel reisgedrag (keuzeprocessen) waarin de effecten van twee vormen van ICT - technologieën voor reisinformatie en technologieën voor teleactiviteiten - op bereikbaarheid worden gemeten. Het model richt zich op individuele - op nut gebaseerde - korte termijn potentiele bereikbaarheid. Het model houdt zowel rekening met risico's gerelateerd aan potentiele alternatieven en beperkingen waar een reiziger mee te maken krijgt wanneer hij beslissingen moet maken, zodat negatieve effecten op bereikbaarheid worden meegenomen. Het model meet niet alleen de effecten van reisinformatie en teleactiviteiten op bereikbaarheid, maar neemt ook de interactie tussen de twee parameters in beschouwing. Numerieke voorbeelden laten de plausibiliteit van het model met betrekking tot het incorporeren van effecten van verschillende vormen van ICT op bereikbaarheid zien. Ook brengen deze voorbeelden de gecombineerde effecten van verschillende vormen van ICT op bereikbaarheid in beeld voor verschillende situaties. De perceptie van een reiziger op de waarde van reisinformatie bij het beoordelen van verschillende reisopties kan verschillen wanneer de mogelijkheid tot telewerken wel of niet bestaat. Een mogelijke verklaring voor dit resultaat is dat reisinformatie niet alleen kan worden gebruikt bij het maken van een keuze tussen reisopties, maar ook kan helpen bij de keuze om überhaupt te gaan reizen of dus te telewerken. De effecten van ICT op bereikbaarheid zijn dus groter als zowel reisinformatie als telewerken tot de opties van een individu behoort, dan wanneer slechts één van de twee beschikbaar is. Er bestaat synergie (positieve interactie-effecten) tussen ICT-reisinformatie en ICT ondersteunende telewerkfaciliteiten in relatie tot effecten van ICT op bereikbaarheid. De beschikbaarheid van reisinformatie en teleactiviteiten hebben dus meer effect op bereikbaarheid dan de som van de twee technologieën afzonderlijk.

Hoofdstuk 5 behandelt een econometrische specificatie (discrete keuze model) van het bereikbaarheidsmodel dat wordt beschreven in *Hoofdstuk 4*. Het keuzemodel integreert beperkingen op aankomsttijden om zo het gebruik van reisinformatie en de optie om te telewerken door reizigers te onderzoeken in het licht van onzekere reistijden en gewenste aankomsttijden. Een zogeheten error component logit model wordt gebruikt. Daarmee wordt geaccommodeerd voor de potentiele correlaties tussen verschillende ICT opties en verschillende routes. Daarbij wordt in dit hoofdstuk het discrete keuze model getest gebruik makende van data verzameld in een reissimulator experiment waar 137 respondenten aan deelnamen.

De schattingsresultaten van het model laten zien dat het ontwikkelde keuzemodel de data goed beschrijft. De model fit en de geschatte parameters suggereren dat het model verscheidene gedragsmatige mechanisme – welke mogelijk spelen wanneer reizigers overwegen reisinformatie te kopen of thuis te werken in de context van onzekere reistijden en tijdsbeperkingen – op pikt. Dit signaleert dat het reizigersgedragsmodel voor het meten de effecten van ICT op bereikbaarheid – welke is gepresenteerd in *Hoofdstuk 4* – empirisch kan worden geoperationaliseerd in een keuzemodel. Het model is in staat om 1) werkelijk gedrag van reizigers te beschrijven in de context van het kopen van reisinformatie en het deelnemen aan telewerken, en 2) de interrelaties tussen reizigers hun keuze over reisinformatie en telewerk-activiteiten op te pikken in de aanwezigheid van ICT in de context van onzekerheid en tijdsbeperkingen.

De epiloog werkt een experiment uit waarin respondenten een prikkel krijgen. Dit experiment is uitgevoerd parallel aan het reissimulator experiment beschreven in *Hoofdstuk 5*. In de epiloog worden de resultaten van het experiment waarin respondenten een prikkel kregen vergeleken met het reissimulator experiment met als doel om het nut van het geven van een prikkel aan respondenten bij het verzamelen van data over keuzegedrag van reizigers te onderzoeken. In het experiment waarin respondenten een prikkel krijgen worden respondenten middels een zorgvuldig ontworpen beïnvloedingsmechanisme aangezet om de ‘juiste’ keuzes te maken. Zover wij weten, is dit de eerste studie gericht op transportonderzoek die resultaten van een studie waarin respondenten een prikkel krijgen vergelijkt met een conventioneel Stated Preference onderzoek. In theorie zou deze methode reizigers moeten helpen bij het maken van keuzes in de gepresenteerde keuzesituaties. Dit kan belangrijk zijn wanneer geprobeerd wordt subtiele gedragsmechanisme – zoals in degene die worden bestudeerd in dit proefschrift – op te pikken met behulp van een discrete keuze model. Echter, conclusies over het nut van het geven van verwerken van een prikkel aan respondenten in een experiment die volgen uit deze studie zijn niet eenduidig. Hoewel het duidelijk is dat deelnemers keuzes maken die in lijn zijn met de prikkels die aan hen gegeven worden, lijkt het erop dat de prikkels niet leidden tot betere concentratie of motivatie onder respondenten. In combinatie met het resultaat van dit proefschrift dat respondenten ook zonder monetaire prikkels bewuste keuzes maakten die goed pasten in het door ons ontwikkelde gedragsmodel (zie *Hoofdstuk 5* voor een gedetailleerde discussie van dit model) kunnen wij voorzichtig concluderen dat het nut van het geven van een prikkel aan respondenten tijdens een keuze-experiment beperkt is.

Tot slot, de belangrijkste conclusies met betrekking tot de twee doelstellingen van dit proefschrift – het ontwikkelen van 1) een model voor het meten van ICT’s effecten op bereikbaarheid, en 2) daaraan relateerde inzichten – zijn als volgt.

Ten eerste, dit proefschrift heeft laten zien dat reizigers hun voorkeuren voor, en het gebruik van reisinformatie tot op zekere hoogte aan elkaar gerelateerd zijn. Het onderzoek laat zien dat persoonlijke smaken en onderliggende factoren (zoals betrouwbaarheid van de reistijd) gezamenlijk de voorkeuren van forenzen – met betrekking tot telewerken en reisinformatie – kunnen beïnvloeden.

Ten tweede, dit proefschrift ontwikkelt een bereikbaarheidsmodel dat individueel reisgedrag (keuzes) in acht neemt, en meet de effecten van verschillende vormen van ICT – technologieën voor reisinformatie en telewerken – op de bereikbaarheid van de reiziger. Het model kan gebruikt worden om de effecten te meten van onbetrouwbaarheid en beperkingen van alternatieven op bereikbaarheid, en om inzicht te krijgen in het gezamenlijk effect van reisinformatie en telewerken. Het onderzoek laat zien dat het bereikbaarheidsmodel empirisch kan worden geoperationaliseerd in een keuzemodel dat in staat is om het werkelijke gedrag van reizigers met betrekking tot het kopen van reisinformatie en de deelname aan telewerken te beschrijven. Bovendien is het model in staat de interrelaties tussen reizigers hun keuzes over reisinformatie en telewerk activiteiten op te op te pikken. Dit betekent dat op basis van een aantal voor de hand liggende aannames inderdaad een dergelijk model gemaakt kan worden welke de zeer subtiele gedragsmatige effecten van ICT op bereikbaarheid weet te beschrijven.

Tot slot, dit proefschrift laat zien dat synergie mogelijk is tussen reisinformatie en telewerken met betrekking tot het effect op bereikbaarheid. Dit, ondanks dat er geen interactie effect of zelf een negatief effect mogelijk is. De verbetering van de bereikbaarheid wanneer zowel reisinformatie als ICT ten behoeve van telewerken beschikbaar is, kan de losse verbeteringen in termen van bereikbaarheid overstijgen.

Beleidsimplicaties, met een focus op de contributie van dit proefschrift aan het DBR onderzoeksprogramma

Dit proefschrift komt voort uit het DBR onderzoeksprogramma, welke zich richt op het verhogen van de bereikbaarheid van de Randstand in Nederland. Binnen deze context is een aantal implicaties van dit onderzoek afgeleid welke relevant zijn voor beleidsmakers die de bereikbaarheid van de Randstad trachten te verbeteren. Meer specifiek, worden beleidsimplicaties gedaan in de context van vier belangrijke aspecten. De eerste twee aspecten volgen uit het gemaakte overzicht van de bestaande literatuur. De aspecten er na komen voort uit het onderzoek dat is uitgevoerd in de context van dit proefschrift.

a) Ten eerste, alvorens beleidsstrategieën te ontwikkelen, is het belangrijk om te adresseren hoe bereikbaarheid gedefinieerd is. Dit, om misverstanden te voorkomen en om er voor te zorgen dat de ICT-beleidsmaatregelen op een objectieve manier kunnen worden geëvalueerd. Dit is te meer belangrijk omdat het concept “bereikbaarheid” op verschillende manieren gedefinieerd en geïnterpreteerd kan worden. De definitie moet bovendien gedragen worden door de beleidspraktijk.

b) Ten tweede, is het belangrijk om nieuwe maten voor bereikbaarheid te ontwikkelen, welke gebruikt moeten worden naast de bestaande maten voor bereikbaarheid. Zie Hoogendoorn-Lanser et al. (2012) voor een overzicht van de veelgebruikte maten in de Nederlandse beleidspraktijk. De huidige veelgebruikte maten voor bereikbaarheid nemen ICT niet, of slechts beperkt mee. Als gevolg zijn deze maten niet in staat om te evalueren of een ICT gerelateerde beleidsmaatregel resulteert in een verbetering van de bereikbaarheid van de Randstad. In die zin is een mate voor bereikbaarheid gebaseerd op een bredere definitie van bereikbaarheid gewenst. Dit onderzoek laat zien dat de zo geheten LogSum maten voor bereikbaarheid – welke gebaseerd is op een utilistisch raamwerk en de vorm aanneemt van een discrete keuze model – op een effectieve manier kan worden uitgebreid zodanig dat het de voorkeuren van reizigers voor ICT meeneemt in de maten voor bereikbaarheid. Deze maten van bereikbaarheid kan worden gebruikt om de effecten van ICT op bereikbaarheid te meten. Om die reden is het aan te bevelen om deze mate van bereikbaarheid te gebruiken bij het plannen en evalueren van ICT-gerelateerd beleid ten behoeve van het verbeteren van de bereikbaarheid

c) Ten derde, is het belangrijk om rekening te houden met de voorkeuren van reizigers ten aanzien van ICT bij het maken van beleid ten behoeve van het verbeteren van de bereikbaarheid van de Randstad. Dit onderzoek laat zien dat de verscheidenheid in voorkeuren van reizigers met betrekking tot ICT bepalend is voor de mate waarin ICT kan bijdragen aan het verbeteren van de bereikbaarheid. Het negeren van dit aspect resulteert hoogst waarschijnlijk in onjuiste inschattingen van de effectiviteit van bepaalde ICT-gerelateerde maatregelen en strategieën ten behoeve van het verbeteren van de bereikbaarheid. Dit resulteert op zijn beurt weer in problemen voor het evalueren van beleidsopties ten behoeve van het verbeteren van de bereikbaarheid omdat zonder de kennis van de voorkeuren van reizigers met betrekking tor ICT een gedegen beoordeling (bijvoorbeeld middels kosten-baten analyse) van beleidsopties lastig is. Het is daarom aan te bevelen voor de beleidspraktijk om expliciet de voorkeuren van reizigers en hun keuzes mee te nemen in het meten van de effecten van ICT op de bereikbaarheid, en bij het maken en evalueren van aanpalende beleidsmaatregelen.

d) Ten vierde, het valt aan te bevelen aan Nederlandse beleidsmakers om beide componenten van ICT, d.w.z. reisinformatie en telewerken / telecommunicatiefaciliteiten, mee te nemen bij het besluiten over beleid om de bereikbaarheid te verbeteren (in plaats van ieder van de componenten los van elkaar mee te nemen) omdat synergie effecten behaald kunnen worden. Het behalen van synergie effecten is niet enkel mogelijk omdat beide type faciliteiten steeds meer worden aangeboden via dezelfde media en apparaten, maar ook omdat het gebruik van reisinformatie en telewerken door reizigers kan resulteren in synergie effecten.

In het kader van deze implicaties, draagt dit proefschrift bij in dit opzicht – het ontwikkelde model (het bereikbaarheidsmodel dat is ontwikkeld binnen de paradigma die gebaseerd is op de mate van bruikbaarheid en binnen het discrete keuze model) in dit proefschrift biedt een alternatief aan voor de huidige beschikbare modellen in de literatuur en de praktijk. Dit model biedt de mogelijkheid om op een effectieve manier de effecten van beide vormen van ICT op bereikbaarheid te meten. Meer specifiek, dit model kan op twee manieren gebruik worden in de beleidspraktijk wanneer de effecten van ICT op bereikbaarheid worden bestudeerd.

a) De eerste manier is dat het model op een exploratieve manier wordt gebruikt om synergie tussen investeringen en andere ICT-gerelateerd beleid te identificeren. Bijvoorbeeld, het model kan gebruikt worden om situaties te identificeren waarin investeringen in reisinformatie en telewerkfaciliteiten zouden kunnen leiden tot een situatie waarin de voordelen van de investeringen in beide soorten ICT elkaar versterken, wat zou kunnen leiden tot complementaire voordelen voor de gebruiker in termen van een verbetering in bereikbaarheid.

b) Een andere manier is dat het model wordt gebruikt om de voordelen van ICT-gerelateerde investeringen voor de bereikbaarheid te voorspellen en te kwantificeren. Deze resultaten kunnen vervolgens worden gebruik voor evaluatie (bijvoorbeeld in kosten-baten analyse) van transportbeleidsmaatregelen. Uiteindelijk kan dit model bijdragen aan beter geïnformeerd beleid.

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